Explaining and reducing the public’s expectations of antibiotics: A utility-based signal detection theory approach

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CRediT author statement

MS: Conceptualisation, Methodology, Software, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualisation, Project Administration; **AT**: Methodology, Software, Resources, Writing – Review & Editing; **MJ**: Methodology, Resources, Writing – Review & Editing.

Abstract

To tackle antibiotic resistance, an unfolding global public health threat, we need to better understand why people expect antibiotics for self-limiting infections because this drives unnecessary consumption of antibiotics. Here, we used a utility-based signal detection theory to explain how people form these expectations by considering their diagnostic uncertainty (e.g., "Is this a bacterial infection?") and the expected utility they associate with their decisions (e.g., "What are the costs of taking antibiotics?"). To test the explanation, we created two types of interventions—focusing on reducing diagnostic uncertainty and increasing the saliency of costs of overuse (to self and others)—to lower inappropriate expectations of antibiotics. In two pre-registered vignette-based experiments (*N*=1,773; general UK adult population), both types of interventions decreased expectations and intentions to request antibiotics compared with a baseline group. We discuss how the theory can inform public health campaigns and stimulate further research.

Keywords: antibiotics expectations, antibiotics requests, antibiotic resistance, utility-based signal detection theory

General Audience Summary

If not appropriately tackled, in 2050, antibiotic resistance will be one of the leading causes of death worldwide, amounting to 10 million deaths every year. Healthcare organisations encourage the judicious use of antibiotics in human medicine to slow antibiotic resistance. In this research, to encourage such behaviour change, we proposed and tested a theory explaining why people expect to be treated with antibiotics when they are not needed.

This theory combines laypeople's diagnostic uncertainty (e.g., "Are my symptoms caused by a bacterial illness?") with subjective values associated with decisions (e.g., "What are the costs of taking antibiotics when not needed?"). Based on this theory, we hypothesised that people would be less likely to expect antibiotics with decreasing layperson's diagnostic uncertainty and increasing costs of inappropriate antibiotic use. In two pre-registered experiments (*N* = 1,773; from the UK general adult population), we found that both types of interventions—reducing diagnostic uncertainty and increasing the saliency of the costs of overuse (to self or to others)—decreased antibiotic expectations and requests in a hypothetical consultation for a viral ear infection (Exp. 1) and cold-like symptoms (Exp. 2) compared with a baseline group. This explanation can help us better understand why people expect antibiotics when they are not needed and how to create effective health communication to reduce antibiotic overuse.

Antimicrobial resistance has become a worldwide threat to humankind comparable to climate change (Centers for Disease Control and Prevention, 2019; Roope et al., 2019; World Health Organization, 2014). Currently, at least 700,000 people die due to antimicrobial resistance every year (The Review on Antimicrobial Resistance, 2016). Unchallenged, in thirty years, antimicrobial resistance could put 10 million lives at risk every year and cost a cumulative 100 trillion USD of economic output (The Review on Antimicrobial Resistance, 2016).

Undeniably, the overuse of antibiotics in human medicine accelerates the natural process of bacteria becoming resistant to antibiotics (Chatterjee et al., 2018; Goossens, Ferech, Vander Stichele, & Elseviers, 2005). Therefore, promoting the judicious use of antibiotics is one of the main strategies proposed to tame the growth of antibiotic resistance. However, to do so effectively, we first need to understand better why people expect antibiotics even when they are not required (Pinder, Berry, Sallis, & Chadborn, 2015; World Health Organization, 2015). These antibiotic expectations contribute significantly to the overuse of antibiotics using two behavioural pathways (Pinder et al., 2015). First, in countries with lax regulatory systems, members of the public can obtain antibiotics routinely without medical consultations and, thus, without appropriate knowledge (Laxminarayan & Heymann, 2012; Morgan, Okeke, Laxminarayan, Perencevich, & Weisenberg, 2011). For instance, 77% to 93% of the urban participants from different low and middle-income countries reported self-medicating with antibiotics in the previous three to twelve months for mostly self-limiting infections (Torres, Chibi, Middleton, Solomon, & Mashamba-Thompson, 2019).

Second, in countries with strict regulations, patients can still obtain unnecessary antibiotics from health care professionals. This is because patients who expect and/or request antibiotics, even when they are clinically inappropriate, are much more likely to be prescribed antibiotics, leading to their overuse (Cockburn & Pit, 1997; Coenen et al., 2013;

Coenen, Michiels, Renard, Denekens, & Van Royen, 2006; Cole, 2014; McNulty, Nichols, French, Joshi, & Butler, 2013; Sirota, Round, Samaranayaka, & Kostopoulou, 2017). For instance, when a patient expected antibiotics, in an experimental study, family physicians were twice as likely to prescribe antibiotics for them than for a patient with the same clinical symptoms without such expectation (Sirota et al., 2017); when family physicians, in a prospective observational study, believed that a patient expected antibiotics, the number of prescribed antibiotics was twelve times higher (Coenen et al., 2013), and, according to self-reported patient data, when patients asked their family physician or nurse for antibiotics, 97% of them were prescribed antibiotics (McNulty et al., 2013).

Despite the important role the public plays in the judicious use of antibiotics, we know surprisingly little about the cognitive mechanisms of how people form their expectations of antibiotics (Donald, 2015). We argue that the cognitive mechanisms should be able to account for two robustly evidenced determinants of antibiotic expectations: diagnostic uncertainty and cost-benefits considerations.

First, when experiencing their illness, people decide about antibiotics in a situation of lay diagnostic uncertainty—the uncertainty surrounding the causes of the illness and the efficacy of the antibiotics. This uncertainty might include a complete conceptual confusion of when antibiotics are needed and when they are not (Cals et al., 2007; Hoffmann, Ristl, Heschl, Stelzer, & Maier, 2014; Lv et al., 2014; McNulty et al., 2013; McNulty, Collin, Cooper, Lecky, & Butler, 2019). In the United Kingdom, for example, 35% of the respondents in a recent study incorrectly believed that antibiotics can also treat viral infections (McNulty et al., 2019); such beliefs reliably predict inappropriate antibiotic expectations (Broniatowski et al., 2018; Thorpe, Sirota, Orbell, & Juanchich, 2021). For this reason, public health education campaigns always aim to clarify the fact that antibiotics can treat only bacterial, not viral, infections (Haynes & McLeod, 2015; Huttner, Goossens, Verheij, & Harbarth, 2010; Thoolen, de Ridder, & van Lensvelt-Mulders, 2012). However, diagnostic uncertainty also stems from an authentic doubt as to whether the symptoms manifest a viral or bacterial infection. For example, illness incoherence—being puzzled by the nature of an illness—predicted people's expectations of antibiotics for their recently experienced cold-like symptoms (Thorpe et al., 2021). Robust experimental evidence also showed that reducing laypeople's diagnostic uncertainty—by providing a family physician's clinical judgment about viral aetiology of the symptoms, sometimes even accompanied by a diagnostic test pointing in the same direction—substantially decreased people's expectations of antibiotics in hypothetical consultations (Thorpe, Sirota, Juanchich, & Orbell, 2020a, 2020b; Thorpe et al., 2021).

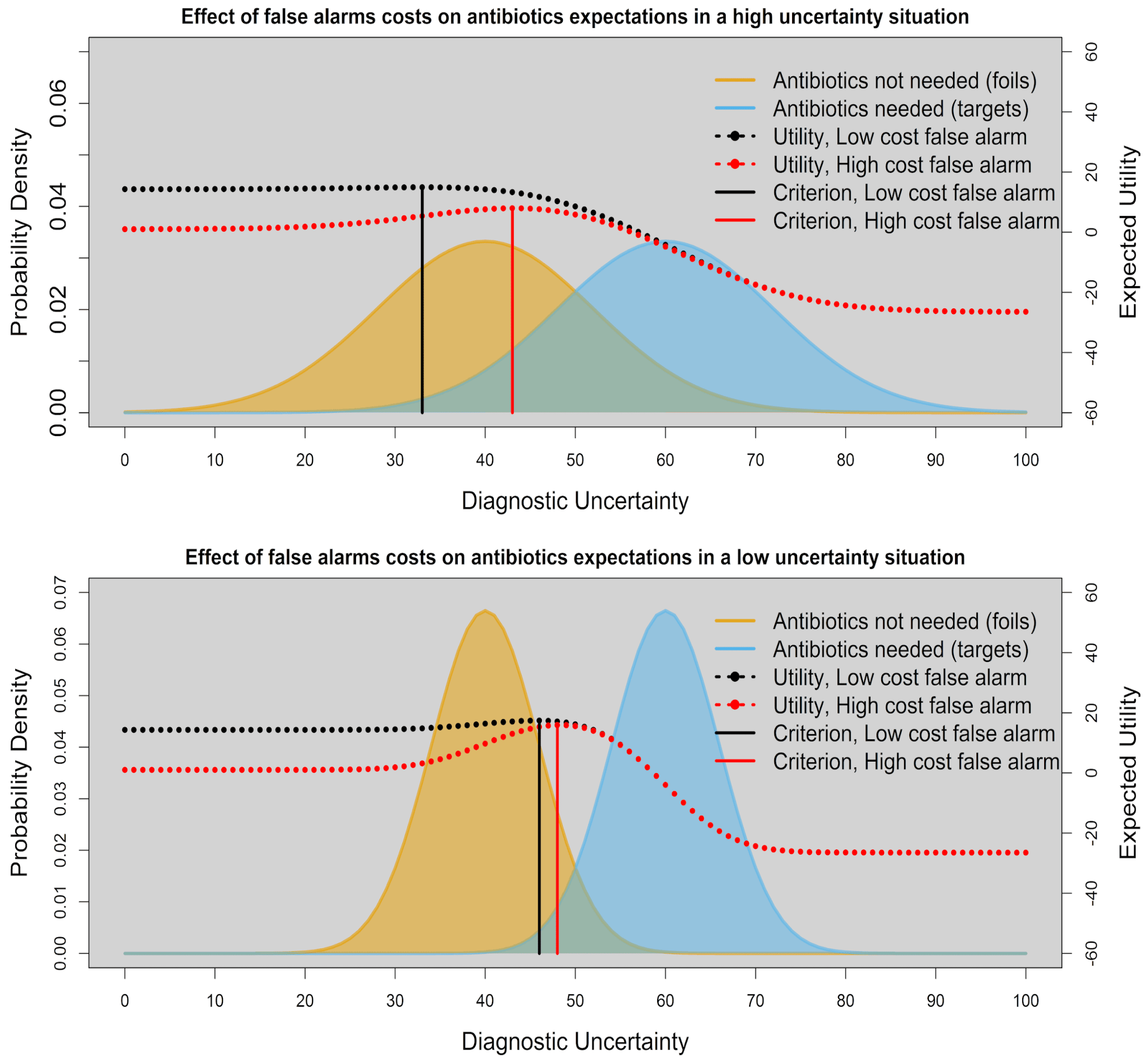
Second, people consider various subjective utilities associated with their decisions to expect antibiotics or not. For instance, people tend to overestimate the benefits of antibiotics to avoid negative consequences for missed illness, and underestimate the risks of side effects (Spicer, Roberts, & Hicks, 2020; Thorpe et al., 2021). People also tend to take into consideration the risks associated with the consequences of antimicrobial resistance but are less likely to do this when they believe they are not personally at risk of it (Fletcher-Miles & Gammon, 2020; Roope et al., 2020). Public health campaigns increasingly include information about the negative consequences of antibiotic overuse (Huttner et al., 2010). Value-based considerations are also critical for the fuzzy-trace theory's explanation of why people expect antibiotics when not needed (Broniatowski et al., 2018; Reyna, 2020). According to this theory, people subscribe to a categorical gist of "why not to take a risk": they prefer the risky option of "possibly staying sick or getting better" with antibiotics rather than "staying sick for sure" without antibiotics (Reyna, 2020).

Here, we adopted a utility-based signal detection theory approach (Lynn & Barrett, 2014; Lynn, Wormwood, Barrett, & Quigley, 2015) to propose cognitive, computationally testable mechanisms that would integrate these two sets of findings into one framework. In short, we construed people's expectations of antibiotics as signal detection decisions occurring in situations of perceptual (here, lay diagnostic) uncertainty aiming to maximise the expected utility rather than accuracy. When a person is experiencing earache, for instance, they must decide whether the illness causing the symptom requires antibiotic treatment or not. The person's decision will depend on their sensitivity—their ability to discriminate between the clinical situations when antibiotics are needed (i.e., "targets"), and the situations when they are not needed (i.e., "foils") (Lynn & Barrett, 2014). However, it will also depend on their bias—the tendency to classify the symptoms (signals) as needing antibiotics or not (Lynn & Barrett, 2014). The person will adopt a liberal bias (i.e., classify unclear clinical symptoms as needing an antibiotic) if they, for example, believe that most bacterial infections lead to severe ear damage and wish to avoid such dire consequences. In other words, if the stakes are high, the optimal outcome is to mistake a viral infection as bacterial rather than to accurately discriminate between a viral and bacterial infection.

We can model the person's decision to expect antibiotics in the current liberally-biased environment—the environment in which antibiotics are overprescribed (Fleming-Dutra et al., 2016; Lynn & Barrett, 2014). In Figure 1, we can see how two factors—similarity and payoff—would affect the optimal criterion location (see also Supplementary Materials). All other things being equal, people will shift their optimal criterion towards higher accuracy—less likely to expect antibiotics—in a situation of low (vs high) diagnostic uncertainty (lower vs upper panel of Figure 1) and when they perceive higher costs associated with taking antibiotics, here modelled via low (vs high) false alarm costs (black vs red curve depicted in both panels of Figure 1).

Figure 1

The decision to expect antibiotics in high (upper panel) and low (lower panel) uncertainty situations as a function of low (vs high) costs of a false alarm.



Note. According to the utility-based signal detection theory, the position of the criterion depends on perceptual uncertainty and the expected utility function. In our simulation, the decision to expect antibiotics (i.e., criterion) is more liberally biased in the situations of high (vs low) lay diagnostic uncertainty, i.e., greater similarity between the "targets", where antibiotics are needed and "foils", where antibiotics are not needed. The decision to expect antibiotics (i.e., criterion) is more liberally biased in the situations of low (vs high) costs associated with a false alarm (i.e., antibiotic resistance). Thus, reducing diagnostic uncertainty and increasing the saliency of the costs of a false alarm should lead to a less liberally biased (and more accurate) decision to expect antibiotics.

Present research

In the present research, we devised two types of model-derived interventions to decrease people's antibiotics' expectations and intentions to request antibiotics. In the first type of intervention, we aimed to reduce laypeople's diagnostic uncertainty by clarifying when antibiotics are useful. In the second type of intervention, we increased the saliency of the individual costs associated with the overuse of antibiotics using two different strategies. First, we made the costs of antibiotic overuse self-relevant using scientific evidence about temporarily elevated antibiotic resistance at the individual level (Costelloe, Metcalfe, Lovering, Mant, & Hay, 2010b). People tend to be aware of the problem of antibiotic resistance but they often believe it does not concern them directly (Fletcher-Miles & Gammon, 2020; Lv et al., 2014); this intervention addressed that issue. Second, we made the cost relevant to another person by outlining the child patient story (Infectious Diseases Society of America, 2017). Patient stories leverage people's tendencies to be more affected by narrative evidence rather than statistical evidence (Betsch, Ulshöfer, Renkewitz, & Betsch, 2011).

We tested two sets of model-testing hypotheses. First, we hypothesised that reducing the diagnostic uncertainty and making the costs of antibiotic overuse more salient would decrease antibiotic expectations (Hypothesis 1.1) and subsequent intentions to request antibiotics (Hypothesis 1.2). Second, we hypothesised that the interventions would not affect intended adherence to a prescribed antibiotic (Hypothesis 1.3). Reducing diagnostic uncertainty should not affect adherence when a person is already quite certain that they have a bacterial illness that requires antibiotic treatment. Making the costs of antibiotic overuse more salient should not affect adherence when a person requires antibiotic treatment because this is perceived as adequate use of antibiotics not overuse of antibiotics. Possible adverse effects of educational interventions are important yet rarely evaluated (NICE, 2015), so for that reason, we measured a decrease in adherence to prescribed antibiotics. Aligned with this prediction, the scarce existing evidence indicates that educational interventions have no adverse effects on antibiotic-related behaviours. For instance, they do not cause increased re-consultation rates or higher rates of specific bacterial infections (e.g., Vodicka et al., 2013).

In addition, we tested three hypotheses based solely on prior research. First, based on prior research reporting increasing awareness of the differences between viral and bacterial illnesses in the UK population (McNulty et al., 2019), we expected that reducing diagnostic uncertainty would have a smaller impact compared with the cost saliency interventions on antibiotic expectations (Hypothesis 2.1) and intentions to request antibiotics (Hypothesis 2.2). Second, based on prior research reporting multicomponent interventions improving attitudes concerning antibiotic use (NICE, 2015), we expected that the interventions would positively increase attitudes towards the appropriate use of antibiotics (Hypothesis 2.3).

Experiment 1

Methods

Participants and design. We determined our sample size stopping rule a-priori while taking into consideration power calculations to test the hypotheses, recruitment method (both experiments were run in parallel using a random allocation, thus causing a potential sample size imbalance between the experiments), and expected attrition rate. We assumed that the interventions, on average, would reduce expectations and requests by at least 0.3 standard deviations, which yielded small effects when applied to the effects of the planned contrast on expectations and requests (Cohen's *f* = .130 to Cohen's *f* = .123)[1]. There were no reliable estimates at the time in prior research so we assumed a reasonably small effect. Assuming $\alpha = .025$, $1\text{-}\beta = 0.90$ and a two-tailed test, we would need $N = 737$ to test Hypothesis 1.1, 1.2 (Exp. 1 & 2) and 2.3 and 2.4 (Exp. 2), and $N = 823$ to test Hypothesis 2.1 and 2.2 (Exp. 1 & 2) to find the ANOVA planned contrasts (numerator *df* =1) statistically significant (Faul, Erdfelder, Lang, & Buchner, 2007). Assuming $\alpha = .05$, $1\text{-}\beta = 0.90$ and a two-tailed test, we would need $N = 724$ to find a 10% drop (from 0.9 to 0.8) in adherence with allocation ratio 3:1 statistically significant and thus provide a test of Hypothesis 1.3 (Exp. 1). We aimed to recruit around 800 participants (i.e., 200 in each arm) but over-recruited by 10% because of the assumed attrition rate due to a-priori defined pre-registered exclusion criteria. Participants were excluded when they (i) failed to complete the questionnaire fully, (ii) completed the questionnaire too quickly (less than 1/3 median time, i.e., less than 1 minute) and (iii) repeatedly failed to complete the instructional reading check question. Out of the 917 completed questionnaires, 23 participants were excluded because they completed the questionnaire unrealistically quickly ($n = 7$), failed the reading check question twice ($n = 13$) or both ($n = 3$). The analytical sample size ($N = 894$) was bigger than the required sample size needed to detect the effect sizes of interest.

Participants were recruited from an online panel (i.e., Prolific). Participants were eligible to take part if (i) they achieved at least 90% approval rate in previous studies, (ii) they resided in the United Kingdom (UK) and (iii) were at least 18 years old. The first criterion aimed to minimise careless responding (Peer, Vosgerau, & Acquisti, 2014), whereas the second criterion aimed to make sure that participants had some experience of the UK's primary care health system. Participants were reimbursed £1.00 for their participation, which

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[1] $When\ f = \frac{\sigma_m}{\sigma}\ and\ \sigma = 1, \sigma_m = \frac{|c|}{\sqrt{k \sum_{i=1}^{k} w_i^2}}\ then\ contrast\ 1\ (|c| = 0.9, w^2 = 12, k = 4)\ yieldsf = 0.130\ and\ contrast\ 2\ (|c| = 0.6, w^2 = 6, k = 4)\ yields\ f = 0.123$

was estimated to last, on average, 12 minutes. Participants' ages ranged from 18 to 84 years, *M* = 36.1, *SD* = 11.4 years; 71.5% of the participants were female, 28.1% male and 0.4% selected an "other" option. The participants had various levels of education: less than high school (1.5%), high school (41.6%), undergraduate degree (43.3%), master's degree (11.2%) and higher degrees such as PhD (2.5%). The sample was also heterogeneous in terms of occupation: management and professionals (26.1%), unemployed, students and homemakers (21.8%), other categories (19.1%), sales and office (12.8%), service (7.6%) and some other less common occupations such as government-workers or farming industry.

In a between-subjects experiment, participants were randomly allocated either to the baseline condition (*n* = 211) or one of the three intervention conditions: (i) reduced diagnostic uncertainty (*n* = 227), (ii) cost saliency (self) (*n* = 229) and (iii) cost saliency (other) (*n* = 227). Participants then reported their antibiotic expectations and intentions to request antibiotics for an upper respiratory tract infection. The random allocation of the participants was done by the Qualtrics built-in randomiser, which operates automatically using the Mersenne Twister algorithm (Matsumoto & Nishimura, 1998). Thus, this study was a double-blind randomised controlled trial.

Materials and procedure. After giving informed consent, participants read one of the four possible texts based on their condition allocation. In the baseline condition, they read about the costs and benefits of gardening. In the reduced diagnostic uncertainty condition, they read information about antibiotics working only for bacterial infections, which was compiled from relevant public health bodies (e.g., the Centers for Disease Control and Prevention; the UK's National Health Service). In the cost saliency (self) condition, participants read about the cost associated with increased antibiotic resistance to an individual who took antibiotics, which was based on a body of scientific evidence (Costelloe, Metcalfe, Lovering, Mant, & Hay, 2010a; Gisselsson-Solen, Hermansson, & Melhus, 2016). Finally, in the cost saliency (other) condition, they read about the costs associated with increased antibiotic resistance to other people by reading the real story of a child affected by antibiotic resistance. (See the exact wording and resources for all conditions in Supplementary Materials.) Participants then answered some reading check questions appearing on the same page to validate that they read the information provided; participants indicated which statement was true in a multiple choice question with four possible answers tailored to the text they had read (see Supplementary Materials).

Afterwards, participants read two vignettes and associated questions presented in a random order to each participant: (i) an acute ear infection with viral aetiology vignette accompanied by the antibiotic expectations and intentions to request antibiotics questions and (ii) a kidney infection with bacterial aetiology vignette accompanied by an antibiotics adherence question. The viral ear infection vignette was designed to assess inappropriate antibiotic expectations and intentions to request antibiotics; it was adopted from prior research (Sirota et al., 2017; Thorpe et al., 2021). The bacterial kidney infection was designed to assess adherence to appropriately prescribed antibiotics. We used evidence-based guidelines for antibiotics prescribing issued by the National Institute for Health and Care Excellence (i.e., NICE) to assess whether the antibiotic expectations were clinically appropriate or not (National Institute for Health and Care Excellence (NICE), 2017). In the ear infection vignette, participants imagined that they had an ear infection that presented with fever and pain and that they went to consult their family physician. Participants learnt from the physician that the ear infection was likely of viral aetiology and would clear by itself. Participants then indicated their expectations for antibiotics by expressing agreement with four items presented in a random order ("I should get a prescription for antibiotics.", "I should be offered a prescription for antibiotics", "I would want my doctor to give me a prescription for antibiotics", and a reversed item "I would not want my doctor to offer me a prescription for antibiotics") on a 6-point Likert scale (*1 = Strongly Disagree, 2 = Disagree, 3 = Mildly Disagree, 4 = Mildly Agree, 5 = Agree, 6 = Strongly Agree*). The internal consistency of the scale was excellent (Cronbach's α = 0.93). Thus, we calculated an average score of the four items (after reversing the last item) for each participant. Participants also indicated their intentions to request antibiotics by answering four questions presented in a random order (e.g., "I would request a prescription for antibiotics", "I would mention antibiotics to my doctor", "I would suggest that I should have antibiotics", "I would demand a prescription for antibiotics") on a 6-point Likert scale (*1 = I certainly would not, 2 = I would not, 3 = I probably would not, 4 = I probably would, 5 = I would, 6 = I certainly would*). The internal consistency of the scale was excellent (Cronbach's α = 0.92). Thus, we calculated an average score of the four items for each participant. In the bacterial kidney infection vignette, participants imagined that they had a set of symptoms for a kidney infection which presented with fever, pain and a burning sensation, and blood in urine, and that they went to consult their family physician. Participants learnt from the physician that the kidney infection was caused by bacteria and that a course of antibiotics was needed to treat it. Participants indicated their adherence to a prescribed antibiotic course (i.e., "Would you take the 14-day course of prescribed antibiotics as recommended by your GP?") using a dichotomous scale (*No = 0, Yes = 1*).

Finally, participants answered a few questions concerning their prior experience of being prescribed antibiotics in the last three years, how frequently they were prescribed antibiotics for bacterial and viral infections as well as demographic questions regarding their gender, age, education and employment.

We conducted the study in accordance with the ethical standards of the American Psychological Association (APA) and obtained ethical approval from the Ethics Committee of the Department of Psychology, University of Essex. We have reported all the experiments, measures, manipulations, and exclusions. The data set, pre-registration and materials are available at https://osf.io/5s82k/.

Statistical analyses. To test our model-derived hypotheses, we ran a planned contrast of the effect of the interventions (vs baseline) on expectations of antibiotics and intentions to request antibiotics using ANOVA (Hypothesis 1.1 and 1.2, respectively). Since the assumptions of homogeneity of variances and normality were not met for most of the comparisons, we used robust tests of equality of means using Brown-Forsythe correction for one-way ANOVA (hereafter *F**), and contrast *t*-tests not assuming equal variances (hereafter *t**) (Glantz & Slinker, 2001). The conclusions for the hypotheses, whether using this analytical strategy or analyses of variance assuming normality and equal variances, were identical (see Supplementary Materials). In addition, we also conducted robustness checks for the effect of the interventions using different plausible analytic strategies (see Supplementary Materials). To test the effect of the interventions on antibiotics adherence, we ran a planned contrast using a chi-square test (Hypothesis 1.3). To quantify support for the models assumed by both the null and alternative hypotheses, we carried out equivalent Bayes factor analyses using 'BayesFactor' package v0.9.12-4.2 (Morey & Rouder, 2015) and its default settings (default priors r scale = 0.5 and 10,000 iterations in Markov Chain Monte Carlo for Bayes Factor (BF) ANOVAs and independent multinomial sampling plan with default prior concentration parameter, a = 1, for BF contingency table). Specifically, for the BF ANOVA the null model assumed an intercept only effect, whereas the main effect model assumed the model with the effect of contrast 1 (i.e., the effect of interventions vs baseline) or contrast 2 (i.e., the effect of cost saliency intervention vs reducing uncertainty intervention) (Hypotheses 1.1 and 1.2, respectively); for BF contingency tables, the null model assumed equality of the two proportions whereas the intervention effect model assumed non-equality of the two proportions (Hypothesis 1.3). We described the results using evidence categories

(Wetzels et al., 2011). We decided to use the BF ANOVA since the statistical inference of ANOVA could be considered trustworthy given the robustness checks. We also assessed moderation of the interventions' effect by age, gender and education using multiple linear regressions.

To test our hypotheses not derived from the model, we ran a planned contrast of the effect of the cost interventions (vs reducing diagnostic uncertainty) on expectations of antibiotics and intentions to request antibiotics using ANOVA (Hypothesis 2.1 and 2.2, respectively). Again, these were accompanied by equivalent default Bayes factor analyses and robustness checks described above. All significance tests were two-tailed tests using a significance level of .05 unless stated otherwise. All these analytical plans, except for the robustness checks, were pre-registered.

Results and Discussion

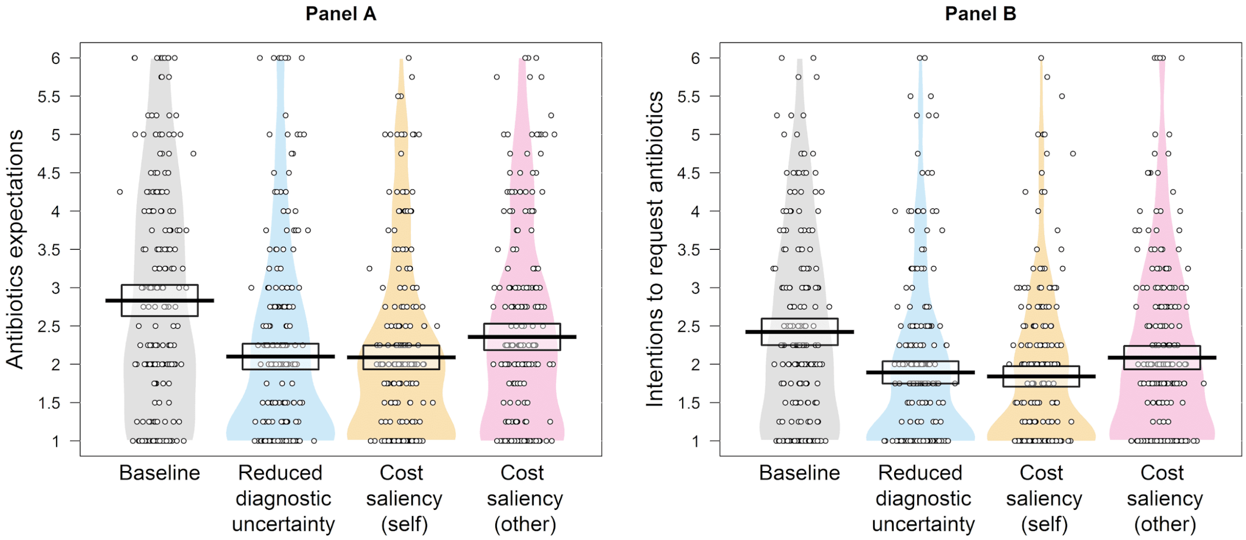
Effect of interventions on antibiotic expectations and intentions to request antibiotics

The participants in the intervention conditions had lower expectations of antibiotics and reduced intentions to request antibiotics for their hypothetical ear infection than those in the baseline group, $F^*(848.97, 3) = 14.77$, $p < .001$ and $F^*(855.64, 3) = 11.34$, $p < .001$, respectively (Figure 2, $N = 894$). In the first planned contrast (critical $\alpha_{adj} = .025$ after applying the Bonferroni adjustment), the interventions ($M = 2.18$, $SD = 1.27$) compared to the baseline group ($M = 2.83$, $SD = 1.50$) substantially and significantly decreased the antibiotic expectations, $t^*(307.73) = 5.69$, $p < .001$, *Cohen's d* = 0.49, yielding extreme relative evidence to support the intervention effect model, $BF_{10} = 9.6*10^6$. The interventions (M = 1.94, $SD = 1.11$) compared to the baseline group ($M = 2.42$, $SD = 1.28$) also significantly decreased the intentions to request antibiotics, $t^*(312.78) = 4.94$, $p < .001$, *Cohen's d* = 0.42, yielding extreme relative evidence to support the intervention effect model, $BF_{10} = 7.6*10^4$.

The conclusions were robust to different analyses not assuming normality. Age, gender and education did not moderate the effect of the interventions (see Supplementary Materials). Thus, we confirmed both model-derived hypotheses—the effect of the interventions on antibiotic expectations (Hypothesis 1.1) and intentions to request antibiotics (Hypothesis 1.2).

Figure 2

Expectations of antibiotics (Panel A) and intentions to request antibiotics (Panel B) for an acute ear infection in the baseline condition and the model-derived interventions (Experiment 1).



Note. N = 894; Horizontal bold lines represent means, boxes represent 95% confidence intervals, beans represent smoothed densities, and circles represent individual responses.

In the second planned contrast (α_{adj} = .025), the reduced diagnostic uncertainty intervention (*M* = 2.10, *SD* = 1.29) did not change antibiotic expectations any less than the cost saliency interventions (*M* = 2.22, *SD* = 1.26), *t**(439.43) = -1.19, *p* = .237, *Cohen's d* = -0.09, yielding moderate relative evidence to support the null model, BF_{01} = 5.6. Reduced diagnostic uncertainty (*M* = 1.89, *SD* = 1.11) also did not alter the intentions to request antibiotics compared with the cost saliency interventions (M = 1.96, SD = 1.10), $t^*(445.39) = -0.78$, p = .437, *Cohen's d* = -0.06, yielding moderate evidence to support the null model, BF_{01} = 8.2. The conclusions were robust to different analyses not assuming normality distributions (see Supplementary Materials). Thus, contrary to our expectations based on previous literature, we found no support for the predicted attenuated effect of the reduced diagnostic uncertainty relative to cost saliency interventions on antibiotic expectations (Hypothesis 2.1) and intentions to request antibiotics (Hypothesis 2.2).

Effect of interventions on adherence intentions

The intentions to adhere to prescribed antibiotics for bacterial pneumonia were very high and remarkably similar across all the conditions: baseline condition (96.7%), reduced diagnostic uncertainty intervention (99.6%), cost saliency (self) intervention (96.5%), and cost saliency (other) intervention (95.6%), $\chi^2(3) = 7.10$, p = .069, Cramer's V = 0.09, $BF_{01} = 3.1*10^2$. To test the critical planned contrast, in which we compared the effect on adherence between the interventions and the baseline condition (97.2% vs 96.7%, respectively), we found no significant effect of the interventions, $\chi^2(1) = 0.03$, p = .865, φ = 0.01, yielding strong evidence to support the model assuming the null effect of the interventions relative to the model assuming the effect of the interventions, $BF_{01} = 2.7*10^1$. Thus, we found no adverse effects of the interventions on intentions to adhere to prescribed antibiotics, supporting the model-derived prediction (Hypothesis 1.3).

Role of prior experience of being prescribed antibiotics

We also conducted an exploratory correlational analysis of the role that prior experience of antibiotics plays in forming antibiotic expectations and intentions to request antibiotics (critical α = .0125 after applying the Bonferroni adjustment). Prior experience of frequently being prescribed antibiotics for viral infections correlated with antibiotic expectations (r_s = .23, p < .001) and intentions to request them (r_s = .23, p < .001), whereas prior experience of frequently being prescribed antibiotics for bacterial infections did not correlate with the expectations or intentions to request antibiotics (r_s = -.01, p = .714; r_s = .01, p = .697, respectively). This exploratory finding is interesting from a clinical point of view but also as further evidence supporting the proposed utility-based signal detection theory. The experience of frequently being prescribed antibiotics for viral infections makes the base rate information about whether one needs antibiotics or not higher than it actually is objectively.

In summary, aligned with the model's predictions, we confirmed that reducing diagnostic uncertainty and increasing the saliency of the cost of a false alarm decreased people's antibiotic expectations and intentions to request antibiotics, while not jeopardising the intentions to adhere to prescribed antibiotics for a bacterial infection. In contrast with our prediction based on prior literature, however, reduced diagnostic uncertainty was not less effective than the cost saliency interventions in lowering the antibiotic expectations and requests.

Experiment 2

Method

Participants and design. Experiment 2 was run in parallel to Experiment 1 using the same questionnaire so participants were randomly allocated to either Experiment 1 or 2. Thus, the participants in this experiment were different from those in Experiment 1. We used the same sampling stopping rule, eligibility criteria and a-priori exclusion criteria as in Experiment 1. Following the exclusion criteria, out of the 896 completed questionnaires, 17 participants were excluded because they completed the questionnaire unrealistically quickly (n = 4), repeatedly failed the reading check question (n = 12) or both (n = 1). The analytical sample (N = 879) was bigger than the required sample size needed to detect the effect sizes of interest.

The participants' ages ranged from 18 to 74 years, *M* = 37.4, *SD* = 11.8 years; 69.6% of the participants were female, 30.1% male and 0.2% selected the "other" option. The participants had various levels of education: less than high school (1.1%), high school (40.6%), undergraduate degree (42.7%), master's degree (12.2%) and higher degrees such as PhD (3.4%). The sample was also heterogeneous in terms of occupation: management and professionals (25.0%), unemployed, students and homemakers (23.3%), other categories (20.5%), sales and office (10.5%), service (7.2%) and some other less common occupations such as production, construction, and government-workers.

The experimental design was identical to the design used in Experiment 1 with participants allocated randomly to one of four conditions: the baseline condition (*n* = 227) or one of the three intervention conditions: (i) reduced diagnostic uncertainty (*n* = 228), (ii) cost saliency (self) (*n* = 216) and (iii) cost saliency (other) (*n* = 208).

Materials and procedure. After giving informed consent, participants read one of the four possible sets of information based on their group allocation. The text in the baseline and intervention conditions and the associated reading check questions were identical to the ones used in Experiment 1. Participants then read (i) a cold-like symptoms vignette accompanied by the antibiotic expectations and intentions to request antibiotics questions and (ii) a novel scale measuring attitudes about the adequate use of antibiotics. The vignette with its questions and the attitude scale were presented to participants on separate pages in a random order. The cold-like symptoms vignette was designed to assess inappropriate antibiotic expectations and requests and the scale was developed to assess more general attitudes towards antibiotics use. The cold-like symptoms vignette was adopted from prior research (Sirota et al., 2017; Thorpe et al., 2021) and are consistent with the NICE guidelines on antibiotic prescribing (National Institute for Health and Care Excellence (NICE), 2017). In the cold-like symptoms vignette, participants imagined that they had fever, headaches, cough and a sore throat and that they went to consult their family physician. Participants learnt from the physician that examinations excluded more serious illnesses and were provided advice on managing their symptoms with painkillers. Participants then reported their expectations of antibiotics and their intentions to request antibiotics using the same items as in Experiment 1. The internal consistency of both scales was excellent (Cronbach's α = 0.92, α = 0.91, respectively).

Participants also completed the newly designed *Adequate Use of Antibiotics* (AQUA) scale that measures participants' attitudes about the adequate use of antibiotics. The scale featured ten items that measured attitudes towards (in)adequate use of antibiotics when (un)necessary, and perception of harm and benefits associated with such use (e.g., reversed item: "It does not matter how many times you take antibiotics, they will not do any harm"; see Supplementary Materials). The scale was developed by the study team and in a pretest showed good internal consistency and predictive validity (see Pretest in Supplementary Materials). Participants expressed their agreement with ten statements on a 6-point Likert scale (*1: Strongly disagree, 2: Disagree, 3: Somewhat disagree, 4: Somewhat agree, 5: Agree, 6: Strongly agree*). The internal consistency of the scale was good (Cronbach's α = 0.74).

Finally, participants answered a few questions concerning their prior experience of being prescribed antibiotics in the last three years, how frequently they were prescribed antibiotics for bacterial and viral infections as well as demographic questions regarding their gender, age, education and employment.

We conducted the study in accordance with the ethical standards of the American Psychological Association (APA) and obtained ethical approval from the Ethics Committee of the Department of Psychology, University of Essex. We have reported all measures, manipulations, and exclusions. The data set, pre-registration and materials are available at https://osf.io/5s82k/.

Statistical analysis. We adopted an identical analytical strategy as in Experiment 1. To test our model-derived hypotheses, we ran a planned contrast of the effect of the interventions (vs baseline) on expectations of antibiotics and intentions to request antibiotics using ANOVA (Hypothesis 1.1 and 1.2, respectively). To test our hypotheses not derived from the model, we ran a planned contrast of the effect of the cost interventions (vs reducing diagnostic uncertainty) on expectations of antibiotics and intentions to request antibiotics using ANOVA (Hypothesis 2.1 and 2.2, respectively). In addition, we also ran a planned contrast of the effect of the interventions (vs baseline) on the attitude towards adequate use of antibiotics using ANOVA (Hypothesis 2.3). Since the assumptions of homogeneity of variances and normality were not always met for all the planned contrasts, we used robust tests of equality of means using Brown-Forsythe correction for one-way ANOVA(F^*), and contrast *t*-tests not assuming equal variances (t^*). We found the same results using ANOVA assuming normality and equal variances (see Supplementary Materials). In addition, we also conducted robustness checks for the effect of the interventions using different plausible analytic strategies (see Supplementary Materials). We carried out equivalent default Bayes factor analyses, correlational and moderation analyses as described in detail in Experiment 1.

Results and Discussion

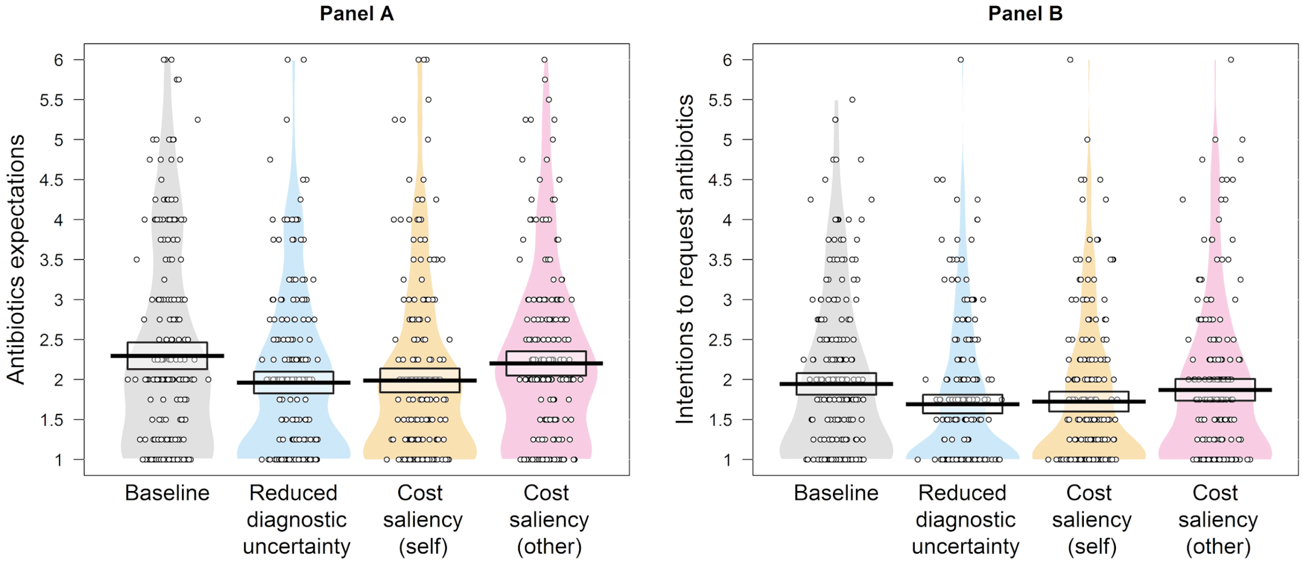
Effect of interventions on antibiotic expectations and intentions to request antibiotics

Similarly to Experiment 1, the participants in the intervention conditions had lower expectations of antibiotics and reduced intentions to request antibiotics for their hypothetical cold-like infection than those in the baseline group, $F^*(3, 856.54) = 4.59$, $p = .003$ and $F^*(3, 860.30) = 3.45$, $p = .016$, respectively (Figure 3, $N = 879$). In the first planned contrast ($\alpha_{adj} = .025$), the interventions ($M = 2.05$, $SD = 1.09$) compared to the baseline group ($M = 2.30$, *SD*

= 1.27) significantly decreased antibiotic expectations, $t^*(347.35) = 2.59$, $p = .010$, $d = 0.21$. The BF model yielded moderate relative evidence to support the intervention effect model, $BF_{10} = 4.3$. The interventions ($M = 1.76$, $SD = 0.94$) compared to the baseline group ($M = 1.94$, $SD = 1.03$) also significantly decreased the intentions to request antibiotics, $t^*(366.26) = 2.34$, $p = .020$, $d = 0.19$. However, they yielded only anecdotal relative evidence to support the intervention effect model, $BF_{10} = 1.7$. These effects were small and smaller than those found with the ear infection, which might be partly explained by the lower levels of the expectations and intentions to request antibiotics for the cold. The conclusions were robust to different plausible analyses not assuming normality. Age, gender and education did not moderate the effect of the interventions (see Supplementary Materials). Thus, we confirmed both model-derived hypotheses—the effect of the interventions on antibiotic expectations (Hypothesis 1.1) and intentions to request antibiotics (Hypothesis 1.2).

Figure 3

Expectations of antibiotics (Panel A) and intentions to request antibiotics (Panel B) for cold-like symptoms in the baseline condition and the model-derived interventions (Experiment 2).



Note. *N* = 879; Horizontal bold lines represent means, boxes represent 95% confidence intervals, beans represent smoothed densities, and circles represent individual responses.

In the second planned contrast (α_{adj} = .025), the reduced diagnostic uncertainty intervention (*M* = 1.96, *SD* = 1.04) did not change antibiotic expectations any less than the cost saliency interventions (*M* = 2.09, *SD* = 1.11), *t**(490.33) = -1.52, *p* = .130, *d* = -0.12, yielding moderate relative evidence to support the null model, BF_{01} = 4.0. Reduced diagnostic uncertainty (*M* = 1.69, *SD* = 0.90) did not alter the intentions to request antibiotics compared with the cost saliency interventions (*M* = 1.80, *SD* = 0.96), *t**(492.81) = -1.39, *p* = .166, *d* = -0.11, yielding moderate evidence to support the null model, BF_{01} = 4.8. The conclusions were robust to different analyses not assuming normality (see Supplementary Materials). Thus, contrary to our expectations based on previous literature, we found no support for the predicted attenuated effect of the reduced diagnostic uncertainty relative to cost saliency interventions on antibiotic expectations (Hypothesis 2.1) and intentions to request antibiotics (Hypothesis 2.2).

Effect of interventions on attitude towards the adequate use of antibiotics

Finally, we found that all three interventions slightly improved the attitude towards the adequate use of antibiotics (reduced diagnostic uncertainty: $M = 5.17$, $SD = 0.59$, cost saliency (self): $M = 5.27$, $SD = 0.56$; cost saliency (other): $M = 5.16$, $SD = 0.53$) compared with the baseline condition that was already very high ($M = 5.12$ out of 6, $SD = 0.61$). Using the planned contrast, we found that the interventions ($M = 5.20$, $SD = 0.56$) did not significantly increase the attitude towards adequate use of antibiotics compared with the baseline ($M = 5.12$, $SD = 0.61$), $t^*(368.68) = -1.71$, $p = .088$, $d = -0.14$, yielding anecdotal relative evidence in favour of the null model, $BF_{01} = 2.5$.

Role of prior experience of being prescribed antibiotics

In the exploratory correlational analysis (critical $\alpha = .0125$), prior experience of frequently being prescribed antibiotics for viral infections correlated with antibiotic expectations ($r_s = .27$, $p < .001$) and intentions to request them ($r_s = .28$, $p < .001$). Prior experience of frequently being prescribed antibiotics for bacterial infections did not play a role in forming the expectations ($r_s = -.05$, $p = .117$) or intentions to request antibiotics ($r_s = .01$, $p = .726$). Thus, a similar pattern was found to that in Experiment 1.

In summary, we replicated the effect of the model-derived interventions on antibiotic expectations and intentions to request antibiotics. However, in contrast with our prediction based on prior literature, we did not find a sufficient effect of the interventions on the general attitude towards adequate antibiotic use and reduced diagnostic uncertainty was not less effective than the cost saliency interventions.

General Discussion

To tackle antibiotic resistance, we need to better understand the reasons why people expect antibiotics when they are not clinically necessary. Here, we proposed and tested one explanation leveraging a utility-based signal detection theory. Aligned with its predictions, participants in our study were less likely to expect antibiotics when (i) they learnt about the viral nature of respiratory tract infections and (ii) they perceived higher costs to them or other people associated with the overuse of antibiotics. People shifted the optimality-driven criterion towards higher accuracy when they were less uncertain about what establishes the signal (vs. noise) and when they perceived higher costs of false alarms, which decreased the overall utility of taking antibiotics. Importantly, both interventions decreased the expectations for antibiotics to a similar extent but did not diminish adherence to the prescribed antibiotic. Finally, the interventions did not affect the general attitude towards the adequate use of antibiotics.

These findings advance the current literature on antibiotic expectations. First, reducing diagnostic uncertainty is a common strategy adopted by public awareness campaigns but it has been hard to evaluate because it is often featured in multi-component interventions without a randomised design and control group (Huttner et al., 2010; NICE, 2015). Our findings show the causal effect of this strategy and thus validate this approach. Second, the effect of the increased cost saliency extends the currently adopted messaging strategies. Public awareness campaigns often inform about antibiotic resistance and the costs associated with it using generic terms (Huttner et al., 2010; Huttner et al., 2019; NICE, 2015). However, although people are aware of antibiotic resistance, they are not aware of the actual consequences of it: they overestimate possible benefits compared to negligible risks associated with taking antibiotics (Broniatowski et al., 2018). So, merely raising awareness of antibiotic resistance is unlikely to be sufficient for modifying public expectations of antibiotics. As demonstrated here, a vivid representation of the consequences of antibiotic resistance—whether linked directly to a person or other people—might be an effective messaging strategy. Our findings are aligned with findings showing that participants perceived that fear messages would change their likelihood of asking a doctor for antibiotics for upper respiratory illnesses (Roope et al., 2020). Based on the size of the effects, it is possible that making the cost relevant to a person directly might be more effective than making the cost relevant to others. However, more systematic research needs to be done to assess which messages are most effective in public campaigns (Huttner et al., 2019).

Taken together, our findings corroborate the utility-based signal detection account of antibiotic expectations (Lynn & Barrett, 2014; Lynn et al., 2015). However, the model's predictive power and its possible practical implications go beyond the predictions and implications outlined so far. The model can also account for other findings in the literature. For instance, it can accommodate the effects of prior experience of frequently being prescribed antibiotics for viral infections on expectations, as demonstrated in this paper as well as the effect of social norms on expectations (McNulty et al., 2019; Thorpe et al., 2021). People's prior direct experience of being prescribed antibiotics inappropriately can be modelled via subjectively perceived base rate information, which could help to explain the liberally biased threshold. Similarly, the effect of social norms—socially mediated experience of being over-prescribed antibiotics—can be accommodated by the subjectively perceived base rate parameter.

Several limitations of our research deserve more attention. First, we adopted a utility-based model of signal detection theory, but, prospect theory can better account for human decision-making than utility theory (Lynn & Barrett, 2014). Even though for our tests these considerations are inconsequential, future research should modify the theory in this respect (Lynn et al., 2015). Second, we tested qualitative predictions of this computational theory.

These were to serve as proof-of-the-concept experiments. Future research could leverage the computational nature of the theory: estimate the parameters of individual decision-makers, derive more precise quantitative predictions and extend the scope of the predictions. Third, our research used realistic and familiar medical situations, but our participants were not making decisions about antibiotics based on real-life experience of illness. Future research could test the proposed mechanisms on patients currently experiencing an upper respiratory tract infection. Finally, our research studied the effect of interventions that were not matched in certain characteristics (e.g., cost saliency for others intervention was longer than other two interventions) and did not assess the longevity of the interventions effects. Future research should focus on testing the effectiveness of the intervention more closely matched in superficial features such as text length and test how lasting are the intervention effects.

To conclude, we propose here that people expect antibiotics even when they are not needed because they optimise the expected utility of their decisions in situations of diagnostic uncertainty. We found supporting evidence for critical experimental tests of such an explanation: reduced diagnostic uncertainty and cost saliency decreased the antibiotic expectations and intentions to request antibiotics for self-limiting illnesses.

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