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Health-Related Disinformation: Should We Focus More on Reducing the Mindware Gap or Corrupted Mindware?

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The main aim of our study was to investigate whether COVID-19 conspiracy beliefs are driven by a lack of useful and potentially protective mindware or by contaminated mindware. On the quota sample of 501 adult Slovaks, we also investigated whether personally relevant content improves scientific reasoning by using two versions of scientific reasoning tasks – one with coronavirus scenarios and one neutral, but we found no effect. While probabilistic reasoning and scientific knowledge negatively predict belief in COVID-19 conspiracy theories, anti-scientific attitudes significantly contribute to their higher acceptance. Thus, addressing anti-scientific attitudes and developing probabilistic reasoning and scientific knowledge may be crucial to attenuate health-related conspiracy beliefs.

Key words: conspiracy belief; probabilistic reasoning; scientific reasoning; anti-scientific attitudes; mindware

Health is often a top priority in polls, yet health-related unfounded beliefs remain some of the most widespread. Quackery, various pseudoscientific New Age beliefs or conspiracy theories about Big Pharma posed a threat to public health even before the pandemic, e.g., through increasing vaccination hesitancy (Carrieri et al., 2019; Čavojová, Lorko, et al., 2024; Montagni et al., 2021) or rejection of cancer treatments (Fournier & Varet, 2024). The COVID-19 pandemic has exposed the dangers of health misinformation even more, linking conspiracy theories to vaccine hesitancy, refusal to wear masks, and reduced wellbeing (for a review, see van Mulukom et al., 2022). Thus, it is crucial to understand what drives people to acquire such beliefs. The early stages of the COVID-19 pandemic provided a suitable backdrop for exploring this topic, as it was a novel and threatening situation for everyone, including scientists. Nobody had enough reliable infor-

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mation at the beginning, thus people had to rely on their previous knowledge, use their abilities and skills to assess new information, and often used their prior beliefs to guide their understanding of a new situation.

In general, reliance on intuitive processing usually leads to more unfounded beliefs, while analytic thinking helps people to examine and reject the initial but wrong intuitions (e.g., Pennycook et al., 2015). However, analytic thinking alone is not enough. According to the tripartite model of human rationality (Stanovich et al., 2016), a person not only needs to have sufficient cognitive abilities, but also an inclination to use them. Furthermore, a person often also needs specific skills to solve the problems (i.e., "mindware"). There are two types of errors related to mindware: a person may lack specific mindware (e.g., rules for calculating probabilities) or have contaminated mindware (e.g., a strong belief in the power of intuition or a strong distrust of science). While both mindware gaps and contaminated mindware have been shown to correlate with health-related unfounded beliefs (e.g., Budžak & Branković, 2022; Čavojová et al., 2022, 2023), so far they have not been examined together. Therefore, in this paper, we investigate both types of mindware problems as predictors of conspiracy beliefs about COVID-19 to establish their relative strength.

Distinction between Mindware Gaps and Contaminated Mindware

Successfully overriding intuitive responses requires both declarative knowledge (what one knows) and procedural knowledge (how to apply it). This set of knowledge, consisting of rules, strategies, and procedures, is referred to as "mindware." Mindware is acquired through learning and experience, which is why individuals vary in their ability to override intuitive responses based on the mindware available to them (Stanovich et al., 2016). Two types of mindware-related errors can hinder rationality: a lack of mindware (mindware gap) or contaminated mindware, which leads to irrational responses. To distinguish between a mindware gap and contaminated mindware, we can look at the nature of the reasoning error and the source of faulty cognition. Mindware gap refers to an absence of relevant knowledge, rules, or cognitive strategies needed to solve a problem or make a decision effectively. Essentially, the individual is missing the "mental tool" that could guide proper reasoning. For example, if someone is unaware of the probability theory or lacks statistical reasoning skills, they may look at the statistical information about COVID-19 death rates in various countries but may be unable to compare this information based on the number of inhabitants. On the other hand, contaminated mindware refers to faulty or maladaptive knowledge, such as a flawed rule, heuristics, or a belief that actively leads to poor reasoning. The individual has knowledge, but it is "incorrectly calibrated," "biased," or otherwise dysfunctional. For instance, believing in a pseudoscientific principle rejecting science in general can lead to contaminated mindware.

Mindware gap and contaminated mindware also differ in the level of awareness – i.e., while people are often unaware that they lack some crucial knowledge or skill, they curiously actively hold onto a piece of faulty knowledge or belief, usually with some level of awareness or explicit endorsement of this belief. They might even be overly confident about the erroneous information, making them less likely to change their reasoning (Grossman & Owens, 2012; Simon & Kim, 2016).

Moreover, while mindware gaps usually stem from lack of exposure to relevant knowledge or training, contaminated mindware arises from exposure to erroneous,

misleading, or biased knowledge. Thus, mindware gap and contaminated mindware may also differ in the susceptibility to correction and education. Errors caused by mindware gaps can often be remedied through education and exposure to the appropriate knowledge (e.g., Donati et al., 2018). When the individual learns the correct rules, principles, or strategies, they can immediately start applying them effectively. Errors due to contaminated mindware may be more resistant to change, as they often involve ingrained beliefs, biases, or faulty heuristics that are more difficult to unlearn or correct (e.g., Ecker et al., 2022). Therefore, it is crucial to understand what drives the beliefs in conspiracy theories about the novel situations (such as COVID-19 in 2020), so we can aim interventions more effectively.

Missing Mindware: Probabilistic Reasoning, Scientific Reasoning, and Scientific Knowledge

In the context of COVID-19, we identified three key areas of potentially beneficial mindware (i.e., mindware gap) – probabilistic reasoning, scientific reasoning, and scientific knowledge – based on the literature discussed below.

Probabilistic reasoning is crucial for understanding health-related statistics, especially during the pandemic, for interpreting infection rates and vaccination risks. It was found that some of the errors in probabilistic reasoning, such as the conjunction fallacy or denominator neglect, are linked to conspiracy beliefs (Ballová Mikušková, 2021; Brotherton & French, 2014). The resistance to the ratio bias phenomenon, or denominator neglect is one of many indicators of probabilistic reasoning and is the focus of our study. Denominator neglect, where people focus on numerators over denominators in probabilistic tasks, is linked to poor numeracy and analytical thinking (Ballová Mikušková, 2015; Reyna & Brainerd, 2008). It can negatively impact understanding of medical information and health decisions, such as interpreting treatment risks (Garcia-Retamero & Galesic, 2009) or mortality rates (Bonner & Newell, 2008; Yamagishi, 1997). Some studies have found weak to moderate associations between denominator neglect and conspiracy beliefs (Ballová Mikušková, 2021; Šrol, 2022). This study aims to explore these associations specifically in the context of COVID-19.

Scientific reasoning is crucial for evaluating scientific evidence and reflects one's ability to grasp scientific methods and principles (Bašnáková et al., 2021; Drummond & Fischhoff, 2017a). Recent studies have shown that scientific reasoning predicts endorsement of various unfounded beliefs, including conspiracy beliefs, beyond the predictive capacity of analytical thinking alone (Čavojová et al., 2020, 2022). Therefore, it is essential to distinguish scientific reasoning from the broader concept of analytical thinking.

Additionally, some studies suggest that people are better at reasoning when they engage with concrete content (Bašnáková et al., 2021) and/or when the content is relevant to them (Chaiken, 1980; Petty & Cacioppo, 1984). Personally relevant content is one of the situational factors that can increase motivation to invest more cognitive effort in the reasoning process (Petty & Cacioppo, 1984). Building on the tri-partite model, personally relevant content – such as the COVID-19 pandemic, which touched the lives of a large majority of people, whether through concerns about their own health, changes in daily routines, economic impact, or social distancing, should help with closing the mindware gap by increasing the motivation for more deliberative thinking. On the other hand, COVID-19 pandemic setting could also trigger contaminated mindware, as the existential threat

is linked with a surge of conspiracy beliefs (van Prooijen, 2020). To examine the effect of the content on people's ability to reason scientifically, we used two versions of scientific reasoning tasks (neutral scenarios and coronavirus-related scenarios). The coronavirus-related content was also used when examining the denominator neglect tasks.

When people consider complex scientific topics like the global coronavirus pandemic and its management, they need basic *scientific knowledge* to better understand aspects such as virus transmission and the importance of social distancing. Scientific knowledge combined with scientific reasoning skills, allows even non-experts to evaluate scientific evidence and make informed decisions (Drummond & Fischhoff, 2017a).

Are Conspiracy Theories Part of Contaminated Mindware?

Originally (Stanovich, 2009) contaminated mindware includes various misinformation, superstitious and pseudoscientific beliefs, faulty heuristics, flawed or incomplete mental models, biased thinking patterns, and excessive reliance on intuition. Moreover, it also includes egocentric reasoning that promotes biased thinking, and misconceptions about our own minds, such as the incorrect belief that we fully understand the reasons behind our actions and are immune to cognitive biases that affect others (West, 2010).

In this study we focused on two general components of contaminated mindware: distrust in science and overconfidence, here represented as the tendency to overestimate one's knowledge. Previous research has shown that anti-scientific attitudes – whether operationalized as distrust in science, science skepticism, or anti-scientific attitudes – are a strong negative predictor of conspiracy beliefs (Fasce & Picó, 2019; Roozenbeek et al., 2020) and inhibit rational thinking (Stanovich et al., 2016). Science skepticism is one of the well-documented factors associated with conspiracy beliefs and many negative health outcomes, such as vaccination refusal (Hornsey et al., 2020), non-compliance with preventive measures during pandemics (Plohl & Musil, 2021), or preference for alternative medicine (Furnham, 2007). Some previous research (Fernbach et al., 2019; Light et al., 2022) has indicated that there is an important interplay between anti-scientific attitudes, objective scientific knowledge and overestimation of one's knowledge, i.e. overconfidence. While objective scientific knowledge is positively related to pro-scientific attitudes, subjective knowledge – which refers to a person's self-assessment of their knowledge – may be more closely related to anti-scientific attitudes. Light et al. (2022) tested this hypothesis and found in a series of five studies that participants with the highest levels of science skepticism had the lowest levels of objective knowledge, but also had the highest self-confidence in their knowledge of certain scientific topics, including COVID-19 vaccination and protective behaviors. When individuals exhibit a strong belief in their expertise despite lacking scientific knowledge, they show a cognitive bias known as the Dunning-Kruger effect (Kruger & Dunning, 1999). This misplaced confidence, detrimental to rationality, can be viewed as contaminated mindware (Berthet et al., 2022). Overconfidence, linked to intuitive thinking (Mata et al., 2013), may also correlate with conspiracy beliefs (Binnendyk & Pennycook, 2022).

Originally, conspiracy beliefs and anti-science attitudes have been considered a form of contaminated mindware by some researchers (Rizeq et al., 2021; Stanovich et al., 2016). However, in our study, we decided to take another approach. Specific conspiracy theories about a novel situation (as was COVID-19)

arise from prior general attitudes, mental models of the world, and biased thinking patterns. For example, anti-science attitudes reflect a broader, general mindset that predisposes individuals to various irrational beliefs, including conspiracy theories. Therefore, we decided to look at conspiracy theories about COVID-19 (which were new at the time of data collection) as an outcome variable and examine how they are predicted by more general factors comprising contaminated mindware. This approach enables us to understand how underlying general dispositions, such as skepticism or distrust toward science, actively contribute to the adoption of more specific irrational beliefs like conspiracy theories about COVID-19. Moreover, the recent study by Stanovich and Toplak (2024) suggests similar approach to change in perspective on conspiracy beliefs as stored declarative knowledge and shift towards a conception of conspiratorial thinking as a cognitive style.

Current Study

Building on the literature and reasoning discussed above, in this study we tested the hypothesis that people with lower skills in probabilistic and scientific reasoning and lower scientific knowledge (mindware gap) and a more anti-science attitude and greater overconfidence (contaminated mindware) will have more conspiracy beliefs about the coronavirus. In addition, we investigated whether scientific reasoning depends on the context in which it is used. To do this, we used two sets of tasks: one with neutral scenarios and one with corona-specific scenarios but testing the same scientific concepts. We hypothesized that by making the task more personally relevant (corona-specific scenarios), people would be more motivated to use their scientific reasoning and subsequently be better able to evaluate the evidence (or lack thereof)

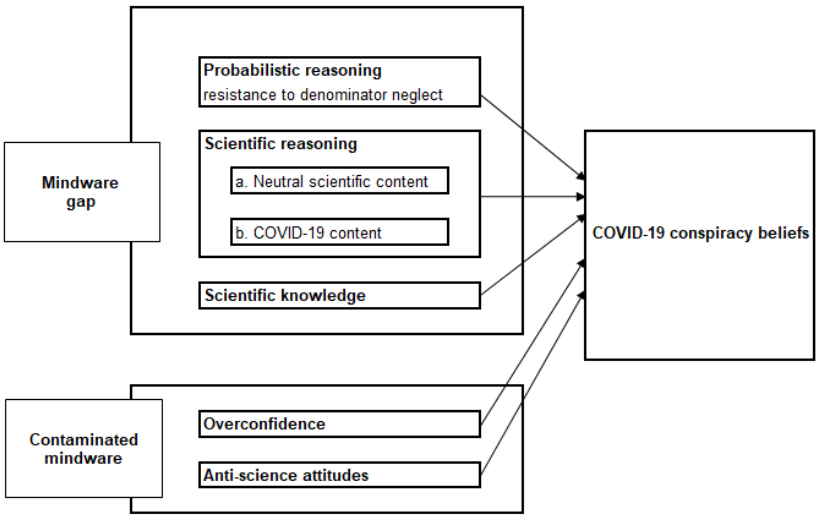

Figure 1 Theoretical framework of the study.

for conspiracy theories about COVID-19. Understanding if trust in health conspiracy theories stems from lack of knowledge or from harmful beliefs is crucial. While we expect that both play some role in endorsement of COVID-19 conspiracy beliefs, when our sources are limited, it is important to know whether we should primarily focus on closing the mindware gap or addressing contaminated mindware. The theoretical framework of this paper is shown in Figure 1.

Methods

Participants and Procedure

The data were collected as part of a larger study on beliefs and behaviors related to the COVID-19 pandemic (Šrol et al., 2022). The present sample consisted of 501 participants (241 men, 260 women), who completed the online survey created in Qualtrics via an invitation from a participant recruitment agency. Participants were aged between 18 – 85 years (M = 45.05, SD = 15.92). When asked about their education level, 8.8% of participants claimed to have an elementary or an incomplete high school education, 73.5% had completed high school education and 17.8% had some college/university education.

The survey took the form of an online questionnaire consisting of eight short blocks. Blocks analyzed in this study contain socio-demographic questions and COVID-19 conspiracy theories (13 items), scientific reasoning (12 items), denominator neglect tasks (6 items), anti-scientific attitudes and science knowledge (23 items), and overestimation (1 item). Other measures not reported here (regarding anxiety and lack of control, news exposure, and prejudice and discrimination) were part of a separate research study. The average time to complete the whole survey was 36 minutes.

Materials

All materials, data, and supplementary materials are publicly available at: https://osf.io/fd8u2/.

Scientific reasoning was measured with six items based on the Scientific Reasoning Scale (Drummond & Fischhoff, 2017a) and modified by Bašnáková et al. (2021). Six additional items that measure the same validity threats but whose content relates to the coronavirus were created for this study. For example, the „causation vs. correlation“ item was about decreasing infection rate („A researcher wants to find out what factors protect people against the new coronavirus. He asks for statistical information and sees that there are fewer infected people among those who do some active sport. This finding implies that active sport will decrease the infection rate of a population.“). Participants responded to the questions by selecting one of the options: *Agree/Disagree* and the sums of correct answers for neutral tasks and coronavirus tasks were used. Cronbach's alpha neutral version α = .50; COVID-19 version α = .43. McDonald's omega neutral version ω = .51; COVID-19 version ω = .43.

Probabilistic reasoning. We used six tasks from the jelly bean task (Kirkpatrick & Epstein, 1992) with modified coronavirus-related content to measure resistance to neglecting the denominator. For example: Imagine two states – A and B. Each of them has reported cases of coronavirus infections and deaths caused by coronavirus. Which of the two states is worse off? State A has 7 million citizens and 210,000 cases of infections, or State B has 3 million citizens and 150,000 cases of infections. Participants responded by selecting one of the options and received a score for the correct answers. Thus, a higher total score indicates resistance to denominator neglect and better

probabilistic reasoning. Cronbach's alpha α = .56; McDonald's omega ω = .60.

Anti-scientific attitudes. We used a 13-item *Anti-Scientific Attitudes* subscale from CART developed by Stanovich et al. (2016). Participants had to indicate on a 6-point scale from 1 (*strongly disagree*) to 6 (*strongly agree*) their agreement with statements such as "I don't place great value on 'scientific facts', because scientific facts can be used to prove almost anything." A higher mean score indicates stronger anti-science attitudes. Cronbach's alpha α = .80; McDonald's omega ω = .80.

Actual scientific knowledge. To test participants' knowledge of scientific concepts, we used 5 items (*true/false*) from the Scientific Literacy Scale (SLS), which is based on the National Science Indicators (Miller, 1998; National Science Board, 2018). We also added five items related to the novel coronavirus (Čavojová et al., 2022). We used a composite score and a higher number indicated better scientific knowledge. Cronbach's alpha α = .25; McDonald's omega ω = .26.

Self-estimation of scientific knowledge and Overconfidence. After the scientific knowledge quiz, we asked participants to indicate how many answers they thought they answered correctly, thus, we gained a variable regarding the self-estimated performance. Overconfidence was calculated by subtracting the actual number of correct points from the estimated number of points. A positive number indicates overestimation and a negative number underestimation of one's abilities.

COVID-19 conspiracy beliefs. We used 8 statements on different COVID-19 conspiracy beliefs and asked participants to rate on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*) the extent to which they believed the respective statement, e.g., SARS-CoV-2 (coronavirus) is a biological weapon created to eliminate the overcrowded human population. A higher mean score indicates higher acceptance of conspiracy beliefs. Cronbach's alpha α = .89; McDonald's omega ω = .89.

Results

Descriptives and Correlations between Main Variables

Descriptive statistics and correlations between all main variables can be found in Table 1.

Table 1 *Descriptives and correlations between variables*

	M	*SD*	*Range*	1.	2.	3.	4.	5.	6.	7.
1. Scientific reasoning neutral	4.14	1.40	0 - 6	1						
2. Scientific reasoning C-19	3.06	1.45	0 - 6	.56***	1					
3. Probabilistic reasoning	3.51	1.32	0 - 5	.32***	.29***	1				
4. Anti-scientific attitudes	3.17	0.70	1.08 - 5.23	-.21***	-.20***	-.19***	1			
5. Actual sc. knowledge	7.09	1.50	2 - 10	.32***	.26***	.31***	-.23***	1		
6. Self-estimation of sc. knowledge	7.56	1.59	2 - 10	.14**	.09*	.11*	-.19***	.21***	1	
7. Overconfidence	0.47	1.94	-5 -+ 8	-.13**	-.13**	-.15**	.03	-.60***	.66***	1
8. C-19 conspiracy beliefs	2.45	.98	1-5	-.21***	-.19***	-.24***	.54***	-.29***	-.13**	.12**

Note. N = 501. M = mean; SD = standard deviation; Sc. = Scientific; C-19 = COVID-19. Range includes minimum and maximum values. Correlations are expressed using the Pearson's correlation coefficients r.

* $p < .05$; ** $p < .01$; *** $p \leq .001$

Table 2 *Means and standard deviations for scientific reasoning neutral and scientific reasoning COVID-19 and comparison of the performances*

	SRS neutral		SRS C-19				
	M	*SD*	*M*	*SD*	χ^2	*p*	*φ*
Item 1. Causation vs. correlation	0.88	0.33	0.47	0.50	176.64	<.001	.18***
Item 2. Confounding variables	0.78	0.41	0.72	0.45	5.32	.021	.15**
Item 3. Construct validity	0.81	0.39	0.41	0.49	160.98	<.001	.17***
Item 4. Control group	0.65	0.48	0.64	0.48	.05	832	.61***
Item 5. Ecological validity	0.59	0.49	0.57	0.49	1.92	.166	.69***
Item 6. Random assignment to conditions	0.43	0.50	0.25	0.43	40.11	<.001	.10*

Note. M = mean; *SD* = standard deviation; SRS = scientific reasoning scale; C-19 = COVID-19. χ^2 = test statistic Chi-Square. Correlations between the paired items are expressed using the *Phi* (*φ)* coefficient.
*p < .05; **p < .01; ***p < .001

All variables on the potentially useful mindware side, i.e., scientific reasoning (both scores), probabilistic reasoning – resistance to denominator neglect and scientific knowledge, correlate positively with each other. Our data show no relationship between overconfidence and anti-scientific attitudes. Conspiracy beliefs are positively associated with anti-scientific attitudes (strong level) as well as overconfidence, however, the correlation is low. Conspiracy beliefs correlate negatively with both versions of the scientific reasoning tests as well as with resistance to denominator neglect and scientific knowledge. All of these negative correlations are consistent with previous findings (Ballová Mikušková, 2021; Čavojová et al., 2022; Georgiou et al., 2021; Sunyík & Čavojová, 2023). Participants overestimated their performance on the scientific knowledge test (M_{actual} = 7.09, $M_{estimate}$ = 7.56) and this difference was statistically significant *t (500)* = 5.45, p < .001. However, the effect size was small, Cohen's d = .24.

Comparing Performance in Scientific Reasoning between Two Versions: Neutral and COVID-19

In four out of six tasks, participants' scientific reasoning skills were better when they were dealing with neutral scenarios, as shown in Table 2. For the remaining two tasks, we found no significant differences. These results contradict our assumption that personally relevant content (i.e., content related to the coronavirus pandemic) improves scientific reasoning. In contrast, participants in the neutral version showed better overall scientific reasoning skills. The difference between the two total scores tested using paired *t*-test was significant ($M_{neutral}$ = 4.14, $SD_{neutral}$ = 1.40, $M_{Covid\text{-}19}$ = 3.06, $SD_{Covid\text{-}19}$ = 1.45, t (500) = 18.01, p < .001). The effect size of the overall difference is large (Cohen's d = 0.80).

Table 3 *Hierarchical linear regression analysis predicting COVID-19 conspiracy beliefs*

	COVID-19 conspiracy beliefs				
Variable	*B (SE)*	*β*	*t*	*p*	95% CI for *β*
Step 1					
Constant	3.07 (.12)		25.35	<.001	
Probabilistic reasoning	**-.18 (.03)**	**-.24**	**-5.48**	**<.001**	[-.32, -.15]
	F (1,499) = 30.07, R^2 = .06, p = < .001				
Step 2					
Constant	4.09 (.21)		19.33	<.001	
Probabilistic reasoning	**-.10 (.03)**	**-.14**	**-2.96**	**.003**	[-.23, -.05]
Scientific reasoning composite	**-.04 (.02)**	**-.11**	**-2.35**	**.019**	[-.20, -.02]
Actual scientific knowledge	**-.14 (.03)**	**-.21**	**-4.58**	**<.001**	[-.30, -.12]
	F (3,497) = 22.03, ΔR^2 = .06, p = < .001				
Step 3					
Constant	1.26 (.33)		3.79	<.001	
Probabilistic reasoning	**-.07 (.03)**	**-.10**	**-2.37**	**.018**	[-.17, -.02]
Scientific reasoning composite	-.01 (.02)	-.04	-.88	.382	[-.12, .04]
Actual scientific knowledge	**-.09 (.03)**	**-.14**	**-3.36**	**.001**	[-.22, -.06]
Self-estimation of scientific knowledge	.01 (.02)	.01	.26	.796	[-.07, .08]
Anti-scientific attitudes	**.67 (.05)**	**.48**	**12.44**	**<.001**	[.41, .56]
	F (5,495) = 48.68, ΔR^2 = .21, p = < .001				

Note. Unstandardized (*B*), standardized regression coefficients (*β*) with significances and 95% confidence intervals for *β* are presented for each predictor. The table shows model statistics for each step, R^2, and changes as ΔR^2 with the appropriate statistical change. Significant predictors (p < .05) are presented in bold.

Predictors of Conspiracy Beliefs

In the last part of the data analysis, we investigated whether conspiracy beliefs are predicted by factors associated with mindware gap or by factors associated with contaminated mindware. However, since the score for overconfidence was calculated from the scientific knowledge, there is a structural relationship between them. Therefore, one strategy[1] to address this is to avoid using the computed confidence variable in regression. Instead, ac-

[1] Another possible strategy to address the structural relationship between actual scientific knowledge performance and overconfidence is to create new ordinal variable from the overconfidence variable which contains three categories as follows: Those participants with values of overconfidence score -1 and less, are classified as underconfident and denoted -1; those with the exact value 0 are classified as well calibrated and denoted 0 and those with the values 1 and higher are classified as overconfident and denoted 1. By converting overconfidence into such ordinal variable, we are reducing (although not fully) the risk of multicollinearity. However, we are aware that such strategy is related to some loss of the variability in the data. The results of this approach did not differ from the results presented in the paper. We present this strategy in supplementary materials: https://osf.io/fd8u2/

tual performance and self-estimated performance should be used separately in the analysis. This approach was used also in a series of experiments by Pennycook et al. (2025). Additionally, we computed one score for scientific reasoning ability as a total score of 12 items from both versions of the scientific reasoning test (M = 7.21, SD = 2.52, Cronbach's alpha α = .66, McDonald's omega ω = .66). Probabilistic reasoning was entered in the first step, scientific reasoning together with actual scientific knowledge in the second step and self-estimation of scientific knowledge and anti-scientific attitudes in the third step. The results can be found in Table 3.

Resistance to denominator neglect, indicating better probabilistic reasoning, and greater scientific knowledge were significant negative predictors of COVID-19 conspiracy beliefs. Scientific reasoning was significant in the second analysis step but lost its predictive power after introducing anti-scientific attitudes in the third step. Anti-scientific attitudes were the strongest positive predictor of COVID-19 conspiracy beliefs. Self-estimation of scientific knowledge did not play a significant role. Overall, these predictors explained 33% of the total variance in both models.

Our results emphasize the importance of mindware, which should include developed probabilistic reasoning skills and scientific knowledge while excluding anti-scientific attitudes, to reduce susceptibility to COVID-19 conspiracy beliefs. In a health-related context, it is crucial to narrow the gap in specific skills while avoiding the adoption of contaminated content.

Discussion

The main aim of our study was to investigate whether COVID-19 conspiracy beliefs are driven by a lack of useful and potentially protective mindware or by contaminated mindware. The results indicate that both factors are relevant. Probabilistic reasoning and scientific knowledge have a protective effect, while anti-scientific attitudes significantly increase the acceptance of these beliefs.

As expected, probabilistic reasoning was a significant factor in predicting endorsement of health-related conspiracy beliefs, and it remained significant even after including the measures of contaminated mindware into the model. People who are more resistant to denominator neglect handle numerical information better, which is essential in the medical field (Peters & Shoots-Reinhard, 2022; Reyna et al., 2009). Consistent with our findings, we suggest that these skills are particularly valuable for individuals in analyzing alarming news, such as conspiracy theories meant to provoke fear. This ability allows them to view conspiracy claims about potential threats with a clear and rational perspective, even in emotionally charged situations (Dieckmann et al., 2009; Peters, 2012).

Similarly, scientific knowledge as well was (and remained) a significant factor in preventing susceptibility to conspiracy theories, consistent with recent findings (Sunyík & Čavojová, 2023). Higher education levels, as an indicator of scientific knowledge, are also linked to lower endorsement of conspiracy beliefs (Georgiou et al., 2019; van Prooijen, 2017). However, previous research has shown that basic scientific knowledge alone is sometimes insufficient to counter unfounded beliefs. For instance, Miller et al. (2016) found that better political knowledge paired with a lack of trust could lead to more conspiracy beliefs. Drummond and Fischhoff (2017b) noted that better scientific knowledge and education could result in more polarized attitudes towards scientific topics which often fuel conspiracy beliefs, such as climate change. Based on our findings, we conclude that prioritizing the acquisition of scientific knowledge and

education is beneficial. However, this should be complemented by promoting positive attitudes towards science and developing specific skills, such as scientific and probabilistic reasoning.

Surprisingly, while there was a significant negative relationship between conspiracy beliefs and scientific reasoning, in the final regression model, scientific reasoning lost its predictive power when anti-scientific attitudes, the strongest predictor of coronavirus-specific conspiracy beliefs, were included. This finding aligns with previous research showing that trust in science is crucial in countering conspiracy beliefs (Fasce & Picó, 2019; Lewandowsky et al., 2013; Roozenbeek et al., 2020). One explanation could be the timing of data collection, early in the pandemic, when scientific knowledge about the disease was still developing. A study by Čavojová et al. (2022) found no difference in preventive behaviors between those with strong and weak scientific understanding and in a later study the authors argued that second order scientific literacy skills – i.e., trust in science – become more important, as not everyone has the ability, motivation or time to engage in scientific reasoning (Čavojová, Šrol, et al., 2023). Trust in science helps people decide which experts to rely on (Chin & Duncan, 2018). Those with general trust in science tend to follow expert recommendations (Plohl & Musil, 2021), especially crucial during the pandemic. Trust in science can guide decision-making independently of specific scientific knowledge or reasoning skills, highlighting its role in navigating new information and making informed decisions.

Thus, our findings underscore the importance of promoting positive attitudes towards science, especially in health-related contexts. This task is challenging due to the complexity of anti-science attitudes, which are influenced by factors such as cognitive limitations, ideologies, vested interests, morality, fears, personal and social identity needs, and conspiracy theory worldviews (Hornsey & Fielding, 2017; Rutjens et al., 2017). A recent review on conspiracy beliefs and science rejection (Rutjens & Većkalov, 2022) suggests effective strategies to mitigate these attitudes, including communicating scientific consensus, accurately portraying scientists in science communication, and reducing the psychological distance from science by presenting information as more personally relevant.

Self-estimated scientific knowledge was not a significant predictor of conspiracy beliefs. Also, the correlation between overconfidence variable and conspiracy beliefs was weak in our study (r = .12). The relationship between overconfidence and conspiracy beliefs is a relatively new area of research that is still developing. Recent studies have shown a correlation between overconfidence and conspiracy beliefs by examining overconfidence as a dispositional factor – "a general tendency to overrate one's cognitive abilities" (Pennycook et al., 2025, p. 4). This dispositional self-confidence can act as a barrier, preventing conspiracy believers from properly questioning their beliefs and recognizing that others might view their beliefs as unusual (Pennycook et al., 2024). Studies showing this positive relationship have focused on reasoning processes. For instance, Vranic et al. (2022) assessed overconfidence by having participants self-assess their answers to syllogism tasks, which indicate analytical thinking. Similarly, Pennycook et al. (2025) conducted eight studies measuring dispositional overconfidence by overestimation of performance on cognitive tasks such as cognitive reflection tests, numeracy, and perception tests. It is possible that our measure of overconfidence, based on knowledge of basic scientific facts, was insufficient to detect this relationship. Our measure focused on fixed knowledge rather than stimulating critical and analytical thinking processes.

Finally, we hypothesized that more personalized content would improve scientific reasoning skills. Contrary to our expectations, participants performed better on neutral scenarios than on coronavirus-specific ones, though both negatively correlated with COVID-19 conspiracy beliefs to a similar extent. The poorer performance on coronavirus-specific scenarios could be due to pre-existing beliefs about the virus, which might influence their thinking. Research shows that people are swayed by prior beliefs when tackling „real-world" problems, leading to different conclusions compared to abstract or hypothetical questions (Greenhoot et al., 2004). The biggest difference in our results was in distinguishing between correlation and causation. In the neutral scenario, participants performed better than in the coronavirus-specific scenario, which involved assessing the relationship between physical activity and infection rates. The correct answer was that no causal conclusion could be drawn. However, many participants inferred causation, likely due to their beliefs about the health benefits of exercise and personal experiences. Early in the pandemic, physical activity was viewed as a safe preventive measure, which might have influenced their reasoning. Additionally, Bašnáková et al. (2021) found that prior beliefs can affect performance on scientific reasoning tasks, leading to both correct and incorrect answers. This suggests that personalized content can sometimes reinforce existing misconceptions rather than promote accurate reasoning.

Conclusion

The recent coronavirus pandemic has put our ability to keep a cool head and navigate the maze of new information to the test. In the early stages of the pandemic, scientists and policy makers were confronted with an unprecedented situation characterized by a lack of comprehensive information. This inherent uncertainty contributed to delays and inconsistencies in formulating effective measures, a dilemma that was mirrored in some countries, including Slovakia. In stark contrast, proponents of conspiracy theories showed unwavering confidence in their claims despite the lack of empirical evidence. The rapidly spreading conspiracy theories offered seemingly unambiguous explanations. Given the potential harm to health that conspiracy beliefs can cause, it is important to identify the protective factors that may contribute to reduced endorsement of conspiracy beliefs. We identified several important factors, such as probabilistic reasoning in addition to scientific knowledge, and positive attitudes toward science. This finding holds potential for tailored intervention or prevention programs aimed at reducing the prevalence of such beliefs. However, our findings also suggest that it is not sufficient to focus solely on improving skills (as the mindware gap factors explained only relatively low variance), as the most important predictor of conspiracy beliefs is anti-science attitudes. This is both good and bad news. While previous research suggested that addressing mindware gap problems (e.g., by teaching relevant skills to children and adults) is easier than tackling contaminated mindware, which tends to be more resistant to change, the positive takeaway is that attitudes toward science are, in fact, malleable (Lieskovský & Sunyík, 2022). Therefore, efforts to improve specific skills and knowledge should also be accompanied by the promotion of positive attitudes towards science, which seems to be one of the crucial factors when facing novel and unpredictable challenges.

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