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**WITH THE LITTLE HELP OF SCIENCE UNDERSTANDING: EXAMINING THE
DIRECT AND INDIRECT ROLE OF SCIENTIFIC REASONING AND TRUST IN
SCIENCE IN NORMATIVE HEALTH BEHAVIOR DURING PANDEMIC**

Vladimíra Čavojová^a, Jakub Šrol^a, & Eva Ballová Mikušková^a

^aInstitute of Experimental Psychology, Centre of Social and Psychological Sciences, Slovak
Academy of Sciences

Corresponding author:

Vladimíra Čavojová

Institute of Experimental Psychology, Centre of Social and Psychological Sciences,

Slovak Academy of Sciences

Dúbravská cesta 9, 841 04 Bratislava, Slovakia

Phone: + 421 - 2 - 5477 5625

Email: vladimira.cavojova@savba.sk

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With the little help of science understanding: Examining the direct and indirect role of scientific reasoning and trust in science in normative health behavior during pandemic

Abstract:

This paper focuses on the science understanding (scientific reasoning and trust in science) and analytic thinking and their role in: 1) having less conspiracy and pseudoscientific beliefs about COVID-19, and 2) behavioral intentions in line with scientific consensus (i.e. following evidence-based guidelines and vaccination intentions). We examined these direct and indirect effect of science understanding on normative health behavior in a representative sample of Slovak population ($N = 1024$). The results showed more support for the indirect path: people who understand science better had generally less epistemically suspect beliefs and as a consequence, tended to behave more in line with evidence-based guidelines and were more likely to get vaccinated. Neither scientific reasoning nor trust in science predicted avoidance of preventive measures directly, but analytic thinking correlated positively with avoiding preventive measures. The strongest predictor of epistemically suspect beliefs was trust in science, which also directly predicted the intention to get vaccinated against COVID-19. Thus, it seems that reasoning about which experts or sources to believe (second-order scientific reasoning) has become even more important than directly evaluating original evidence (first-order scientific reasoning).

Key words: science understanding; scientific reasoning; trust in science; epistemically suspect beliefs; health behavior; vaccination

Introduction

Since the beginning of COVID-19 pandemic in 2020 people have become increasingly aware of the importance of science in disentangling the uncertainty surrounding the yet unknown coronavirus, and coming with effective cure and vaccination to combat the disease (Gallup, 2019; Sibley et al., 2020). Moreover, during the course of unfolding pandemic another important aspect of science understanding has come to attention: while the conspiracy theories and other unfounded beliefs tend to spread during the times of social upheaval and crisis (Grzesiak-Feldman, 2013; Swami et al., 2016; van Prooijen & Douglas, 2017; van Prooijen & van Vugt, 2018) – which, indeed, quickly proved to be the case with COVID-19 pandemic – higher trust in and understating of science seemed to serve as a shield against such beliefs (Čavojová, Šrol, & Ballová Mikušková, 2020). However, clearly, increasing scientific knowledge is not enough; growing information and scientific consensus about the coronavirus often enables various interpretations of data and conspiracy believers selectively pick up pieces of information that suit their theories, often exploiting disagreements between experts. In other words, we witness the paradox that the trust of the public in science does not increase with expanding scientific knowledge about the virus (Battiston et al., 2021). It is because uncertainty is driven also by “paradigm change”, when “hypotheses and theories about novel scientific facts (the COVID-19) are still very fluid (hence not mature) and subject to almost immediate falsification” (Farina & Lavazza, 2020, p. 4). In this phase the experts often disagree and give ambiguous or contradictory pieces of advice, as was evidenced by the initial reluctance of WHO to recommend facial masks.

When experts disagree and sometimes can have different views on the same facts (or even what the facts are) or which data are reliable, how can we expect the public to understand these complicated matters? We believe that despite having been exposed to scientific progress in real time, people actually still do not understand how science works (how it solves disagreements,

the incremental increase of knowledge, etc.) and they are not sufficiently capable of reasoning scientifically (i.e. know how to interpret evidence), therefore they are more susceptible to conspiracy and pseudoscientific beliefs that are, in turn, associated with refusal to follow evidence-based guidelines and vaccination as the main means of containing the pandemic. Thus, in this paper, we focus on the science understanding (scientific reasoning and trust in science) and analytic thinking and their role not only in having less conspiracy and pseudoscientific beliefs about COVID-19, but also in the behavioral intentions in line with scientific consensus (i.e. following evidence-based guidelines and vaccination intentions). While the previous research showed quite convincingly that endorsing epistemically suspect beliefs¹ leads to suboptimal health behavior, the effect of science understanding is less straightforward (Čavojová, Šrol, & Ballová Mikušková, 2020). Therefore, the aim of this study is to examine direct and indirect effects (through endorsement of epistemically suspect beliefs) of science understanding on health behavior during the COVID-19 pandemic.

Science understanding: knowledge, reasoning, and trust in science

Even before COVID-19 pandemic many scholars stressed the role of science as a vaccination against pseudoscientific beliefs (Fasce & Picó, 2019; Sagan, 1996) and emphasized the role of civic scientific literacy for responsible citizenship and making informed decisions (Lederman et al., 2014; Miller, 1983, 1998, 2004; OECD, 2003; Trefil, 2008). However, to understand science is difficult with its increasingly complex nature, especially in the context of COVID-19 pandemic that was characterized by the constant flow of new information as the new knowledge about the virus was being produced. There is a growing consensus among scholars

¹ Usually, the beliefs that are not supported by the current scientific evidence are referred to as epistemically suspect beliefs and comprise of three kinds of beliefs: conspiracy theories, pseudoscientific and paranormal beliefs (Čavojová, Šrol, & Jurkovič, 2020; Pennycook, Cheyne, et al., 2015). In this paper we focus on two types of epistemically suspect beliefs related to COVID-19 pandemic: conspiracy theories and pseudoscientific beliefs.

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that for a citizen to make informed decisions related to science understanding, they must have some basic knowledge of science (conceptual understanding), understanding of scientific methodology and trust in science and its values (Fasce & Picó, 2019; Miller, 1983, 1998, 2004). Thus, science understanding involves not only having science knowledge, but also the ability to use them to evaluate scientific evidence (i.e. first-order scientific reasoning, Chinn & Duncan, 2018). Even if not everyone can use their first-order scientific reasoning due to lack of necessary specific knowledge or skills, people should still benefit from second-order scientific reasoning, which would help them to “decide which scientific experts to believe, even though they cannot understand the details of experts’ reasoning” (Chinn & Duncan, 2018, p. 91). In other words, trust in science can be relatively independent from scientific reasoning and analytic thinking; although people with better first-order scientific reasoning should trust science more (due to their better understanding of science), even people with low scientific reasoning and analytic thinking can trust scientists and rely on their expertise (due to the awareness of the limits of their own thinking).

Therefore, the first aim of the present study is to examine the role of science understanding in endorsement of epistemically suspect beliefs about COVID-19 and health behavior in line with scientific consensus (following evidence-based guidelines and vaccination). For the purposes of the present study, we conceptualize science understanding as consisting of both the ability to evaluate scientific evidence and understanding scientific methodology (first-order scientific reasoning) and trust in science (second-order scientific reasoning). Moreover, avoiding epistemically suspect beliefs and successful navigation in normative behavior in crisis requires not only science understanding, as the specific knowledge (sometimes also called “mindware”) that is necessary to evaluate the plausibility of questionable claims, but also the motivation and the ability to think analytically (Čavoјová, Šrol, & Jurkovič, 2020; Stanovich, 2011). Therefore, we included also analytic thinking as a predictor in this study.

In the next sections we will review evidence for two hypothesized ways in which science understanding affects health behavior: (1) better science understanding prevents epistemically suspect beliefs, and having less epistemically suspect beliefs leads to health behavior more in line with scientific consensus, which we will call the *indirect path*, and (2) better science understanding directly leads to health behavior more in line with scientific consensus (*the direct path*). Further, as we will show below, the evidence for the direct path is quite contra-intuitively somewhat less conclusive than for the indirect path.

Science understanding as a predictor of lower endorsement of epistemically suspect beliefs

Although several studies showed that scientific reasoning, trust in science, and analytic thinking (good grasp on statistics, probability and resistance to cognitive biases) are significant predictors of epistemically suspect beliefs (e.g., Čavojová, Šrol, & Ballová Mikušková, 2020; Fasce & Picó, 2019; Šrol, 2020), so far these predictors have not been studied simultaneously in relation to the endorsement of such beliefs. Rejection of science and endorsement of pseudoscience was shown to be connected with conspiracy thinking even before COVID-19 (Lewandowsky et al., 2013; Lobato et al., 2014; Lobato & Zimmerman, 2018; Van der Linden, 2015); recent research shows that conspiracy theories about COVID-19 are associated with lower scientific reasoning, having less correct knowledge about COVID-19, but having more false beliefs about COVID-19 (Čavojová, Šrol, & Ballová Mikušková, 2020). Similarly, Lobato et al. (2020) found that general skepticism about science is connected with higher conspiracy mentality and willingness to spread various misinformation about coronavirus related to its severity, treatment and conspiracies.

Also, analytic thinking has been one of the most widely tested predictors of COVID-19 conspiracy beliefs in many countries, and irrespective of the way it was conceptualized (cognitive reflection test vs. self-reported measures of analytic thinking), it was consistently shown that the more people engage in analytic thinking the less conspiracy beliefs about

COVID-19 they have (e.g. Čavojová, Šrol, & Ballová Mikušková, 2020; Erceg et al., 2020; for review see van Mulukom et al., 2021). Analytic thinking is closely related to numeracy, which promotes the scientific thinking and accuracy of judgements evaluation (Ghazal et al., 2014). Conversely, lack of numeracy is associated with cognitive biases, such as denominator neglect that can lead to failure to correctly assess risks, and epistemically suspect beliefs, including endorsement of complementary and alternative medicine (Pennycook, Fugelsang, et al., 2015; Reyna & Brainerd, 2008), and COVID-19 misperceptions (Pennycook, McPhetres, Zhang, et al., 2020). It seems that highly numerate people can better assess the likelihood of events and risks, and this probably helps to protect against epistemically suspect beliefs. Similarly, one of the main reasons behind vaccination refusal is that people incorrectly assess the risks of contracting the preventable disease vs. possible adverse effects of vaccination against the benefits provided by vaccination, therefore better numeracy should be associated with more pro-vaccination attitudes and willingness to get a jab. Better numeracy should also help people to recognize the highly improbable nature of many conspiracy theories against the probability of random events.

Epistemically suspect beliefs as a predictor of lower adherence to evidence-based guidelines to combat pandemic (preventive behavior, vaccination): Indirect path

From the start, the COVID-19 pandemic is accompanied by various epistemically suspect beliefs, most notably conspiracy theories and pseudoscientific beliefs. The interlinking of conspiracy and pseudoscientific beliefs is especially visible not only in relation to the recent COVID-19 pandemic, but also to vaccination. Anti-vaccination movement has used many pseudoscientific arguments since its conception and the deep distrust of science, scientists and its processes is reflected in many conspiracy theories surrounding any vaccination. As the vaccination against COVID-19 promises the most viable way to overcome pandemic and many

resources have been invested so that vaccination was available in an unprecedented short time, this was countered also with the rise of many conspiracy theories. The positive correlation between endorsement of conspiracy theories (either related to COVID-19 or more general conspiracy ideation) and anti-vaccination attitudes have been found in many studies from the recent period (e.g. Allington et al., 2020; Romer & Jamieson, 2020; for review see van Mulukom et al., 2021).

Even before pandemic, people high in conspiratorial thinking have been shown to be more likely to engage in questionable health practices (Lamberty & Imhoff, 2018; Lobato et al., 2014). During pandemic such conspiracy theories have serious consequences, as they can undermine any official actions aimed at containing the pandemic, such as decreeing curfews and lockdowns to minimize mobility and social contact, wearing facial masks and other safeguarding behaviors. Indeed, most research from the last year showed that believing in COVID conspiracy theories was negatively related to self-reported adherence to behavioral guidelines (Allington et al., 2020; Bierwiazzonek et al., 2020; Constantinou et al., 2020; Erceg et al., 2020; Freeman et al., 2020; Karlsson et al., 2020; Oleksy et al., 2020; Pavela Banai et al., 2020; Romer & Jamieson, 2020; Teovanović et al., 2020a); although, there were some exceptions to this rule (Alper et al., 2020; Juanchich et al., 2020). However, when hygiene and distancing were measured separately, conspiracy beliefs were negatively associated with adherence to distancing guidelines, but not to hygiene guidelines (Biddlestone et al., 2020b; Bierwiazzonek et al., 2020; Bruder & Kunert, 2020; Marinthe et al., 2020; Pummerer et al., 2020). It is probably due to the fact that people high in conspiratorial thinking do not trust the government and thus seem to prefer non-normative actions that go against governmental regulations (Jolley et al., 2019; Marinthe et al., 2020).

On the other hand, as we have discussed in the previous section, science understanding seems to be one of the protective factors against various epistemically suspect beliefs. Thus, science

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understanding should lead to adherence to evidence-based guidelines (including willingness to get vaccination) through diminishing the effect of epistemically suspect beliefs. It would be an indirect positive effect of science understanding on normative health behavior in the times of crises. For example, having less scientific knowledge made it more difficult for people to discern false from true information and more likely to spread disinformation about COVID-19 (Pennycook, McPhetres, Zhang, et al., 2020). Higher interest and trust in science has been related to having less conspiracy beliefs and greater knowledge about COVID-19 (Bruder & Kunert, 2020; Constantinou et al., 2020; Erceg et al., 2020); on the other hand, distrust of science was associated also with populist attitudes that are closely related to conspiracy beliefs about COVID-19 independent of political ideology (Eberl et al., 2020). Scientific reasoning was shown to be significant predictor, contributing to susceptibility to both cognitive biases and epistemically suspect beliefs over and above the other cognitive predictors (Čavojová, Šrol, & Jurkovič, 2020) and it also predicted the belief in efficacy of alternative medicine (Čavojová & Ersoy, 2020).

However, as we will review in the last subsection, the results on the direct effect of science understanding and adherence to normative health behavior are somewhat less conclusive.

Science understanding as a predictor of adherence to evidence-based guidelines to combat pandemic (preventive behavior, vaccination): Direct path

Besides its correlation with conspiracy and other epistemically suspect beliefs about COVID-19, science understanding (or its components) have been examined in their relation to following preventive evidence-based guidelines, such as washing hands, social distancing, and mask wearing. Because government regulations and restrictions were interpreted as based on expert recommendations and because the effectiveness of these measures depends on the willingness

of individuals to behave according to them, the trust in science and scientists was shown to be key to preventive measures compliance (Dohle et al., 2020; Koetke et al., 2020; Plohl & Musil, 2020). Moreover, as Dohle et al. (2020) stated, a pandemic is a complex situation and trust could reduce this complexity. People who trust science and scientists perceived COVID-19 as riskier, believed more in the effectiveness of preventive measures and behaved accordingly (Ayalon, 2021; Dohle et al., 2020; Kuiper et al., 2020; Pagliaro et al., 2021; Plohl & Musil, 2020; van Mulukom, 2020); this applied also before the pandemic, trust in science related to compliance with public health policies, restrictions and guidelines (for review of research see Battiston et al., 2021). Conversely, Sulik et al. (2020) identified several predictors of adherence to COVID-19 preventive behavior, and the trust in science predicted adherence when it was the only predictor (when social conformity and/or approval of preventive measures were included, the effect of trust in science decreased; on the other hand, science indirectly affected the relation between ideology and adherence behavior). The effect of trust in science was observed also in Szczuka's et al. study (2020); moreover, authors assumed that the exposure to scientists and thus to scientific knowledge could affect cognitive processes. This assumption was supported by Sailer et al. (2021) – information seeking led to greater knowledge about coronavirus and a better general science understanding, and together with high trust in medicine, this greater knowledge was associated with stronger adherence to preventive measures. Moreover, less knowledgeable people with high trust in medicine complied more with coronavirus preventive measures. Interestingly, Brzezinski et al. (2020) found that in countries with lower belief in science (indexed by prevalence of climate sceptics) the adherence to physical distancing measures is also lower.

However, the trust in science is often affected by ideology, which has also consequences for compliance with COVID-19 preventive measures. For example, Plohl and Musil (2020) found

that those higher on political conservatism, religious orthodoxy and conspiracy ideation have lower trust in science and are less willing to comply with preventive measures.

Similarly, science understanding has been consistently linked with another preventive behavior – vaccination intention. Unfortunately, as we described in the previous section, vaccination attitudes can be influenced by misinformation (e.g. hoax that MMS vaccine causes autism) and conspiracy theories (e.g. vaccines are used to control minds of people). Earnshaw et al. (2020) report that people who believed conspiracies indicated 3.9 lower intentions to vaccinate against COVID-19. Refusal of vaccination and use of pseudoscientific practices correlated negatively with analytic and scientific thinking (Anderson, 2016; Čavojová, Šrol, & Ballová Mikušková, 2020; Sarathchandra et al., 2018).

On the other hand, the effect of scientific reasoning and analytic thinking on adherence to preventive measures was somewhat less conclusive. For example, in some studies there was no relationship between higher scientific reasoning and engaging in recommended protective behaviors (Čavojová, Šrol, & Ballová Mikušková, 2020), probably due to a lot of conflicting advice from the authorities at the beginning of pandemic (e.g. about wearing facial masks), when the study was conducted. Similarly, inconclusive results were obtained in studies examining association of analytic thinking with adherence to evidence-based guidelines. For example, analytic thinking (measured by Cognitive Reflection Test) related to willingness to follow preventive measures (e.g., hand washing, and keeping social distance) (Stanley et al., 2020; Teovanović et al., 2020a). Also, people who engaged more in analytic Type 2 processes complied to a higher extent with social-distancing measures and rejected COVID-19 conspiracy theories more often (Swami & Barron, 2020). Still, in other studies analytic thinking was not especially helpful in preventive behavior. For example, people high in cognitive sophistication (specifically analytic thinking, numeracy, basic science knowledge, and bullshit skepticism) had less misconceptions about COVID-19, but cognitive sophistication did not motivate

preventive behavior change (Pennycook, McPhetres, Bago, et al., 2020), or emotions elicited by pandemic proved to be better predictor of COVID-19 preventive behavior than type 2 reasoning (Leblanc-Sirois et al., 2020). Lastly, some studies found no correlation between cognitive reflection or intuitive thinking style and preventive measures (Alper et al., 2020), or, even found that people low on cognitive reflection were more likely to follow recommended measures against COVID-19 (hygiene, social distance) than people high in cognitive reflection (Thoma et al., 2021). These results seem to support the motivated reasoning hypothesis (Kahan et al., 2012; Taber et al., 2009), according to which people with better cognitive sophistication may be more able to defend their views, even if these go against the current preventive measures.

Therefore, in the present paper we want to extend the previous findings by examining differential roles of analytic thinking, the first and the second order scientific reasoning (scientific reasoning and trust in science), and examining not only adherence to anti-pandemic guidelines but also propensity for breaking rules and misusing exceptions in these guidelines. Moreover, as the previous research suggests, second order scientific reasoning (trust in science) may play a more important role especially for people with low scientific reasoning when they decide whether they should follow the preventive guidelines.

Present study

To summarize, we tested the following hypotheses and research questions:

1. We expected to replicate the correlation between conspiracy (and pseudoscientific) beliefs about COVID-19 and non-normative health behavior (refusal to follow evidence-based guidelines and negative attitudes and intentions toward vaccination).

2. We expected to replicate the negative correlation between science understanding (scientific reasoning, analytic thinking, trust in science) and epistemically suspect beliefs about COVID-19 and anti-vaccination attitudes.
3. We expected that science understanding would contribute indirectly to normative health behavior (adherence to evidence-based guidelines and willingness to vaccinate) via lower endorsement of epistemically suspect beliefs.
4. We expected that trust in science understanding would be directly associated with normative health behavior (adherence to evidence-based guidelines and willingness to vaccinate). We explored the direct association of scientific reasoning and analytic thinking with normative health behavior.
5. We explored differential contributions of science understanding (scientific reasoning and trust in science) and analytic to epistemically suspect beliefs and non-normative health behavior.

Methods

Participants

The present sample consisted of 1024 participants (486 men, 536 women), aged between 18 – 81 years ($M = 44.17$, $SD = 15.33$), who were recruited by the agency to be representative of Slovak population with regard to age, gender, and education. 37.7 % of the sample had elementary or incomplete high school education, 39.1% had complete high school education, and 23.9 % had some college or complete college education.

Design

The survey took the form of an online questionnaire created in Qualtrics. The data were collected as part of a larger study on beliefs and behaviors related to the current COVID-19

pandemic². The participants first answered several demographic questions and then proceeded to the blocks of questions related to their beliefs and behavior related to COVID-19 pandemic, such as endorsement of conspiracy and pseudoscientific beliefs about COVID-19, their well-being, sense of helplessness and anxiety, exposure to information, social consequences of conspiracy beliefs including prosocial behavior, anti-vaccination attitudes and intention, following the preventive recommendations, scientific reasoning, numeracy, cognitive reflection, optimism bias, trust in science, and personality. Data related to social consequences of unfounded beliefs about COVID-19 and the relationship with anxiety, helplessness and exposure to information were analyzed for the separate study (“citation blinded”).

Materials

Descriptive statistics and internal consistency estimates for all materials can be found in Table 1.

Science understanding.

Scientific reasoning. The first-order scientific reasoning ability was measured using items based on the Scientific reasoning scale (Drummond & Fischhoff, 2017). For the present study, we used six items that were developed by Bašňáková et al. (2021). For example, the “causation vs correlation” item was about increasing birth rate: “A researcher wants to find out how to increase natality. He asks for statistical information and sees that there are more children born in cities which have more hospitals. This finding implies that building new hospitals will increase the birth rate of a population. Agree/Disagree”. Each correct answer

² Data for this study were collected in November 2020, when the 2nd wave of pandemic hit Slovakia. Cases of infected and hospitalized cases grew rapidly, and strict lockdown with national ATG testing was introduced just a week prior to the data collection.

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was assigned 1 point and we calculated the total score as the sum of all correct answers, thus a higher number indicates better scientific reasoning.

Trust in science. To measure the second-order scientific reasoning, i.e. trust in science and scientists, we used six items from Credibility of Science Scale by Hartman et al. (2017).

Participants responded to all items on a 7-point Likert scale, from 1 = disagree very strongly to 7 = agree very strongly. An example item was: “*People don’t realize just how flawed a lot of scientific research really is.*” We calculated the mean rating on all items and prior to all analyses, all items were reverse coded so that the higher scores indicate higher trust in science. *Analytic thinking:*

We measured analytic thinking by 13 items – five were modified tasks measuring denominator neglect, four were measuring probabilistic reasoning/numeracy, and four were taken from the modified Cognitive reflection test. To measure *denominator neglect*, we used five tasks modelled after jelly bean tasks (Kirkpatrick & Epstein, 1992) using coronavirus-related content. 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 that has 7 millions of citizens and 210 000 cases of infections, or State B that has 3 millions of citizens and 150 000 cases of infections?” Participants responded by selecting one of the options and received a score for the correct answers; higher score thus indicates resistance to denominator neglect and better numerical abilities. To measure *probabilistic reasoning/numeracy* we used four items taken from (Lipkus et al., 2001) with slightly modified COVID-19 related content. For example, “If there is 10% chance of contracting COVID-19, how many people out of 1000 will contract this disease?” (Answer: 100). Sum of total correct answers reflected participants’ probabilistic thinking/numeracy. Lastly, we used four items from the *cognitive reflection* test – two items from the numerical version (Frederick, 2005) and two items from verbal version (Sirota et al., 2020), for example: “If you

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were running a race, and you passed the person in 2nd place, what place would you be in now?” (correct answer: 2nd, intuitive answer: 1st). Sum of total correct answers reflected participants’ analytic thinking, but in some preliminary analyses we also used the sum of correct answers for every one of the three dimensions of analytic thinking separately.

Non-normative health behavior:

Following government regulations. Following the governmental recommendations and regulations was measured in two ways. First, we asked participants to indicate *their adherence to the four general recommendations and regulations* (following imposed curfew, hygienic recommendations, wearing masks, social distancing) on a 10-point scale (1 = *I don’t follow them at all*, 10 = *I follow them all completely*). The mean score reflects the self-reported adherence to guidelines and governmental regulations.

Avoiding government regulations. However, we also asked participants about specific instances of breaking the rules or misusing exceptions – seven related to curfew, four related to hygiene, three related to mask wearing, and three related to social distancing. For each admitted instance of such behavior (“yes” answer) participants received a point and the mean score was used as a measure of *non-normative behavior (avoiding the rules)*.

Vaccination intentions:

Vaccination intention. We asked participants two questions: If there was, at the moment³, an available vaccine against COVID-19 approved by European Union, would you get vaccinated? If there was, at the moment, an available vaccine against COVID-19 approved by

³ The study was conducted in November 2020, when vaccines were not yet approved for the public use, but it was clear that it is only a matter of few weeks, when vaccination will start.

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European Union, would you encourage your close ones to get vaccinated? Participants again answered on a 5-point scale (1 = *certainly not*, 3 = *I don't know*, 5 = *certainly yes*).

Anti-vaccination attitudes. To measure anti-vaccination attitudes, we used six items from Wallace et al. (2019), e.g. “Vaccination does more harm than good.” Participants indicated their agreement on a 5-point scale (1 = *strongly disagree*, 5 = *strongly agree*). Higher scores indicated stronger anti-vaccination attitudes.

Epistemically suspect beliefs about COVID-19:

Pseudoscience and conspiracy beliefs related to COVID-19. Pseudoscience beliefs about COVID-19 were measured by four items, such as “By wearing facial masks against COVID-19 person risks poisoning by toxic carbon dioxide.” Conspiracy beliefs pertaining specifically to COVID-19 were measured by ten items such as “COVID-19 was artificially created as a biological weapon intended to eliminate the overcrowded human population”. Participants rated all statements on a scale from 1 (“completely disagree”) to 5 (“completely agree”). The average rating on all items in the respective dimension was used as an index of participants’ endorsement of pseudoscientific or conspiracy beliefs about COVID-19.

Results

The materials and the dataset supporting the conclusions of this article are available in the OSF repository, <https://osf.io/a9j76/>.

The relationships among the main variables in the study are first examined through the correlation analysis (Table 1). We inspect the correlations between analytic thinking, science understanding, epistemically suspect beliefs, vaccination intentions, and non-normative health behaviors.

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We can see that both conspiracy and pseudoscientific beliefs correlated quite strongly with following evidence-based guidelines (hygiene, social distancing, wearing masks) ($r = -.34$, $r = -.37$), as well as vaccination intentions ($r = -.54$, $r = -.49$) in expected directions. Both conspiracy and pseudoscientific beliefs also correlated with avoiding specific recommendations related to curfew, hygiene, wearing facial masks, and social distancing, although these correlations were somewhat weaker ($r = .11$ to $r = .29$).

Similarly, we found expected correlations between science understanding and conspiracy and pseudoscientific beliefs ($r = -.27$ to $r = -.42$), anti-vaccination attitudes ($r = -.17$ to $r = -.35$) and vaccination intentions ($r = .10$ to $r = .25$). However, correlations between science understanding and non-normative health behavior were somewhat mixed and even significant correlations were very weak. Unexpectedly, scientific reasoning correlated with avoiding hygiene measures ($r = .11$).

Similar results were obtained for measures of analytic thinking. While all analytic thinking measures (except denominator neglect) correlated negatively with both conspiracy and pseudoscientific beliefs ($r = -.16$ to $r = -.26$) and anti-vaccination attitudes ($r = -.11$ to $r = -.20$), only probabilistic reasoning correlated with vaccination intentions ($r = .15$) and most of the analytic thinking measures correlated positively with non-normative health behavior, especially with avoiding hygiene measures ($r = .06$ to $r = .16$) and negatively with following guidelines ($r = -.06$ to $r = -.18$).

-- Insert Table 1 here --

Science understanding, epistemically suspect beliefs, and health behaviors: direct and indirect paths

To examine the direct and indirect paths between science understanding and health behaviors, we have conducted two mediation analyses where trust in science and scientific reasoning predicted non-normative health behavior (following/avoiding preventive measures) or vaccination intentions both directly and indirectly through decreased belief in COVID-19 epistemically suspect beliefs. Additionally, in both models we included analytic thinking as a predictor of scientific reasoning ability. Both mediation models were conducted using structural equation modelling in R package *lavaan* (Rosseel, 2012). Non-normative health behavior, vaccination intention, COVID-19 epistemically suspect beliefs, and analytic thinking were included in the models as latent variables, estimated from observed indicators (for information about which indicators were used to estimate latent variables, see Table 1). As we only had a single indicator for both scientific reasoning ability and distrust in science, these variables were included in the models as observed factors. Structural models were estimated using DWLS estimation and standard errors were based on 5,000 bootstrap samples.

As can be seen from Fig. 1, analytic thinking, scientific reasoning, and trust in science all predicted COVID-19 epistemically suspect beliefs, which were in turn strongly associated with non-normative health behavior, i.e. avoiding government-issued preventive measures against the spread of COVID-19 pandemic. While neither scientific reasoning nor trust in science predicted non-normative health behavior directly (only through epistemically suspect beliefs), there was also a positive relationship between analytic thinking and avoiding COVID-19 preventive measures. This indicates that analytic thinking had two distinct effects on non-normative health behavior. First, people with higher analytic thinking tended to endorse less conspiracy and pseudoscientific beliefs about COVID-19, partially because of

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their higher scientific reasoning ability, and thus reported lower tendency to avoid preventive measures. However, other than having higher scientific reasoning ability and lower endorsement of COVID-19 epistemically suspect beliefs, people with higher analytic thinking also reported moderately higher tendency to engage in non-normative health behavior. It is important to note that while analytic thinking was moderately and COVID-19 epistemically suspect beliefs were strongly correlated with avoiding the preventive measures against COVID-19, the model accounted for 28% of variance in non-normative health-behavior. Therefore, there are likely other factors which were not measured here but which may play an important role in following the preventive measures, for example, conscientiousness, or trust in government (e.g. Kohút et al., 2021).

indirect path ($a1*b1$) = .01, unstandardized
estimate: 0.00, SE = 0.01, 95%CI [-0.01, 0.01]

$\chi^2(46) = 138.34, p < .001, CFI = .97, TLI = .96,$
RMSEA = .044, SRMR = .042

indirect path ($a2*b2$) = -.10, unstandardized
estimate: -0.02, SE = 0.01, 95%CI [-0.03, -0.01]

indirect path ($a1*d21*b2$) = -.03, unstandardized
estimate: -0.01, SE = 0.003, 95%CI [-0.01, 0.00]

indirect path ($a3*b2$) = -.18, unstandardized
estimate: -0.02, SE = 0.003, 95%CI [-0.03, -0.01]

Figure 1. Standardized estimates for the mediation model with trust in science, scientific reasoning, and analytic thinking as predictors of non-normative health behavior (avoiding government-issued preventive measures) with COVID-19 epistemically suspect beliefs as mediator. Ovals indicate latent variables, squares indicate observed variables in the model.

Curved lines indicate covariances between variables. Paths that are not statistically significant ($p > .05$) are presented with gray dashed arrows. * $p < .05$; ** $p < .01$; *** $p < .001$

When considering attitudes toward vaccination and the intention to get vaccinated against COVID-19 (see Figure 2), the results were quite consistent with the model above albeit with several important differences. First of all, there was no direct association between analytic thinking and vaccination intentions and attitudes. Both scientific reasoning and analytic thinking predicted vaccination intentions only via decreased endorsement of epistemically suspect beliefs. On the other hand, trust in science predicted vaccination intentions and behaviors both directly, and through lower endorsement of epistemically suspect beliefs. Finally, epistemically suspect beliefs were even more strongly related to vaccination intentions and behaviors than to avoiding preventive measures. Consequently, the variables together explained 52% of variance in the vaccination intentions and attitudes.

indirect path ($a1*b1$) = $-.03$, unstandardized estimate: -0.03 , $SE = 0.03$, 95%CI $[-0.10, 0.02]$

$\chi^2(19) = 52.28, p < .001, CFI = .99, TLI = .98, RMSEA = .041, SRMR = .035$

indirect path ($a2*b2$) = $.13$, unstandardized estimate: 0.17 , $SE = 0.05$, 95%CI $[0.08, 0.28]$

indirect path ($a1*d21*b2$) = $.04$, unstandardized estimate: 0.05 , $SE = 0.02$, 95%CI $[0.01, 0.10]$

indirect path ($a3*b2$) = $.24$, unstandardized estimate: 0.19 , $SE = 0.02$, 95%CI $[0.14, 0.23]$

Figure 2. Standardized estimates for the mediation model with trust in science, scientific reasoning, and analytic thinking as predictors of vaccination intentions with COVID-19

epistemically suspect beliefs as mediator. Ovals indicate latent variables, squares indicate observed variables in the model. Curved lines indicate covariances between variables. Paths that are not statistically significant ($p > .05$) are presented with gray dashed arrows. * $p < .05$; ** $p < .01$; *** $p < .001$

Discussion

Science understanding and non-normative health behavior: comparing direct and indirect paths

The most novel contribution of this study is examining the direct and indirect paths in which science understanding affects non-normative health behavior, such as avoiding preventive measures and refusing vaccination. Our results generally corroborated previous findings that people who understand science better have generally less epistemically suspect beliefs – either about COVID or more generic ones (Čavojová, Šrol, & Jurkovič, 2020; Lobato et al., 2014) – and that as a consequence, people with less epistemically suspect beliefs tend to behave in line with evidence-based guidelines and safe-guarding behavior (for review see van Mulukom et al., 2021). However, we were also able to examine the direct effect of science understanding on the adherence to normative health behavior and vaccination intention and our results showed a more complicated picture.

Interestingly, neither scientific reasoning nor trust in science predicted avoidance of preventive measures directly, but analytic thinking correlated positively with avoiding preventive measures. It suggests that while analytic thinking is an important prerequisite for scientific thinking that prevents people from acquiring epistemically suspect beliefs and thus engaging in more normative health behavior, it is also associated with avoiding exactly the same behavior. We can only speculate, but the probable answer can lie in motivated reasoning hypothesis, according to which the more cognitively sophisticated people are better able to justify their

beliefs and actions (Kahan et al., 2012; Kraft et al., 2015; Taber et al., 2009; but see also Pennycook & Rand, 2019). It seems that even though more analytically disposed people reject conspiracy theories that, for example, encourage people to refuse wearing facial masks it enables them to rationalize their not wearing facial masks in specific circumstances due to negotiating with other reasons (e.g. I am going alone outside for a walk and the risk of contracting or spreading the virus is low, therefore, I can ignore the requirement of wearing the mask, because I am otherwise behaving responsibly.). Some of the items we used for measuring avoiding regulations, in fact, provided rationalizations for this kind of behavior, which also support motivated reasoning hypothesis. Of course, we cannot be sure with this interpretation, but the results show that there are more reasons for avoiding the preventive measures than just endorsement of epistemically suspect beliefs and some of these reasons may well be based on analytical thinking. However, this model explained 28 % of variance, therefore other factors besides analytic thinking play a role in adherence to preventive measures. For example, Kohút et al. (2021) found out that agreeableness and conscientiousness correlated with active protection/following recommendations at the beginning of pandemics (but not later). Similarly, in previous research in Slovakia during the first wave of pandemic (Čavojová, Šrol, & Ballová Mikušková, 2020) people followed some recommendation regardless of their scientific reasoning, and in some cases, people with better scientific reasoning engaged more in behaviors such as stockpiling, and less in behaviors such as avoiding large crowds or immediately throwing away tissues into a bin after sneezing.

Similar picture highlighting the effect of science understanding mainly through lower endorsement of epistemically suspect beliefs emerged when we analyzed vaccination intentions, as a second example of normative health behavior. Here, there was no direct association between analytic thinking and vaccination intentions and attitudes and epistemically suspect beliefs were even more strongly related to vaccination intentions and behaviors than to

avoiding preventive measures. This is in line with previous research showing that conspiracy beliefs were linked not only with reluctance against COVID vaccination (for review see van Mulukom et al., 2021) but also with reluctance against flu vaccination (Čavojová, Šrol, & Ballová Mikušková, 2020) or MMR vaccine (Jolley & Douglas, 2014).

Why we observe the direct effect of trust in science less frequently than the indirect effect can be explained by Bennett's (2020) distinction between epistemic and recommendation trust.

He argues that when people are asked not only to trust authorities, but also to follow recommendations of experts/scientists, this requires *recommendation trust* (in contrast with epistemic trust). Conditions for meeting recommendation trust are more demanding than conditions needed for epistemic trust, because to have a good reason to follow recommendation, people must believe in sincerity and competence of experts, and also that the actions experts recommend are in people's interest. Trusting sincerity and good will of experts is highly corroded by conspiracy theories that often attack these kinds of authorities and raise suspicions against their motivations. Thus, Bennet (2020) asserts that "when science leads policy, it must work harder to merit public trust" (p. 2) and could be reason why trust in science helps people to have beliefs in line with scientific consensus, but why it is often harder to also behave in line with this consensus.

Similarly, Farina and Lavazza (2020) suggest that people can refuse bio-medical experts' recommendations, because these are not neutral for individuals and society. Even though from the medical and scientific point of view these recommendations are evidence-based, Farina and Lavazza (2020) claim that still they should be evaluated not only according to their epistemic status and their adherence to scientific criteria, but also other values and broader views should be taken into account. Moreover, these values are often conflicting (e.g. right to health, political freedom, right to run a business) and guidelines are often moderated by

political concerns, and therefore the trust in authorities issuing the recommendations can be more affected by other variables, besides science understanding.

Our results generally suggest that the most important role of science understanding lies in preventing the acquisition of epistemically suspect beliefs that are predictive of non-normative behavior. Extant literature showed that people believing in conspiracy theories and pseudoscience engage in non-normative health behavior, such as using alternative medicine (Čavojová & Ersoy, 2019; Lindeman, 2011), questionable health practices against COVID-19 (Čavojová, Šrol, & Ballová Mikušková, 2020; Pummerer et al., 2020; Teovanović et al., 2020b), refusing to follow pandemic guidelines, such as social distancing (Biddlestone et al., 2020a; Bruder & Kunert, 2020; Marinthe et al., 2020; Pummerer et al., 2020), and unwillingness to get vaccinated (Allington et al., 2020; Bertin et al., 2020; Cislak et al., 2021; Freeman et al., 2021; Hornsey et al., 2020; Romer & Jamieson, 2020; Soveri et al., 2021). Scientific reasoning and trust in science seem to be two interrelated factors that help people not only to evaluate evidence for various claims but also choosing the most reliable sources of information and thus acquiring the exact knowledge.

Dissecting scientific understanding: Differential roles of scientific reasoning and trust in science

Another novel contribution of this study lies also in examining differential predictive power of analytic thinking, scientific reasoning, and trust in science. We have already discussed that analytic thinking was the strongest predictor of scientific reasoning that contributed to having less epistemically suspect beliefs and thus behaving more in line with scientific consensus. On the other hand, analytic thinking also contributed to avoiding some preventive measures, probably due to motivated reasoning. However, from both models (Fig 1 & 2) it seems that the strongest predictor of epistemically suspect beliefs is trust in science. While in preventive behavior the effect of trust in science was mainly through lower endorsement of epistemically

suspect beliefs, in case of vaccination it had also the direct effect on intention to get vaccinated against COVID-19. Similarly, Sturgis et al. (2021) found that not only trust in science predicts vaccine confidence at the individual level, but also at the societal level. Moreover, their results showed that in countries with a high level of trust in science and scientists, the positive correlation between trust in science and vaccine confidence is stronger than in countries with lower levels of social trust in science. They conclude that the trust in science is highest in Western Europe, Austral-Asia, and Northern America, while it is lowest in Africa, South America and Eastern Europe. Interestingly, among the countries with lowest level of social consensus on trust in science was also the Czech Republic, which is geographically and culturally very close to Slovakia (which was not part of Sturgis et al. study).

People refusing vaccination against COVID had safety concerns and in Soveri et al. (2021) study, trusting the safety of the vaccine was the strongest predictor of willingness to take a jab. Trusting the safety of the vaccine is inherently linked to trust in the process of developing vaccines, clinical trials and controls, i.e. the science and its processes. Trust in authorities (and scientific authorities among them) was shown to be an important predictor of many conspiracy theories (Achimescu et al., 2020; Bruder & Kunert, 2020; De Coninck et al., 2021; Freeman et al., 2020; Kim & Kim, 2021; Šrol et al., 2021; van Mulukom, 2020) and it mediated the negative effect of conspiracy theories on adherence to guidelines (Bruder & Kunert, 2020; Karić & Međedović, 2021; Pavela Banai et al., 2020; Plohl & Musil, 2020; Pummerer et al., 2020).

In general, this finding is in line with recent literature that suggests that there are two ways how to deal with infodemic of false information and questionable claims – either in increasing one's own scientific literacy, i.e. acquiring more knowledge and necessary skills or in increasing media literacy, i.e. learning what source of information one can trust. For practical reasons it is not possible to subject each piece of information to analytic scrutiny and scientific reasoning – often we do not have sufficient tools, conditions nor abilities. Therefore,

people need to decide which experts and scientists to trust and they usually base their assessment of truth value of any statements on three criteria (Shapin, 1995): (1) plausibility of the statement (whether it is in line with what they know about the world), (2) intellectual entitlement of the source (whether the statement was issued by an expert in a field), and (3) honesty of the source (whether the source can be trusted). Nevertheless, we have witnessed during the course of the pandemic, even well-informed experts can get lost in the flood of the new information that requires expertise from other fields (e.g. mathematical modeling, network science) and that people usually choose to trust those experts who tell things that fit into a person's already held views of the world. Thus, it seems that reasoning about which experts or sources to believe (i.e. second-order scientific reasoning; Chinn & Duncan, 2018) has become even more important than directly evaluating original evidence (first-order scientific reasoning; Chinn & Duncan, 2018).

Conclusion

The main aim of the paper was to examine how science understanding contributes not only to lower endorsement of epistemically suspect beliefs but also to higher adherence to normative health behavior, such as following evidence-based preventive guidelines and willingness to get a vaccination against COVID-19. Moreover, we also focused on examining how the actual ability to reason scientifically differs from trust in science and analytic thinking in their specific contributions to beliefs and behavior in line with scientific consensus of the time. Our results suggest that the most important role of science understanding lies in preventing the acquisition of epistemically suspect beliefs that are predictive of non-normative behavior and that the trust in science plays a vital role⁴ not only in rejecting questionable claims that

⁴ Generally, we use trust in science as predictor of epistemically suspect beliefs, but it is important to note that the relationship can be reverse and that epistemically suspect beliefs predict low trust in science. Most probably the relationship goes in both ways and it is impossible to disentangle it, especially in correlation study such as ours.

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contradict current scientific knowledge, but in case of vaccination directly affects the people's intentions to get vaccinated. In the complex world we live in, we are dependent on the science and technology to solve the problems we face (many of which caused by humans themselves), but the science has become so specialized and complicated that it is increasingly difficult to understand. Science education thus becomes crucial, but not only to enhance people's ability to reason scientifically, but mainly to increase the understanding of how science works and whether to trust it.

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Table 1. Means, standard deviations, Cronbach's α and mutual correlation for all study variables.

	<i>M</i>	<i>SD</i>	α	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
<i>Science understanding</i>																	
1.Scientific reasoning	3.97	1.52	.57														
2. Trust in science	4.65	1.29	.88	.30													
<i>Analytic thinking</i>																	
3. Denominator neglect	3.37	1.37	.55	.31	.16												
4. Probabilistic thinking	1.85	1.5	.56	.36	.25	.22											
5. Cognitive reflection	1.50	1.21	.53	.30	.17	.22	.39										
6. Composite analytic thinking score	6.72	2.60	.66	.45	.26	.72	.70	.74									
<i>Epistemically suspect beliefs</i>																	
7. COVID-19 conspiracy beliefs	2.31	1.10	.94	-.28	-.42	-.06	-.26	-.18	-.22								
8. COVID-19 pseudoscience beliefs	1.98	1.00	.82	-.27	-.37	-.06	-.26	-.16	-.21	.87							
<i>Vaccination intentions</i>																	
9.anti-vaccination attitudes	2.87	1.10	.87	-.17	-.35	-.03	-.20	-.11	-.15	.56	.55						
10.vaccination intention	2.80	1.38	.94	.10	.25	-.06	.15	.03	.05	-.54	-.49	-.63					
<i>Non-normative health behavior</i>																	
11.following recommendations (R-O-R)	8.61	1.66	.82	-.07	.08	-.18	-.03	-.06	-.13	-.34	-.37	-.27	.34				
12.avoiding curfew	0.28	0.22	.50	-.02	-.11	.08	-.02	.00	.03	.29	.27	.19	-.20	-.54			
13.avoiding hygiene	0.29	0.25	.39	.11	-.03	.16	.10	.09	.16	.11	.12	.10	-.14	-.46	.23		
14.avoiding masks	0.34	0.36	.66	.01	-.08	.13	.02	.03	.09	.23	.24	.19	-.23	-.45	.29	.26	
15.aviding distancing	0.35	0.38	.73	.01	-.01	.06	-.02	.04	.04	.18	.22	.17	-.20	-.50	.38	.29	.29

Notes. Significant correlations are marked in bold. All correlation $r > .11$ are significant at $p < .001$. All correlation $r > .01$ are significant at $p < .01$. All correlation $r > .06$ are significant at $p < .05$.