

SCIENTIFIC LITERACY AND COVID-19

Scientific literacy linked to attitudes toward COVID-19 vaccinations: A pre-registered study

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ABSTRACT (148/200 words)

The ongoing COVID-19 pandemic, which began in early 2020, is a global public health crisis. To prevent the spread of COVID-19, it is necessary to promote vaccine administration and preventive behaviors (e.g., mask, handwashing, social distancing). However, some people have negative attitudes toward vaccine administration and preventive behaviors. Based on the information-deficit model, the present study investigated how scientific literacy and perceived understanding of COVID-19 are associated with attitudes toward COVID-19 vaccinations and preventive behaviors. The findings demonstrated that both scientific literacy and perceived understanding of COVID-19 vaccines were positively associated with attitudes toward COVID-19 vaccines. Additionally, perceived understanding of COVID-19 preventive behaviors (but not scientific literacy) was positively associated with attitudes toward/practice of COVID-19 preventive behaviors. Collectively, our findings revealed the role of cognitive factors in preventing the global public health crisis and demonstrated the roles of objective and subjective knowledge on attitudes toward COVID-19 vaccinations and preventive behaviors.

Keywords: COVID-19; Scientific literacy; Vaccines; Preventive behaviors; Attitudes; Objective knowledge about science

1. Introduction

The COVID-19 pandemic is a global public health crisis. In December 2019, SARS-CoV-2 emerged in Wuhan, China. Following this, the virus spread around the world and has now killed millions of people (Rodríguez Mega, 2020). To prevent the spread of COVID-19, it is crucial to promote vaccine administration and preventive behaviors (e.g., mask, handwashing, social distancing). However, the rate of some of preventive behaviors is still less than optimal (Azlan et al., 2020; He et al., 2021) and a certain percentage of people are reluctant to get vaccinated. A global survey across 19 countries has indicated that 14.2% of respondents are reluctant to accept a COVID-19 vaccine even if it is generally available (Lazarus et al., 2021). It has also been reported that 25.9% of respondents are reluctant to accept a COVID-19 vaccine on their employer's recommendation (Lazarus et al., 2021). Given considerable variation of attitudes toward the vaccinations and preventive behaviors, it is important to gauge the factors underlying these individual differences.

1.1. Information-deficit model

The information-deficit model is a theoretical framework for science communication including attitudes toward COVID-19 vaccines and preventive behavior (Ransing et al., 2021). The information-deficit model assumes that the public is rational, and it also suggests that hesitancy of vaccines/preventive behaviors might be due to insufficient scientific knowledge (Ransing et al., 2021). It should be noted that this model has been criticized (see Smith, 2017). One study has shown that providing scientific knowledge to people does not always increase vaccination acceptance (Sadaf et al., 2013). However, in terms of attitudes toward COVID-19 vaccines/preventive behavior, there have been some findings consistent with the information deficit model.

1.2. Factors associated with COVID-19 vaccine attitudes

Previous research has revealed that factors associated with scientific knowledge are linked with COVID-19 vaccine attitudes (e.g., Sturgis et al., 2021; Petravić et al., 2021; Robertson et al., 2021). Educational levels were associated with COVID-19 vaccine refusal/hesitancy (Petravić et al., 2021; Robertson et al., 2021; Schwarzsinger et al., 2021). Those with higher (vs. lower) educational levels tend to be less hesitant to

COVID-19 vaccinations (Petravić et al., 2021; Robertson et al., 2021; Schwarzinger et al., 2021). Furthermore, it has been shown that psychological factors such as trust in the vaccine safety (Karlsson et al., 2021), trust in science (Sturgis et al., 2021), and perceived vaccine safety (Karlsson et al., 2021) are positively associated with vaccination intentions or confidence about vaccination. Additionally, cognitive factors including higher analytical reasoning skills (Murphy et al., 2021), higher scientific reasoning skills (ability to understand statistical information such as “causation versus correlation”) (Čavojová et al., 2020), and higher cognitive functions (measured by diverse cognitive tests including verbal declarative memory) (Batty et al., 2021) were associated with positive attitudes toward COVID-19 vaccination. These findings suggest that scientific knowledge might relate to COVID-19 vaccine attitudes.

1.3. Factors associated with attitudes toward/practice of COVID-19 preventive behaviors

A growing body of evidence has also revealed that factors associated with scientific knowledge have influenced on attitudes toward/practice of COVID-19 preventive behaviors (e.g., Brzezinski et al., 2020; Xu & Cheng, 2021). For instance, those who have greater belief in science (Stosic et al., 2021), higher need for cognition (Xu & Cheng, 2021), and higher self-control (Xu & Cheng, 2021) reported frequent mask-wearing behavior during the pandemic. Furthermore, those who have a higher need for cognition (Xu & Cheng, 2021), higher self-control (Xu & Cheng, 2021), and higher working memory capacity (Xie et al., 2020) were more likely to follow social distancing during the COVID-19 pandemic. Moreover, recent research has shown that anti-intellectualism (distrust of experts and intellectuals) is associated with less mask usage and social distancing (Merkley & Loewen, 2021). Given these findings, it might be suggested that scientific knowledge relates to attitudes toward COVID-19 preventive behaviors.

1.4 The role of scientific literacy as objective knowledge of science

Based on the information-deficit model, the present study investigated the role of scientific literacy on attitudes toward COVID-19 vaccines and preventive behaviors. Scientific literacy is a cognitive factor depicting objective knowledge of science (Fernbach et al., 2019), though there have been debates on the precise definition (Miller,

1983). The information-deficit model assumes that a lack of scientific literacy contributes to negative attitudes toward science (e.g., Bak, 2001). Relevant to the present study, a line of research has shown that scientific literacy is associated with attitudes toward biotechnology-related topics (Fernbach et al., 2019; McPhetres et al., 2019; Rutjens et al., 2018). For example, those who have lower scores on scientific literacy tend to show negative attitudes toward vaccines (Rutjens et al., 2018). Although the importance of scientific literacy in the era of COVID-19 has been suggested (Fotou & Constantinou, 2020), little is known about how scientific literacy associate with attitudes toward COVID-19 vaccines and preventive behaviors. With this in mind, the present study investigated how scientific literacy relates to attitudes toward COVID-19 vaccines and preventive behaviors.

2. Methods

2.1. Participants

A total of 500 Japanese participated in an online survey in exchange for 100 JPY. The participants were recruited on Crowdworks (<https://crowdworks.jp/>) and they completed the survey on Qualtrics (<https://www.qualtrics.com/jp/>). A priori power analyses using G*power (Faul et al., 2007) indicates that 451 participants would be sufficient to detect a small effect size ($f^2 = 0.02$) with 85% power at an alpha level of 0.05. Given the possibility that some of participants would fail the attention check, we collected data from 500 participants. No participants failed the attention check and the final data collected included all 500 participants (296 males, 196 females, 8 prefer not to say, mean age of 39.30, SD = 9.99). The data were collected in April 2021, the critical period when COVID-19 vaccines are scheduled to become available to the general public in Japan. Studies described herein were approved by the ethics committee of School of Medicine Tohoku University and were conducted in accordance with the Declaration of Helsinki. Our study was pre-registered on AsPredicted.org (#63121).

2.2. Measures

2.2.1. Scientific literacy

The degree of scientific literacy was measured by objective knowledge about science (Fernbach et al., 2019). Participants asked 15 true–false questions on scientific literacy

(e.g., “Electrons are smaller than atoms”) adapted from Fernbach et al. (2019). The questions are based on a 7-point scale anchored by “definitely true” and “definitely false.” We calculated –3 to 3 points depending on the correctness. For example, we calculated 3 points (–3 points) when a participant chose “definitely true” and the correct answer was “true” (“false”). The total points across all questions were regarded as the measure of scientific literacy (Fernbach et al., 2019). All questions are provided in the Appendix A.

2.2.2. Perceived understanding of COVID-19 vaccines and preventive behaviors

The perceived understanding of COVID-19 vaccines and preventive behaviors were measured, respectively. Participants read the instructions on how to evaluate their levels of perceived understanding. The instructions were the same as previous literature on genetically modified foods (Fernbach et al., 2019) and are shown in the Appendix B. Next, the participants rated their perceived understanding of COVID-19 vaccines and preventive behaviors, respectively on a single item of a 7-point scale anchored by “vague understanding” and “thorough understanding.”

2.2.3. Attitudes toward COVID-19 vaccines

Attitudes toward COVID-19 vaccines were measured by 3 items. Participants answered their COVID-19 vaccine intention, trust in COVID-19 vaccines, and perceived efficacy of COVID-19 vaccines on a 7-point Likert scale (1=not at all, 7=very much). The mean ratings of 3 items were used as an indicator of attitudes toward COVID-19 vaccines ($\alpha = .875$). A higher score indicates greater positive attitudes toward COVID-19 vaccines.

2.2.4. Attitudes toward COVID-19 preventive behaviors

Attitudes toward COVID-19 preventive behaviors were measured by 3 items. Participants answered their belief about the efficacy of COVID-19 preventive behavior (mask use, hand wash, and three Cs¹) on a 7-point Likert scale (1=not at all, 7=very much). The mean ratings of their beliefs about the efficacy of COVID-19 were used as

¹ The 3Cs is a slogan coined by the Japanese government in 2020 for warning people to avoid 3 factors of cluster infection. The 3Cs stands for Closed spaces with poor ventilation, Crowded places with many people nearby, and Close-contact settings such as close-range conversations.

indicators of attitudes toward COVID-19 preventive behaviors ($\alpha = .788$). A higher score indicates more positive attitudes toward COVID-19 preventive behaviors.

2.2.5. Practice of COVID-19 preventive behaviors

The practice of COVID-19 preventive behaviors was measured by 3 items. Participants answered their daily frequency of COVID-19 preventive behaviors (mask use, hand wash, and three Cs) on a 7-point Likert scale (1=not at all, 7=very much). The mean ratings of 3 items were regarded as an indicator of practice of COVID-19 preventive behaviors ($\alpha = .740$). A higher score indicates more frequent practices of COVID-19 preventive behaviors.

2.2.6. The Fear of COVID-19 scale

The Japanese version (Wakashima et al., 2020) of the Fear of COVID-19 scale (Ahorsu et al., 2020) was collected. The scale includes 7-items and one factor. The scale indicated adequate internal reliability ($\alpha = .87$; $\omega = .92$) (Wakashima et al., 2020). Participants rated each item on a five-point scale from 1 (strongly disagree) to 5 (strongly agree). The total score was used for analyses, with a higher score indicating greater fear of COVID-19.

2.3. Survey procedure

First, participants answered questions on two blocks (subjective knowledge about COVID-19 vaccines and preventive behaviors, scientific literacy). The order of blocks and items within blocks were randomized. Next, participants indicated their attitudes toward COVID-19 vaccines and their attitudes toward/practice of COVID-19 preventive behaviors. The order of questions (attitudes toward COVID-19 vaccines, attitudes toward and practices of COVID-19 preventive behaviors) were randomized. The items within the questions were also randomized. Finally, participants answered the Japanese version of the Fear of COVID-19 scale (Wakashima et al., 2020), their demographic information (gender, age, educational level), and whether or not they have underlying disease(s).

2.4. Statistical analysis

We conducted regression analyses (ordinary least squares: OLS) to investigate how (1) scientific literacy relates to attitudes toward COVID-19 vaccines; (2) scientific literacy relates to attitude toward/practice of COVID-19 preventive behaviors; (3) perceived understanding of COVID-19 vaccines relates to attitudes toward COVID-19 vaccines; (4) perceived understanding of COVID-19 preventive behaviors relates to attitudes toward/practice of COVID-19 preventive behaviors. Additionally, by adding education level as a covariate, we conducted multiple regression analyses.

We also conducted regression analyses to investigate the role of gaps between scientific literacy and perceived understanding of COVID-19 vaccines and preventive behaviors. The gaps were calculated by subtracting the (z-scored) scientific literacy from the (z-scored) perceived understanding. Specifically, we conducted the following regression analyses: (1) the role of the gaps on attitudes toward COVID-19 vaccines; (2) the role of the gaps on attitudes toward/practice of COVID-19 preventive behaviors. These analyses did not yield significant results (Table A1 in Supplemental Material) and are not discussed further.

3. Results

Demographic information of the participants is shown in Table 1. The zero-order correlations of variables are presented in Figure 1. The results of regression analysis indicated that scientific literacy was positively associated with attitudes toward COVID-19 vaccines (Table 2). In contrast, scientific literacy did not relate to attitudes toward/practice of COVID-19 preventive behaviors. The results also indicated that perceived knowledge of COVID-19 vaccines was positively correlated with attitudes toward COVID-19 vaccines. Similarly, perceived knowledge of COVID-19 preventive behavior was positively associated with attitudes toward and practice of COVID-19 preventive behaviors. Visual illustrations of the main findings are shown in Figure 2.

Table 1. Demographic information of the participants

Demographic variable	Value
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Age		
	Mean (SD)	39.29 (9.99)
	Min-Max	18-74
Gender (%)		
	Male	39.2
	Female	59.2
	Unanswered	1.6
Education (%)		
	Below high school diploma	2.2
	High school diploma	20.6
	Vocational	20.4
	Bachelor's Degree	54.2
	Master's Degree	2.6
Underlying condition (%)		
	Yes	8.4
	No	91.6

Note. Sample size was 500.

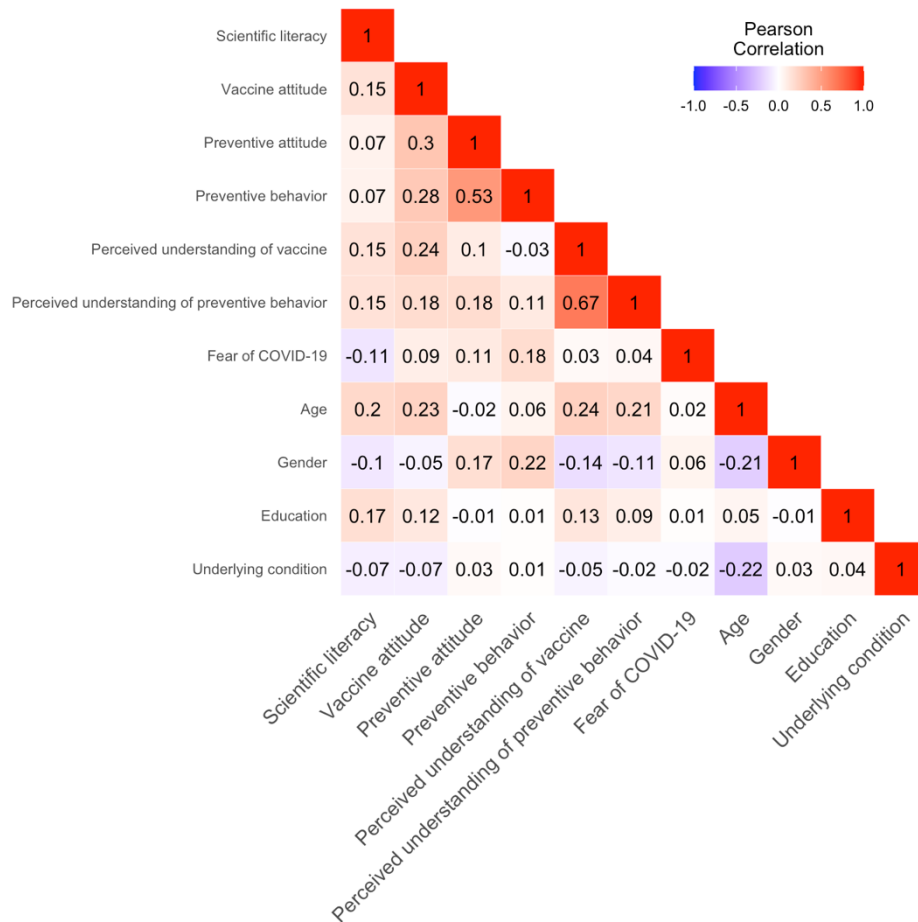


Figure 1. Heat map showing zero-order correlations among variables.

Table 2. Roles of scientific literacy and perceived understanding on attitudes toward vaccines and attitudes/practices of COVID-19 preventive behavior.

Dependent	Independent	β	SE	t	p	95% CI		R^2
						lower	upper	
COVID-19 vaccine attitudes	Scientific literacy	0.153	0.044	3.452	<.001	0.066	0.240	0.023
	Perceived understanding of COVID-19 vaccines	0.242	0.043	5.576	<.001	0.157	0.328	0.057

Attitudes toward COVID -19 preventive behaviors	Scientific literacy	0.070	0.045	1.563	.119	-	0.158	0.005
						0.018		
	Perceived understanding of COVID-19 preventive behaviors	0.184	0.044	4.174	<.001	0.097	0.270	0.034
Practices of COVID-19 preventive behaviors	Scientific literacy	0.071	0.045	1.594	.112	-	0.159	0.005
						0.017		
	Perceived understanding of COVID-19 preventive behaviors	0.114	0.045	2.551	.011	0.026	0.201	0.013

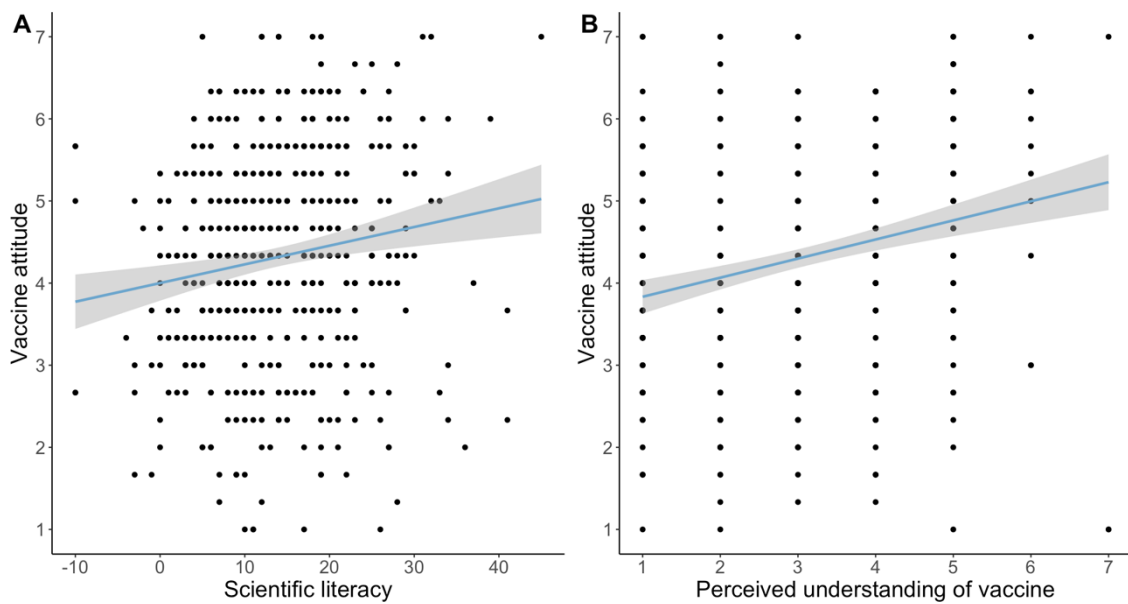


Figure 2. (A) Scatterplot of the relations between scientific literacy and COVID-19 vaccine attitudes. (B). Scatterplot of the relations between perceived understanding of COVID-19 vaccines and COVID-19 vaccine attitudes. The solid lines represent best-fitting regression lines. The shaded areas represent the 95% confidence interval around the regression line.

It is possible that educational levels influence our main findings. In other words, the relations between scientific literacy and attitudes toward COVID-19 vaccines might reflect education levels. To test this possibility, we re-ran the main analyses including education level as a covariate. The results of additional analyses demonstrated that the key findings remain significant after controlling educational level (Table 3).

Table 3. Roles of scientific literacy and perceived understanding on attitudes toward vaccines and attitude/practice of COVID-19 preventive behaviors after controlling for educational level.

Dependent	Independent	β	SE	t	p	95% CI		adj.R ²
						lower	upper	
COVID-19 vaccine attitudes	Scientific literacy	0.137	0.045	3.055	.002	0.049	0.225	0.028
	Perceived understanding of COVID-19 vaccines	0.231	0.043	5.288	<.001	0.145	0.317	0.062
Attitudes toward COVID -19 preventive behaviors	Scientific literacy	0.074	0.045	1.622	.105	-0.016	0.163	0.001
	Perceived understanding of COVID-19 preventive behaviors	0.186	0.044	4.207	<.001	0.099	0.273	0.031
Practice of COVID-19 preventive behaviors	Scientific literacy	0.072	0.045	1.585	.114	-0.017	0.161	0.001
	Perceived understanding of COVID-19 preventive behaviors	0.114	0.045	2.543	.011	0.026	0.202	0.009

Given the above findings, it might be possible that scientific literacy relates to perceived understanding of COVID-19 vaccines, which in turn affect attitudes toward COVID-19 vaccines. For exploratory purposes, we conducted a mediation analysis using the PROCESS macro for SPSS (Hayes, 2013) with 5000 bootstrap samples. In this analysis, we entered scientific literacy as the independent variable (X), attitudes toward COVID-19 vaccines as the outcome variable (Y), perceived understanding of COVID-19 vaccines as the mediator variables (M). If the 95% bias-corrected confidence intervals did not include zero, we regarded them as significant (Preacher & Hayes, 2004).

The results demonstrated that perceived understanding of COVID-19 vaccines partially mediated the relations between scientific literacy and attitudes toward COVID-19 vaccines (Figure 3). That is, participants with scientific literacy may have more perceived understanding of COVID-19 vaccines and subsequently have more positive attitudes toward COVID-19 vaccines.

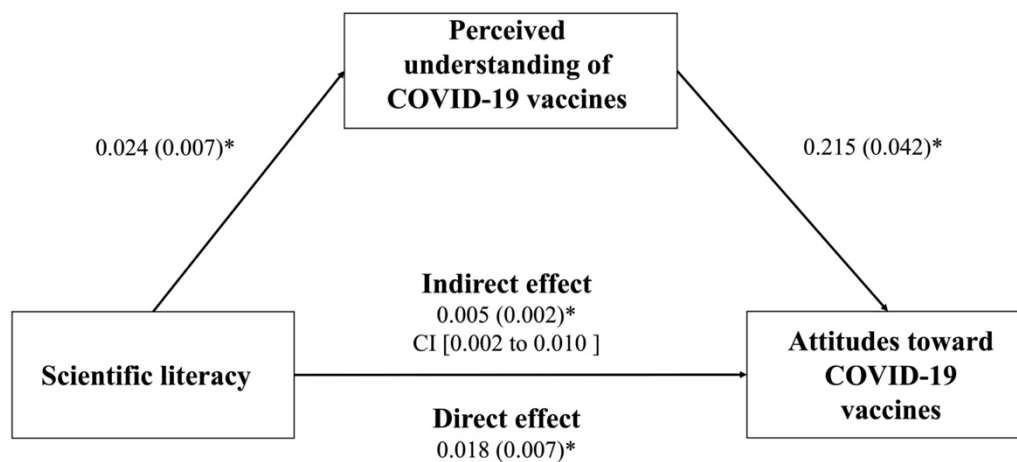


Figure 3. The relations between scientific literacy and attitudes toward COVID-19 vaccines mediated by perceived understanding of COVID-19 vaccines. Unstandardized coefficients are displayed. Standard errors are represented in parentheses. * $p < .05$.

4. Discussion

The present study investigated how scientific literacy and perceived understanding of COVID-19 are associated with attitudes toward COVID-19 vaccines and preventive behaviors. The findings demonstrated that both scientific literacy and perceived understanding of COVID-19 vaccines are positively associated with attitudes toward COVID-19 vaccines. Additionally, perceived understanding of COVID-19 preventive behaviors (but not scientific literacy) was positively associated with attitudes toward/practice of COVID-19 preventive behaviors. Collectively, these findings revealed the role of cognitive factors in preventing the global public health crisis and demonstrated the roles of objective and subjective knowledge on attitudes toward COVID-19 vaccinations and preventive behaviors.

Our findings contribute to the role of scientific literacy on public attitudes to science and technology topics. Previous research found that the role of scientific literacy on public attitudes to science and technology issues is dependent on the issues (Drummond & Fischhoff, 2017; Fernbach et al., 2019). On the one hand, those with more science literacy tend to display polarized beliefs on some issues (e.g., stem cell research, human evolution) (Drummond & Fischhoff, 2017). Those with higher science literacy tend to accept or display positive attitudes toward nanotechnology and genetically modified foods (Drummond & Fischhoff, 2017; Fernbach et al., 2019). Our findings demonstrated the positive impact of scientific literacy on attitudes to COVID-19 vaccines (but not COVID-19 preventive behaviors). These findings suggest that scientific literacy might be positively associated with topics relevant to technology (e.g., nanotechnology, genetically modified foods, COVID-19 vaccines).

Contrary to COVID-19 vaccinations, we found no significant relations between scientific literacy and attitudes toward/practice of COVID-19 preventive behaviors. The non-significant relation of scientific literacy is largely consistent with previous research (Fernbach et al., 2019; Rutjens et al., 2018). For example, Fernbach and colleagues revealed that scientific literacy was associated with attitudes toward genetically modified foods but not climate change attitudes (Fernbach et al., 2019). This suggests that scientific literacy does not always explain the attitudes to scientific or public health issues. One possible reason for the null results of attitudes toward/practice of COVID-19 preventive behaviors is baseline differences in attitudes. Our participants show more positive attitudes toward COVID-19 preventive behaviors ($M = 5.484$) than COVID-19

vaccinations ($M = 4.319$). Moreover, participants have already adopted COVID-19 preventive behaviors in their everyday life ($M = 6.262$). This might diminish the effects of scientific literacy on attitudes toward/practice of COVID-19 preventive behavior. Rather, other motives such as conformity to social norms might have prominent roles in attitudes toward/practice of COVID-19 preventive behaviors (see Nakayachi et al., 2020).

Our findings support the knowledge deficit model. The model attributes public skepticism or misunderstanding of science to a lack of knowledge (Bak, 2001). The model implies that experts should transfer their scientific communications to the general public to foster their scientific knowledge. Our findings demonstrated that both general scientific knowledge and perceived knowledge of COVID-19 vaccinations positively associate with attitudes toward COVID-19 vaccinations. Moreover, perceived understanding of COVID-19 preventive behaviors is positively associated with attitudes toward/practice of COVID-19 preventive behaviors. These findings suggest that potential campaigns and interventions aimed at increasing COVID-19 vaccinations and preventive behaviors might result in increased acceptance of COVID-19 vaccinations and preventive behaviors. Together, the present results provide partial support for the knowledge deficit model within the context of COVID-19 vaccinations and preventive behaviors.

Our data were collected in April in Japan when the vaccinations were still limited to health care workers and the general public was waiting for vaccine distribution. Recent research in Japan found that only 62.1% of respondents had a high likelihood of getting vaccinated (Machida et al., 2021). This implies the variability of the vaccine attitudes in Japan. The present findings demonstrated that the higher levels of scientific literacy and perceived understanding of vaccines were associated with greater positive the attitude toward vaccination. Our findings might contribute to understanding the heterogeneity of the vaccine attitudes in Japan and provide useful information for the development of strategies to promote vaccine acceptance.

In a broad sense, this study aimed to find out how to stop the global epidemic of COVID-19 as quickly as possible, but at the same time, it also suggests the importance of science communication to increase scientific literacy to the general public from normal times as a role of scientists. Future work should investigate whether high scientific literacy, which supports high levels of preventive behaviors toward COVID-19 as shown in this study, is broadly related to health behaviors.

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Appendix A.

Questions on scientific literacy derived from Fernbach et al., (2019)

- The center of the Earth is very hot.
- The continents have been moving their location for millions of years and will continue to move.
- The oxygen we breathe comes from plants.
- Antibiotics kill viruses as well as bacteria.
- All insects have eight legs.
- All radioactivity is manmade.
- Men and women normally have the same number of chromosomes.
- Lasers work by focusing sound waves.
- Almost all food energy for living organisms comes originally from sunlight.
- Electrons are smaller than atoms.
- All plants and animals have DNA.
- Humans share a majority of their genes with chimpanzees.
- It is the father's genes that decide whether the baby is a boy or a girl.
- Ordinary tomatoes do not have genes, whereas genetically modified tomatoes do.
- The earth orbits the sun.

Appendix B.

Introduction used for the perceived understanding questions adapted from Fernbach et al., (2019)

We will ask you to rate your understanding of COVID-19 vaccines and COVID-19 preventive behavior on a seven-point scale. To ensure you understand the scale, this section explains what the seven levels of understanding mean, using the example of how a crossbow works. Please read each description to get a sense of how to use the scale. As you will see, a 7 implies detailed and deep knowledge, a 1 implies very little knowledge, and a 4 is in the middle.

Level 7 knowledge (detailed and deep): A person with level 7 knowledge of crossbows can tell you all about their parts and how they work together. This person could tell you that a crossbow has a stiff, flexible piece of metal as a bow with a wire or strong line; that the bow is permanently mounted on a block of wood or metal; and that the wire is pulled back by something that gives a mechanical advantage—either a lever, a small block and tackle, or a crank wound around a spool that pulls a wire attached to the bow wire. The bow wire is held back by a pin connected to a trigger, and an arrow is set in front of it. The pin is directly connected to the trigger so that when you pull on the trigger, it causes the pin to pivot around a point such that the end moves downwards and releases the bow wire. When the pin releases the string, the bow very quickly un-flexes, rapidly imparting the energy stored in the flexed bow to the arrow.

Level 4 knowledge (middle): A person with level 4 knowledge might know that the crossbow is a fixed bow and arrow arrangement; that it gets more power than a normal bow and arrow because it allows you to pull the string back extra hard and then trap it there, rather than hold it; and that it is then released by a trigger.

Level 1 knowledge (very little): A person with level 1 knowledge might know what a crossbow looks like and what it does (shoots arrows).