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Expediting a paradigm shift in disease prevention to reduce airborne transmission of virus-laden aerosols via comics and animation

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Despite strong scientific evidence, global recognition of airborne transmission of respiratory viruses remains limited. Public understanding of virus-laden aerosols and willingness to adopt relevant precautionary measures are low. To address this gap, this study developed and tested three science communication formats, text, explainer comics, and animation, to evaluate their effectiveness in enhancing knowledge of virus-laden aerosols and encouraging adoption of five preventive measures. It also explores variations in media effectiveness across countries, occupations, and genders. The study employed an experimental design involving 3217 participants, educators, healthcare workers and university students, from Indonesia, Malaysia, the Philippines and Taiwan. They received surveys via text, explainer comics, or animation, while a control group received no media. Data were analysed using ANOVA and Post Hoc Sidak tests. Results were further summarized through growth percentage analysis. All media significantly improved knowledge of virus-laden aerosols ($p < 0.001$), with explainer comics and animation being more effective than text across countries, occupations, and genders ($p < 0.001$). On the other hand, animation appeared to most effectively increase willingness to adopt precautions against virus-laden aerosols ($p < 0.100$). Media effectiveness on willingness varied across countries, indicating cultural influences. While no media were effective across occupations, animation was most effective for females ($p < 0.050$). Environmental control measures, such as air filtration and UV disinfection, were generally preferred across countries, occupations and among females. In conclusion, comics and animation effectively enhance knowledge. Animation plays a crucial role in reducing resistance to preventive measures, especially in encouraging the use of air filtration and UV disinfection. Therefore, governments and disease control agencies should prioritize these media and emphasize precautionary measures to facilitate a paradigm shift and reduce airborne disease risk. The relevance of this study with 17 UN Sustainable Development Goals (SDGs) and Inner Development Goals (IDGs) is also discussed.

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Introduction

The COVID-19 pandemic has caused profound global impacts on health, education, economics and employment, environment, food and nutrition (Lekagul et al., 2022), highlighting the urgent need for effective and efficient responses to unprecedented public health emergencies. At the early stages of the pandemic in December 2019, governments and disease control agencies primarily focused on mitigating fomite and droplet transmission through practices like hand washing and surface cleaning (Lewis, 2022). However, these measures overlooked precautions against airborne transmission, including improving indoor ventilation, air filtration and disinfection (Burridge et al., 2022) and ensuring proper mask fit (Das et al., 2022). It became evident that relying solely on fomite- and droplet-based strategies was insufficient in controlling the rapid spread of COVID-19, especially in mitigating superspreading events, which were later confirmed to be fuelled through airborne transmission (Wang et al., 2021).

Early in the COVID-19 pandemic, the global society faced considerable resistance in recognizing airborne transmission (Jimenez et al., 2022), even though a large body of research has indicated airborne transmission as a significant route to spread respiratory viral diseases (Rezaei and Netz, 2021; Wang et al., 2021). A lack of insightful understanding of airborne transmission of respiratory virus-laden aerosols is one of the key factors underlying the slow responses or even resistance of global societies in coping with and preventing airborne transmission of COVID-19, facilitating the rapid spread of the pandemic (Lewis, 2022; Morawska et al., 2023). It was not until 2 years after the outbreak that the World Health Organization (WHO) acknowledged airborne transmission as the dominant transmission mechanism in spreading COVID-19 (Lewis, 2022; WHO, 2023a). As acknowledged by the former chief scientist of WHO, Dr. Soumya Swaminathan, it was the biggest mistake for the chief scientist not to call SARS-CoV-2 airborne much earlier (Kupferschmidt, 2022). These facts not only highlight an urgent call for a paradigm shift in disease control to include precautionary measures to prevent airborne transmission of virus-laden aerosols, but also point out the importance, necessity, and urgency of identifying effective ways in conveying key scientific knowledge to inform the decision makers and public in terms of disease control and prevention such that appropriate precautionary measures can be implemented to save lives. A paradigm shift in disease control and prevention will allow society, disease-control, and decision-making agencies to better prevent and control the airborne infectious diseases and thus safeguard both healthcare workers and the broader population (Hyde et al., 2021).

Science communication has often been achieved under the assumption of the "public deficit model" (Sturgis and Allum, 2004; Suldovsky, 2016), to disseminate scientific knowledge to society to shape public perceptions and attitudes. However, prior to the COVID-19 pandemic, efforts and available resources aiming at educating the public regarding the airborne transmission of virus-laden aerosols and their effective precautionary measures were extremely scarce. Existing initiatives primarily focus on general COVID-19-related information through the utilization of different media, such as infographics (Adi and Setiautami, 2021), informational texts (Lee and You, 2021), video-based interventions (Valeri et al., 2021), music (Lutomia et al., 2022) and news media exposure to virologists (Utz et al., 2022). Some of these initiatives have successfully demonstrated the media's impact on augmenting public knowledge and awareness concerning SARS-CoV-2, the virus that caused the COVID-19 pandemic (Adi and Setiautami, 2021), as well as mitigating public fear associated with COVID-19 (Valeri et al., 2021). While knowledge related to precautionary measures in preventing droplet and fomite transmission was broadly disseminated to the public, such as handwashing and surface cleaning, these two conventionally well-perceived transmission pathways have been confirmed to be less important than initially anticipated and are not the dominant transmission routes responsible for the rapid spread of COVID-19.

Moreover, to educate the public and disseminate scientific information accurately, effectively, and efficiently during a global pandemic, it is crucial to tackle "infodemics" (Gallotti et al., 2020) and combat "anti-intellectualism" (Merkley and Loewen, 2021). This requires information sources that are widely trusted and consumed (Collis et al., 2022), ensuring that the information to be conveyed is both scientifically sound and effectively delivered (Van Bavel et al., 2020). Beyond the reliability of facts, public trust in science also depends on how individuals interact with information and establish perceptions of its *value* within their social and cultural contexts. According to the Granular Interaction Thinking and Information Theory (GITT) framework (Vuong and Nguyen, 2024), information exchange is not merely a transfer of data, but a process of *value formation* shaped by relationality, granularity, and indeterminacy, three properties governing how people absorb, interpret, and retain knowledge. Trusted information sources reduce uncertainty in meaning-making by filtering noise and enhancing coherence between new inputs (scientific messages) and existing cognitive and cultural schemas. In this sense, the dissemination of science during public health crises such as COVID-19 involves not only correcting misinformation but also fostering value-aligned informational interactions that enable the public to perceive relevant scientific knowledge as both *useful* and *trustworthy*. This informational process strengthens social resilience and collective well-being by anchoring science communication within a shared system of values and trust.

Following Shannon's view of information as potential alternatives, animation can be understood as a tool that presents a *broader and more interconnected set of alternatives* than text. Unlike static text, animation simultaneously conveys visual cues, contextual relationships, and dynamic processes (e.g., cause–effect sequences, spatial changes, or behavioural outcomes). These elements expand the informational field available to viewers and enable richer combinations of information. When these informational combinations interact with pre-existing knowledge, personal experience, cultural beliefs, or perceived risks, they increase the *probability* that viewers form meaningful insights and ultimately re-evaluate the value of the message. It is assumed in general that media with a higher-quality granular interaction are related to a more effective communication of cognitive and behavioural information.

To address the insufficient public understanding of the transmission of virus-laden aerosols and convey scientifically sound knowledge via effective media for science education, we took an innovative approach by developing a series of explainer comics and animations utilizing visuals, narrative storytelling and anthropomorphism to "acculturate" a new paradigm for preventing and mitigating airborne transmission of respiratory infectious diseases to the public (Van Der Leeuw, 2020). The study was grounded in narrative theory, which posits that people understand and interpret the world through stories (Bruner, 1991) that help process complex information, retain key events, and grasp abstract concepts (Polkinghorne, 1988). In addition, narratives are more likely to be remembered and transmitted when they align with cognitive biases for social, survival-related, risk-focused, and minimally counterintuitive information (Little and Dunstone, 2025). The narratives were built on the existing

Table 1 Quasi-experimental design.

Group	Experiment	Survey
Control	-	O_1
Media Treatment 1 (Text)	X_1	O_1
Media Treatment 2 (Comics)	X_2	O_1
Media Treatment 3 (Animation)	X_3	O_1

and prevalent understanding of droplet transmission, employing a "culturally common storyline" with discernible components like scenes, characters, conflicts, and resolutions (Hinyard and Kreuter, 2007). Metaphor and anthropomorphism are used, similar to how Vietnamese political cartoons depict corruption as rats or insects to expose systemic issues and foster collective reflection (Ho et al., 2021), our project applies analogous narrative strategies to make the invisible dynamics of respiratory disease transmission understandable and emotionally resonant. By personifying invisible entities like droplets and virus-laden aerosols, the educational media allowed people to visualize and connect with the "quest" of virus-laden aerosols, covering crucial scientific knowledge related with different aspects of airborne transmission of virus-laden aerosols, including generation, transport, survival, deposition, infection mechanisms, spreading factors, and effective precautionary measure, with the "reappraisal" of the pandemic as a situation that can be readily understood and managed (Wang et al., 2021).

We employed this visual, storytelling and anthropomorphism approach to enhance understanding and acceptance of airborne transmission of virus-laden aerosols. This narrative method has the potential to encourage individuals and institutions to adhere to the precautionary measures against virus-laden aerosols, empower individuals to take proactive steps to protect themselves and others in their surroundings, and motivate governmental entities, disease-control and prevention agencies, and public building owners to implement and reinforce disease mitigation policies to safeguard public health and save lives. The use of engaging visualization (Stebner et al., 2017) narratives and relatable characters facilitates empathy and a shared understanding, making the broader community more receptive to necessary precautionary measures, ultimately preventing or mitigating the spread of virus-laden aerosols. This study aims to investigate how this set of educational materials presented with different media formats in communicating key scientific knowledge about airborne transmission of virus-laden aerosols to people of different countries (cultures), occupations and genders, and the capacity of knowledge conveyed via different media to shift people's willingness to engage in precautionary measures against virus-laden aerosols. Using an experimental approach, this study examined the effectiveness of text, explainer comics, and animation in enhancing knowledge of virus-laden aerosols and promoting the willingness to adopt five preventive measures across different countries, occupations, and gender groups.

Methods

Research design. The study employed a quasi-experimental design. There were three experimental educational media: text, comics, and animation, and a control group in which the participants were not exposed to any media. The three media treatments had three language versions: English, Indonesian, and Mandarin Chinese. The research design is presented in Table 1.

Participants. The experiment involved three representative groups of participants: educators, healthcare workers, and university students in Indonesia, Malaysia, the Philippines, and Taiwan. These groups were chosen to represent the young generation, primary knowledge providers, and those exposed to virus-laden aerosols in high-risk working environments. They were exposed to three different media formats: (1) informational text: conveying 'logical-scientific' and context-free information, (2) comics: a visually engaging narrative approach, and (3) animation: an immersive experience of dynamic visuals, audio, and storytelling approach (see Supporting Materials for the three media formats used in this study). Besides the three treatment groups, the experiment also included a control group without any educational media to establish a baseline for assessing the impact of the chosen formats. Additionally, in terms of numbers, the participants were 3217 adults (>18-years-old) in total who were from Indonesia ($N = 970$), Malaysia ($N = 718$), Philippines ($N = 597$), and Taiwan ($N = 932$), categorized into university students ($N = 1559$), educators ($N = 942$), and healthcare workers ($N = 716$). In terms of gender, the participants included 2097 females and 1120 males. The other characteristics, selection criteria, and randomization processes of the participants are described in detail in the main text and in Supplementary Tables S1 and S2 online.

Data collection. The study collected the data for about a year, starting from 7 July 2022 to 14 June 2023. The complete timeline for the data collection in relation to the timeline of airborne transmission of COVID-19 is presented in Supplementary Fig. S3 online. We collected the data using questionnaires, focusing on two key variables: (1) knowledge of virus-laden aerosols and (2) willingness to engage in precautionary measures against virus-laden aerosols. The scales of knowledge of virus-laden aerosols and willingness to engage in precautionary measures were developed by the researchers to align with the content of the intervention media. The questionnaires underwent an expert validity review by three scholarly experts in the relevant field, and 10 university students were invited to participate in cognitive interviews to provide feedback on their comprehension of the questionnaire items and their approach to answering them, which were used for further revisions. A pilot study survey was also conducted to review the measurement invariance across languages, countries, and occupations. They passed back-translation processes and pilot testing for internal consistency or reliability. The more detailed elaboration for data collection is presented in the online Supplementary.

Data analysis. This study checked the outliers and missing data before the analysis. We conducted outlier analysis using box-plot analysis and found no significant outliers affecting the research variables. For the details, please refer to the online Supplementary. Besides, we performed a case processing summary and found no missing cases in the variables related to knowledge of virus-laden aerosols and willingness to engage in precautionary measures, including both the general measure and all five specific items of precautionary measures. Furthermore, we assessed the assumptions required for one-way ANOVA, and our study met these assumptions. Specifically, our data exhibited homogeneity and normality. Finally, we conducted a one-way analysis of variance (one-way ANOVA) to investigate whether there were significant differences among the various media (text, comics, animation, and control) of science education in terms of their effects on the dependent variables, including knowledge of virus-laden aerosols and willingness to engage in precautionary measures, both in the general sense and with respect to the five specific precautionary measures. We also performed the Post Hoc *Sidak Test* to identify and reveal exactly which groups of media of science education differ from one another. The detailed results of

Post Hoc analysis are presented in Supplementary Tables S4–S10 online. To ensure the accuracy of the analysis, two researchers conducted the analysis, and the results and reports were cross-checked by three researchers.

Results

Effects of media in enhancing scientific knowledge of virus-laden aerosols across country, occupation, and gender groups. We first examined the effectiveness of knowledge given by different media formats in enhancing the essential scientific knowledge of virus-laden aerosols across countries, occupations, and genders. The growth percentage in knowledge of virus-laden aerosols of treatment groups with respect to the control group is calculated according to Eq. (1).

$$\text{Growth Percentage} = \frac{\text{Mean of Treatment} - \text{Mean of Control}}{\text{Mean of Control}} \times 100\% \quad (1)$$

Equation (1) provides the growth percentage by which the mean knowledge level of treatment groups is enhanced from that of the control group. The mean knowledge level, ranging from 0 to 1, represents the average of correct answers to 16 true-false questions (see Supplementary online). The general result of 3217 adults consistently demonstrated that while all three media formats are significant in enhancing the knowledge of virus-laden aerosols, comics and animation are generally more effective than plain text (Fig. 1A). This finding explicitly highlights the positive effect of comics and animation in effectively promoting the knowledge of virus-laden aerosols.

We then delved deeper to see whether the comics and animations continue to uphold their effects in better enhancing knowledge than text across varying countries, occupations, and genders. This test is essential in extending the generalizability of the outcomes and assessing the consistency of the overall findings, ensuring robustness against potential cultural or individual determinants. We conducted additional ANOVA and post hoc analyses by considering the factors of country, occupation, and gender. These analyses further elucidated the patterns and subtle nuances within these specific groups. The growth percentage with respect to the control group and the ANOVA results demonstrated significant media effects, particularly the pronounced effects of comics and animation in promoting knowledge for all nine chosen groups, marked by country, occupation, and gender ($p < 0.001$).

From the post hoc results, comics and animations consistently emerged as the two most effective media formats across the four participating countries (Fig. 1B), with the growth percentages of the three media formats being the highest for Malaysia, followed by Taiwan, the Philippines, and Indonesia. In terms of occupation (Fig. 1C), comics and animations also appeared to be more effective than plain text in all three occupational groups. University students exhibited the highest growth percentage among the groups of healthcare workers and educators. This observation implies that the young generation of society, represented by university students, tends to have a more open and receptive mindset to absorb new knowledge, particularly effectively via comics or animation, than the other two groups. In terms of gender, animation and comics also showed higher knowledge growth than plain text for both genders (Fig. 1D), with females and males having comparable growth percentages.

These findings provide robust support for the effectiveness of explainer comics and animations in more efficiently conveying key scientific knowledge of virus-laden aerosols than plain text, regardless of country, occupation, or gender. This consistency can be viewed as a sensitivity test, underscoring the reliability of the results regarding the media effects.

Willingness to adjust behaviours to engage in precautionary measures is culturally dependent. We next analysed the growth percentage in the willingness to engage in precautionary measures for the three media formats with respect to the control group across country, occupation, and gender (Fig. 2). The willingness level, assessed on a 5-point Likert scale ranging from 1 to 5, represents the average of five self-reported attitudinal items related to five distinct precautionary measures, including: (1) wear a mask properly with fit, (2) avoid clustering, (3) keep distance of 1–2 m, (4) use air filtration, and (5) use UV disinfection. Our results unravelled the variations in the willingness among different treatment groups, suggesting that cultural and contextual influences are key factors in affecting individuals' willingness to change their behaviours in abiding by precautionary measures.

The general result of 3217 adults indicates animation boosts people's willingness to engage in precautions more effectively than text and comics (Fig. 2A). In terms of countries which have different cultural influences, text and animation show significant positive media effects in enhancing the willingness for participants in the Philippines to change their behaviours to abide by the precautions (Fig. 2A). While comics and animation also show higher impacts than text in enhancing the willingness of participants from Malaysia and Taiwan, the results are not as significant as that for participants in the Philippines. Nevertheless, participants of Philippines, Malaysia and Taiwan generally exhibit positive enhancement effects on the willingness after receiving the essential knowledge regarding airborne transmission of virus-laden aerosols, in contrast to those from Indonesia (Fig. 2B). Furthermore, healthcare workers appear to have generally higher willingness to engage in precautions than university students and educators once receiving the essential knowledge, regardless of the media formats; however, animation appears to be more effective than text and comics for this occupation group ($p = 0.281$, Fig. 2C), likely because their occupation environments normally contain higher concentration of virus-laden aerosols than the other two occupation groups. It is particularly intriguing to note that female participants consistently demonstrate higher enhancement in the willingness to modify their behaviours to engage in precautions than the male counterparts regardless of the media formats from which the knowledge was provided, with a specifically significant media effect from animation in boosting the willingness (Fig. 2D). This finding implies that animation more likely triggers the empathy within the female audience than text and comics such that their willingness to adopt the precautions is significantly boosted.

Higher enhancement in the willingness to engage in the environmental control of virus-laden aerosols. To gain deeper insight into the media effects for each of the five precautionary measures, we conducted further ANOVA and post hoc analyses (see Supplementary Tables S6–S10 online). The five precautionary measures can be categorized into two dimensions based on the results of the exploratory factor analysis by using principal component analysis (PCA) (see Table 2), including the personal control dimension (such as wearing a mask properly with fit, keeping physical distance more than 1–2 m, and avoiding clustering) and the environmental control dimension (such as utilizing air filtration, and using UV disinfection).

Figure 3 shows variations in participants' attitudes, as reflected in the willingness to adjust behaviours to engage in precautionary measures, among the four countries. This suggests that cultural differences play a decisive role in influencing people's willingness to initiate a paradigm shift.

In terms of enhancing the willingness in personal control measures of virus-laden aerosols, including wearing a mask

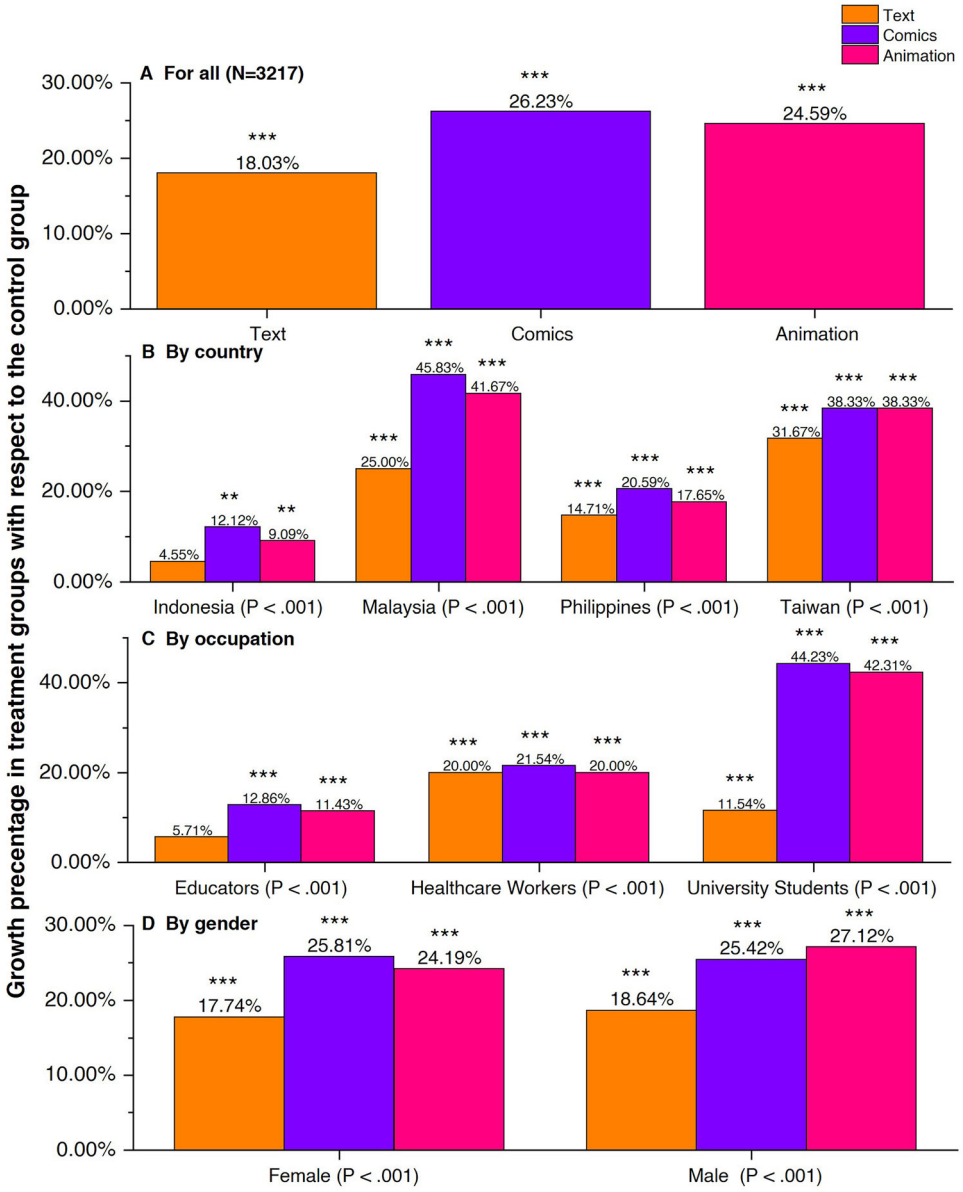

Fig. 1 Patterns in the enhancement of virus-laden aerosols knowledge. Media effects of text, comics, and animation in enhancing knowledge of virus-laden aerosols, shown as the growth percentage with respect to the control group: **A** for all ($N = 3217$), **B** by country, **C** by occupation and **D** by gender. The *P*-values at the *x*-axis are obtained from the ANOVA analyses and the *P*-values at the top of the bars are obtained from the post hoc analyses (* <0.100, ** <0.050, *** <0.001, see supplementary Table S4 online).

properly with fit, avoiding clustering, and keeping 1–2 m of social distance, animation was found most effective than other media formats in Malaysia, while animation and text were both more effective than comics in the Philippines (Fig. 3A–C). It is noteworthy that the increase in willingness to engage in the environmental control of virus-laden aerosols (air filtration and UV disinfection) is generally higher than the personal control measures for participants from the Philippines and Taiwan, but not necessarily so for participants from Malaysia and Indonesia (Fig. 3D and E).

Moreover, it is also noted that despite the increased knowledge level regarding airborne transmission of virus-laden aerosols after receiving essential scientific knowledge presented in the three media formats, participants in Taiwan and Indonesia seemed somewhat reluctant to embrace the three chosen personal control measures. However, they expressed an increase of willingness to adopt the two chosen environmental control measures (Fig. 3D and E). This phenomenon is particularly pronounced for participants from Taiwan. This outcome suggests that reinforcing and implementing environmental control measures in certain countries, especially those that have experienced collective resistance in abiding by personal control measures, are likely more publicly receptive and thus critical means to mitigate the risk of airborne transmission of fatal infectious respiratory diseases.

When observing different occupational groups, the growth of willingness to engage in personal control measures varies across groups and media formats (Fig. 4A–C). Animation consistently appeared to effectively enhance the willingness for healthcare workers and university students. All three occupation groups demonstrated an enhanced willingness to engage in the environmental control measures, regardless of the media formats from which the knowledge was conveyed (Fig. 4D and E). For university students, animation appeared most effective in

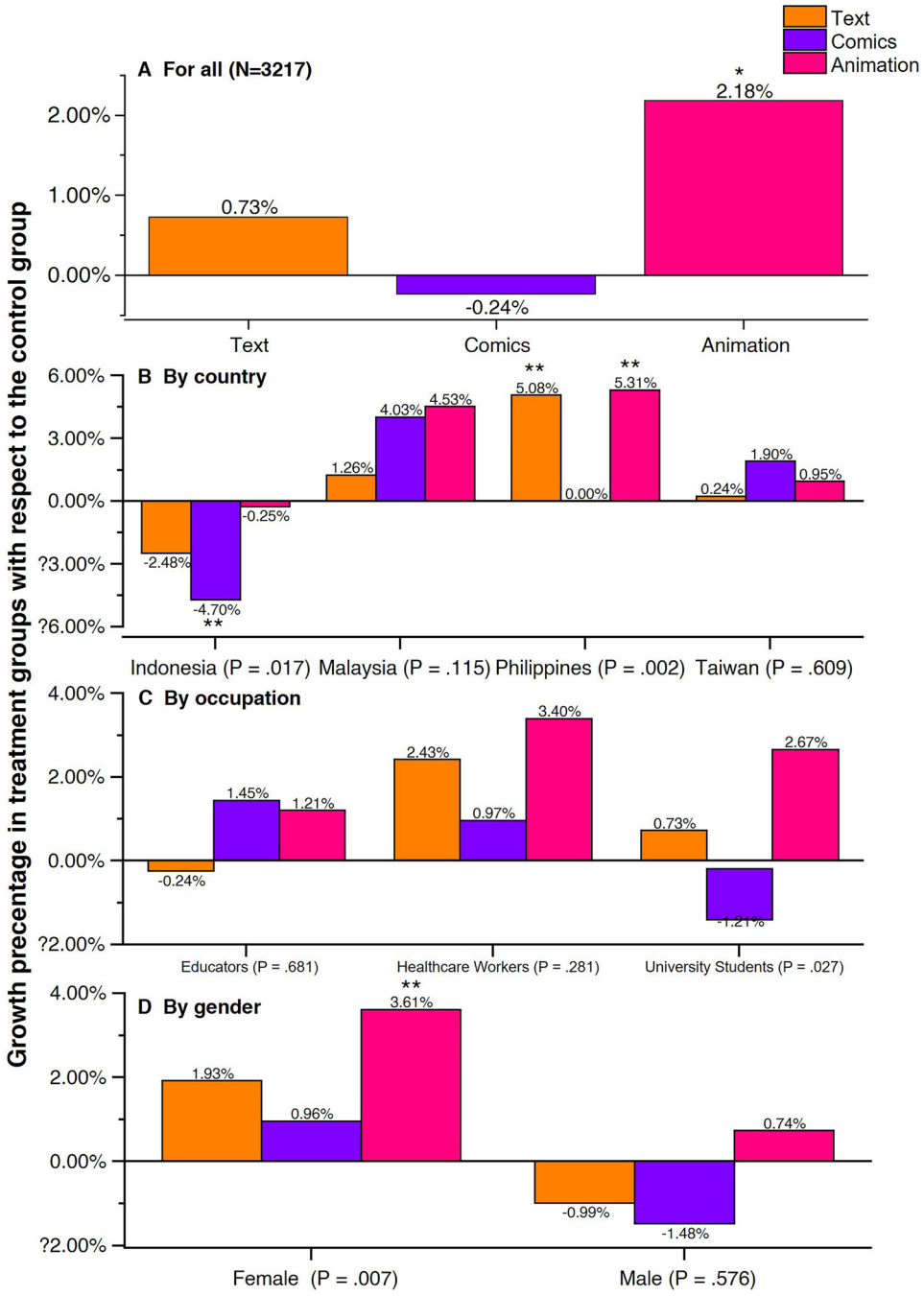

Fig. 2 Patterns in enhancement of willingness to engage in all measures. Media effects of text, comics, and animation in enhancing the willingness to adjust behaviours to engage in virus-laden aerosols precautionary measures, shown as the growth percentage with respect to the control group: **A** for all ($N = 3217$), **B** by country, **C** by occupation, and **D** by gender. The *P*-values at the *x*-axis are obtained from the ANOVA analyses and the *P*-values at the top of the bars are obtained from the post hoc analyses (* <0.100, ** <0.050, *** <0.001, see Supplementary Table S5 online).

Table 2 The results of principal component analysis of five precautionary measures.

Domain	Items	Factor loading
Personal control	Wearing a mask properly with a good fit	0.878
	Maintaining a physical distance of more than 1–2 m	0.859
	Avoiding clustering.	0.864
Environmental control	Utilizing air filtration (e.g., air cleaners equipped with HEPA filters)	0.842
	Using UV disinfection with cautions	0.903

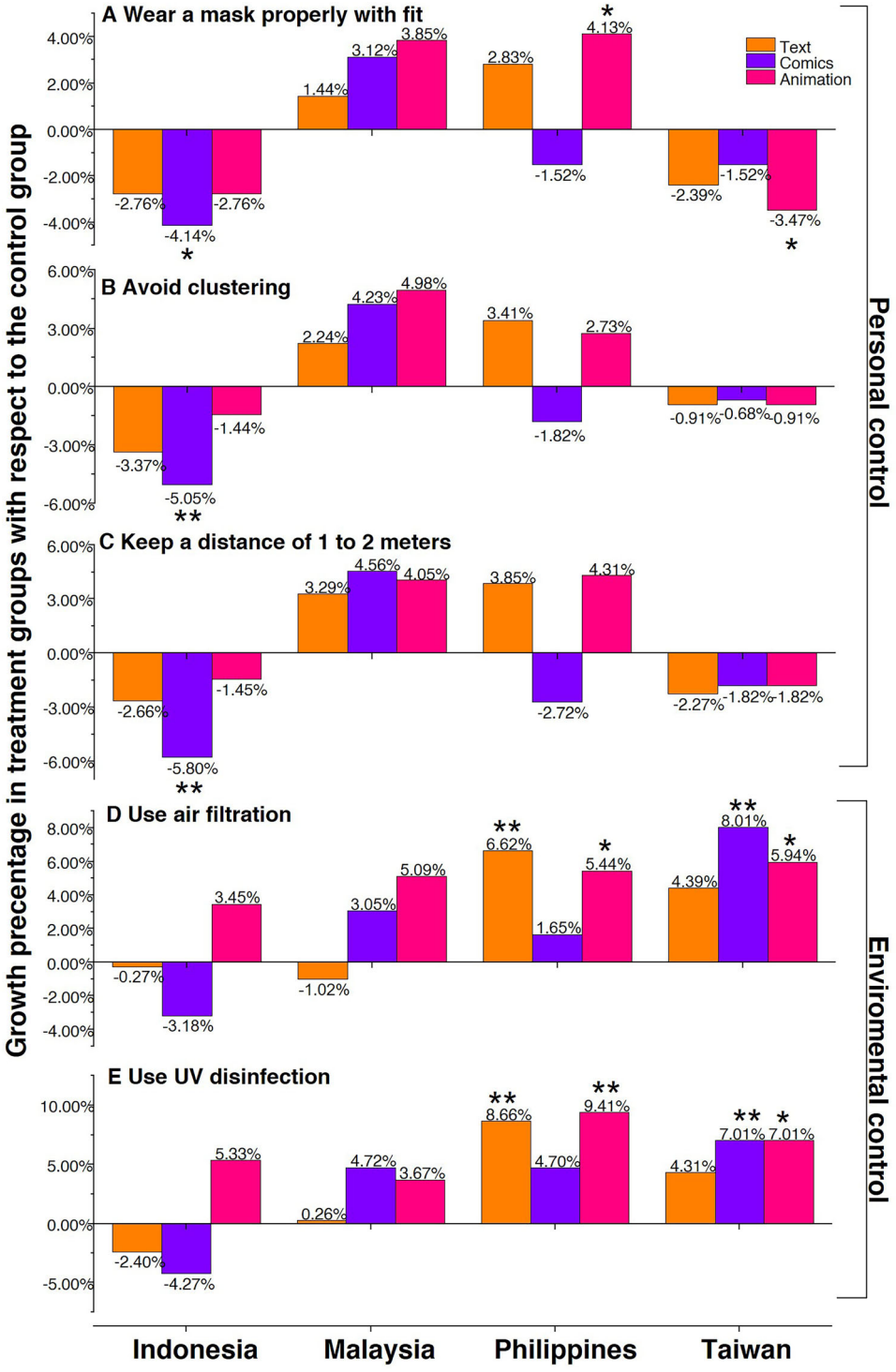

Fig. 3 Patterns in enhancement of willingness to engage in each measure by country. The enhancement of willingness to engage in five effective virus-laden aerosols precautionary measures after receiving knowledge given in three different media formats, including text (orange), comics (purple), and animation (pink), expressed in terms of growth percentage with respect to the control group for the four chosen countries. **A** Wear a mask properly with fit, **B** avoid clustering, **C** keep distance of 1–2 m, **D** use air filtration, and **E** use UV disinfection. The *P*-values at the top of the bars are obtained from the *post hoc* analyses (* <0.100, ** <0.050, *** <0.001, see Supplementary Tables S6–S10 online).

boosting their willingness to engage all five precautionary measures, with the two environmental control measures (air filtration and UV disinfection) being the most significantly enhanced measures. For healthcare workers, animation also appeared to be the most effective media format in enhancing the willingness to adopt the environmental control measures, although both animation and text were helpful in increasing their willingness to follow the personal control measures. Animation exhibits a significant effect in enhancing the willingness to engage in environmental control measures (air filtration and UV disinfection) for both healthcare workers and university students (Fig. 4D and E); whereas, for educators,

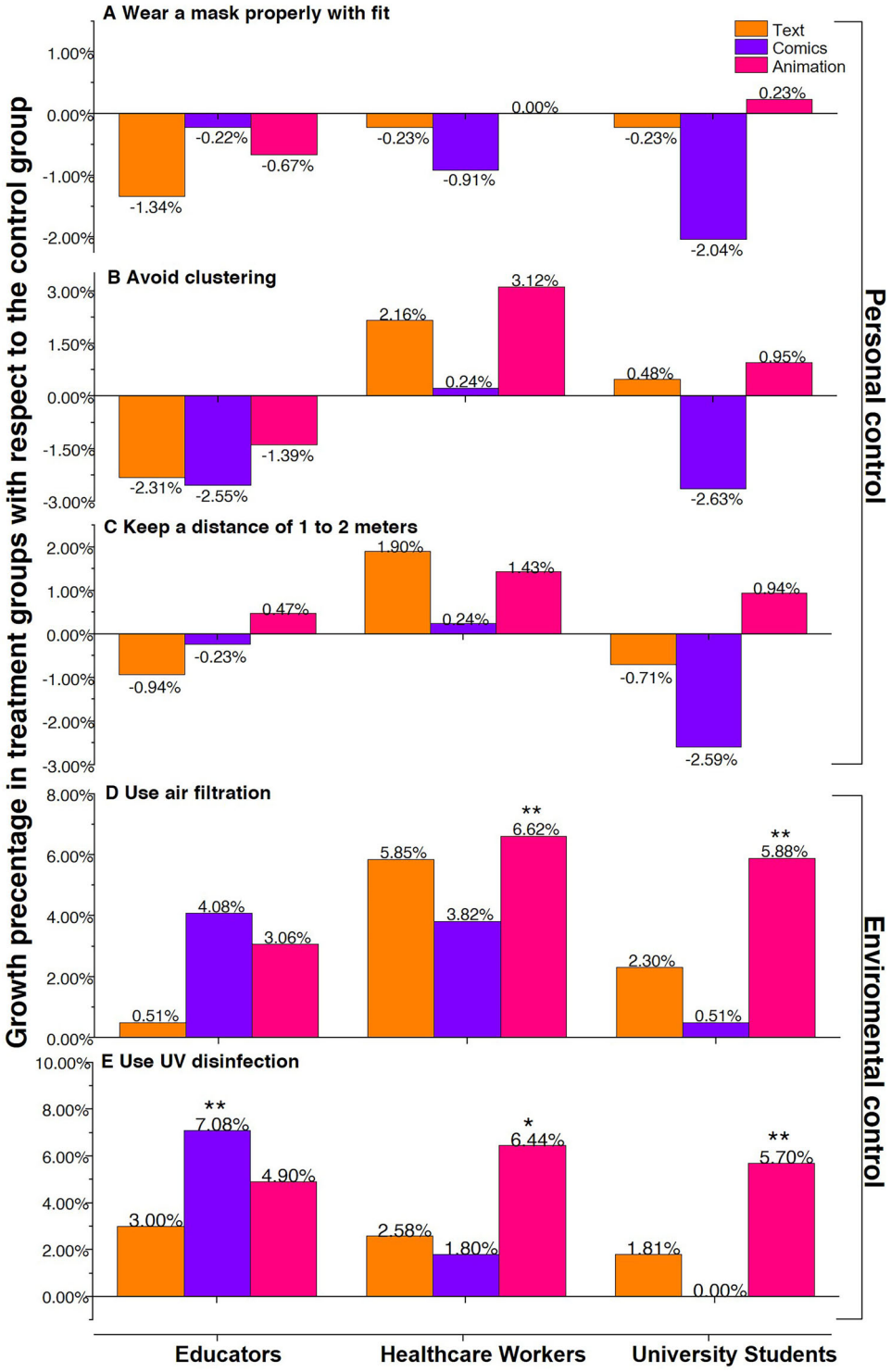

Fig. 4 Patterns in the enhancement of willingness to engage in each measure by occupation. The enhancement of willingness to engage in five effective virus-laden aerosols precautionary measures after receiving knowledge given in three different media formats, including text (orange), comics (purple), and animation (pink), expressed in terms of growth percentage with respect to the control group, elaborated by occupation. **A** Wear a mask properly with fit, **B** avoid clustering, **C** keep distance of 1–2 m, **D** use air filtration, and **E** use UV disinfection. The *P*-values at the top of the bars are obtained from the post hoc analyses (* <0.100, ** <0.050, *** <0.001, see Supplementary Tables S6–S10 online).

comics were found to be more effective in increasing the willingness to engage in the environmental control measures, particularly UV disinfection (Fig. 4D and E).

In terms of gender, animation and text both appeared to effectively increase the willingness of female participants to engage in all five precautionary measures, whereas comics also showed effectiveness in boosting the effectiveness in enhancing the willingness to engage in environmental control measures (Fig. 5A–E). Particularly, all three chosen media formats had significant effects in enhancing the willingness to engage in air filtration (Fig. 5D). On the contrary, the growth in males' willingness appeared negative for the three personal control

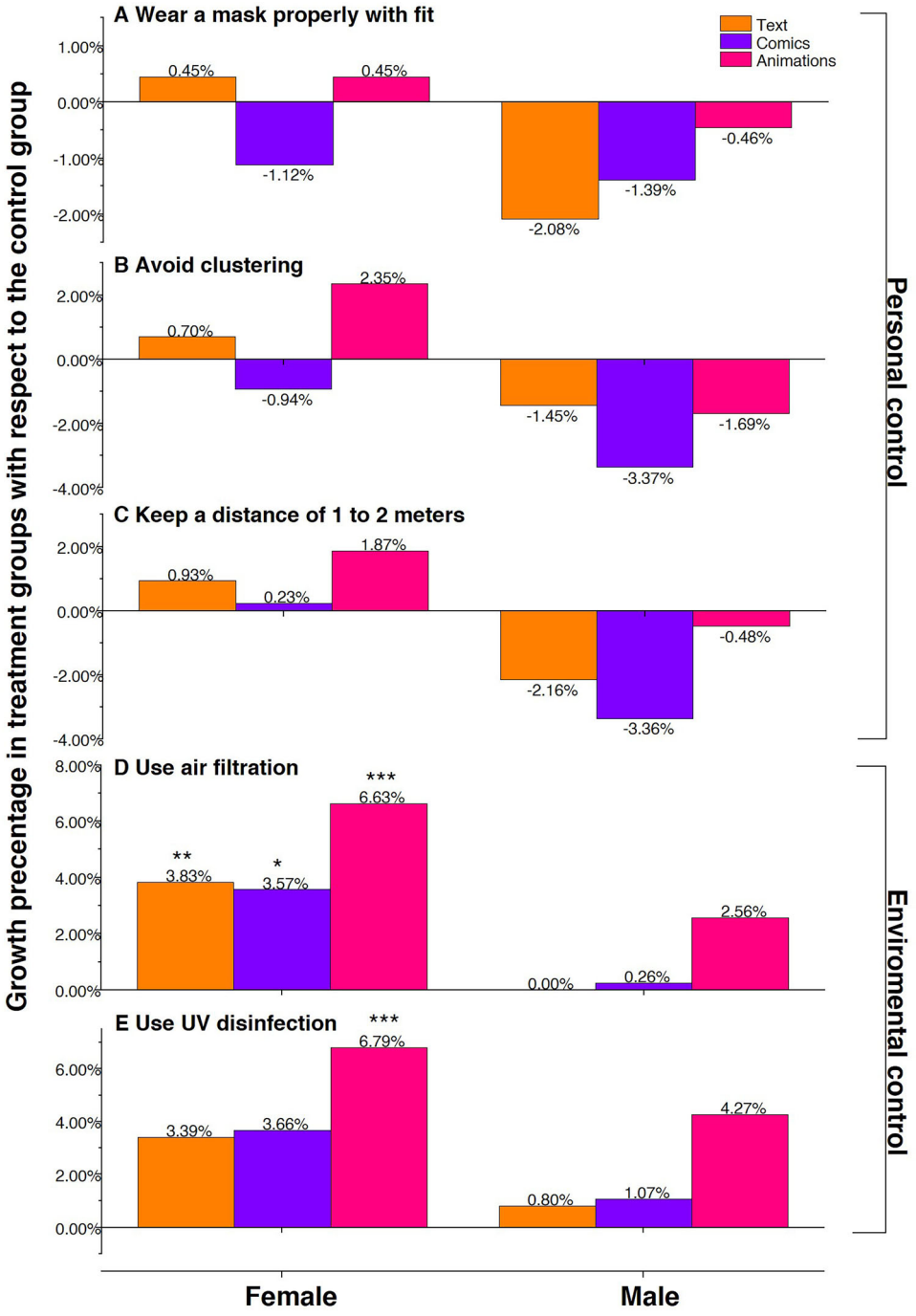

Fig. 5 Patterns in the enhancement of willingness to engage in each measure by gender. The enhancement of willingness to engage in five effective virus-laden aerosols precautionary measures after receiving knowledge given in three different media formats, including text (orange), comics (purple), and animation (pink), expressed in terms of growth percentage with respect to the control group, elaborated by occupation. **A** Wear a mask properly with fit, **B** avoid clustering, **C** keep distance of 1–2 m, **D** use air filtration, and **E** use UV disinfection. The *P*-values at the top of the bars are obtained from the post hoc analyses (* <0.100, ** <0.050, *** <0.001, see Supplementary Tables S6–S10 online).

measures (Fig. 5A–C), and only appeared slightly positive for the two environmental control measures, with the animation being the more effective media format than the other two media formats (Fig. 5D and E).

In summary, all nine groups show enhanced willingness to adjust their behaviours to engage in environmental control measures after the treatments of knowledge, though certain groups show certain levels of hesitance to implement personal control measures. This finding puts higher importance and priority on disease control and prevention agencies, governments, healthcare organizations, and building owners to implement environmental control measures as shared responsibility to mitigate the risk of airborne diseases and safeguard public health. Nevertheless, the personal control measures cannot be fully substituted by the environmental controls. Our findings thus point out the needed endeavours to be made in public education and communication to further enhance people's willingness to engage in the personal control measures.

Discussion

Enhancing key scientific knowledge regarding airborne transmission of virus-laden aerosols through comics and animation. Our findings, accessed from the perspectives of country, occupation, and gender, generally support the 'deficit model' of science communication (Simis et al., 2016), which posits a positive correlation between informed knowledge and learners' attitude, in this case, the essential scientific knowledge regarding airborne transmission of virus-laden aerosols and the participants' willingness to adjust their behaviours to engage in precautionary measures. The pronounced effects of comics and animation in enhancing knowledge over plain text reflect the strength and advantages of non-textual and visually engaging content for conveying scientific knowledge (Simis et al., 2016). Such effects are consistent with the findings of Urquiza-Fuentes and Velázquez-Iturbide (2013) on the educational effects of animation on short-term and long-term knowledge acquisition.

Beyond these multimedia advantages, the effectiveness of the comics and animation may also stem from the narratives and anthropomorphic elements embedded within them. Our materials likely leveraged several cognitive biases known to support the cultural transmission of stories, including biases toward social information, survival-related cues, and risk-focused events (Little and Dunstone, 2025). By embedding virus-laden aerosols in familiar social environments and framing them in terms of health risks and protective behaviours, the narratives aligned more closely with these cognitive tendencies than plain informational text, thereby enhancing attention, emotional engagement, and recall.

Cultural and contextual factors also contribute to this pattern. Our participants from Indonesia, Malaysia, Taiwan, and the Philippines share collectivist cultural orientations that emphasize group well-being and compliance with community health norms. This cultural tendency may contribute to the positive correlation observed between increased scientific knowledge and willingness to adopt precautionary behaviours. In Indonesia and the Philippines, strong familial and community-oriented values have been linked to adherence to collective health practices (Alampay, 2024; Wagner et al., 2025). Likewise, high levels of public trust in science-based health information in Malaysia (Mohamed et al., 2023) and Taiwan (Yueh et al., 2022) support acceptance of preventive measures during health crises. Both male and female participants demonstrated substantial knowledge gains of virus-laden aerosols.

Furthermore, occupational background may also shape the association between acceptance of new knowledge and willingness to adopt it. Healthcare workers, due to their close proximity to medical information, showed strong receptiveness to visually enriched scientific communication. Educators and university students, who are generally familiar with multimodal learning (Saiful, 2021), also benefit from the narrative and visual scaffolding offered by comics and animation. Such gains in virus-laden aerosol knowledge, however, are possible only when these groups remain open and critical toward updated scientific information and related decision-making. During COVID-19, almost all governments and public health agencies initially focused solely on fomite and droplet transmission, putting significant efforts and resources into emphasizing hand washing and surface cleaning (Lewis, 2022). However, this emphasis overlooked precautions against airborne transmission, such as improving indoor ventilation, air filtration and disinfection (Burridge et al., 2022), and ensuring proper mask fit (Das et al., 2022). Global society also faced substantial resistance in recognizing airborne transmission (Jimenez et al., 2022), despite extensive evidence already identifying it as a major route for the spread of respiratory viral diseases (Rezaei and Netz, 2021; Wang et al., 2021). Therefore, the whole society should cultivate an *open learning mindset*, *critical thinking* and *systems thinking* (Inner Development Goals, 2025) toward emerging scientific evidence. Developing stronger scientific literacy, alongside open learning attitudes, critical thinking, and systems thinking, would enable both the general public and frontline professionals to respond more rapidly and effectively when facing future pandemics.

Beyond cultural, occupational, and gender contexts, the effectiveness of comics and animation may also derive from the narratives and the anthropomorphism elements. Narratives allow a clear representation of multiple voices from different characters to facilitate cognitive processing of the information (Aeilts et al., 2021). When the characters in the comic and animation conduct the behaviours and fulfil the expectations of effective precautionary measures for airborne transmission of virus-laden aerosols, per social learning theory (Bandura and Walters, 1977) and self-efficacy theory (Maibach and Flora, 1993), it may enhance people's confidence in taking reasoned actions (Slater, 1999). Moreover, the "picture superiority effect" may also play a role in making comics and animation more effective science education materials than plain text (Stenberg, 2006). The new knowledge may challenge or reshape people's pre-conceived thinking on how the infectious respiratory disease transmission was constructed or mentally represented in a way that helps reduce potentially negative emotional responses and increase positive emotional responses in engaging precautionary measures against virus-laden aerosols during the pandemic (Wang et al., 2021).

Enhancing willingness to adhere to virus-laden aerosols precautionary measures: Environmental control measures are preferentially accepted over personal control ones. From the results shown in Figs. 3–5, we observed that the 'deficit model' of science communication, conveyed in three different media formats, is generally more successful in influencing people's willingness to adjust their behaviours to engage in environmental control measures than the personal control measures. The disparity between environmental and personal control suggests that the deficit model of "knowledge to attitude" may be subject to psychological, social, and cultural influences. A global survey on COVID-19 beliefs (Collis et al., 2022) revealed the impact of cultural differences on the divergent beliefs of publics about the importance of taking actions against COVID-19 and related issues. Our findings explicitly point out that even if the knowledge is effectively conveyed to the participants, it does not necessarily translate directly to people's willingness to adjust their behaviours to follow the precautionary measures against virus-laden aerosols, particularly when the needed control measures involve behaviour pattern changes at the personal level. This observation readily manifests an old slang describing human's behaviours, "to know is one thing, to do is another". This finding may be rationalized by taking human nature and thus socialized behaviours into consideration. The personal control measures to a certain degree limit human nature to socialize (Cacioppo and Ortigue, 2011; Sakman, 2019), and are therefore more likely impacted by the social and cultural factors. As human beings tend to gather and interact with each other within social distance, aerosol precautionary measures, such as universal mask wearing, and keeping social distance larger than 1 or 2 m, may hinder social and emotional interactions to certain degrees.

Some studies reported the possible correlation between mask-wearing and social anxiety (Saint and Moscovitch, 2021). Mask wearing may act as a barrier, inhibiting people's accurate interpretation of social and emotional cues. The cultural factor

also plays a decisive role in affecting the public's perceptions of the social norms associated with wearing masks (Saint and Moscovitch, 2021). For instance, in certain cultures, it is generally perceived that people wear masks only when they are severely ill (Kwan et al., 2021). This provides a potential explanation to rationalize why implementing mandatory personal control measures has faced varying levels of resistance from the public in certain countries, or even increased people's psychological distress and loneliness (Losada-Baltar et al., 2021), mental well-being (Ahmed et al., 2020; Benke et al., 2020), and morality (Tomasello, 2014). Furthermore, the restricted degree of freedom may be another possible root cause explaining the hesitance of abiding by personal control measures when the disease control agencies implement mandatory personal control measures. For instance, in numerous European nations, citizens have organized protests aimed at governments, highlighting concerns over imposed restrictions on civil liberties, including limitations on private gatherings, social interactions, and mandates for mask-wearing in all places (Neumayer et al., 2023). Such resistance may stem from perceptions of violated rights and freedoms, leading to hesitancy in adhering to personal precautionary measures.

In the meanwhile, our findings show that people are more inclined to implement the environmental control measures than the personal ones, such as implementing air purifiers equipped with HEPA filters and UV disinfection, as a part of shared collective responsibility. This tendency can be better understood through the cultural contexts of participants, as culture fundamentally shapes how people respond to public health crises like COVID-19 (Lu et al., 2021). The countries represented in our sample vary in their degree of cultural "tightness", defined by strong social norms and low tolerance for deviant behaviour (Gelfand et al. 2011). Indonesia is classified as a "tight" culture and the Philippines as "moderately tight" (Uz, 2015), while both Malaysia (Gelfand et al., 2011) and Taiwan (Gelfand et al., 2021) are also considered "tight" cultures. Research shows that cultural tightness is associated with greater compliance during COVID-19, suggesting that individuals in tighter societies are more willing to conform to collective-level interventions (Dong et al., 2021). Therefore, the preference among participants for environmental control measures may reflect shared cultural orientations toward collective action and adherence to measures that align with community-level protection.

However, this preference is not exclusive to people from culturally "tight" societies. Because pandemics are global health crises, whose importance and urgency are beyond isolated individual concerns, inner traits such as *connectedness*, *systems thinking*, *an inclusive mindset*, *empathy* and *compassion* for others' suffering (Inner Development Goals, 2025) are essential for people from all cultures (Gelfand et al., 2011), as viruses do not discriminate by cultural background. These inner traits are crucial in mitigating or preventing outbreaks. Moreover, environmental control measures highlight the crucial contributions from governmental agencies, authorities, owners of buildings and public places, and companies, reinforcing a sense of shared responsibility and collective action across sectors. This contrasts with personal control measures, which place responsibility solely on individuals.

Since the majority of public may perceive the pandemic as a collective societal issue requiring coordinated, collaborative, and cooperative actions (Hattke and Martin, 2020), it appears more acceptive for the public to engage the environmental control measures as they do not infringe on personal rights to socialize, and at the same time they promote a "shared responsibility" in tackling adversities like COVID-19. Taking these potential psychological factors into account, it is extremely crucial for all public environmental settings worldwide, such as hospitals, healthcare facilities, shopping malls, restaurants, airports, and common public transportation, to widely implement the environmental control mitigation measures, such as improving the ventilation in the public buildings or transportation tools, adding air filtration or UV disinfection to reduce the risk of airborne transmission of virus-laden aerosols.

Reducing concentrations of virus-laden aerosols in indoor spaces necessitates adequate ventilation, a strategy strongly recommended by major health agencies such as the WHO (2020) and the National Institute for Occupational Safety and Health (NIOSH) (2024) after the hard lessons learned from COVID-19. Adequate ventilation can be achieved through increased air exchange rate, natural ventilation, or optimized ventilation systems. Implementing or reinforcing air filtration via upgrading HVAC systems to MERV-13 or higher, or deploying portable HEPA air purifiers can also substantially remove airborne pathogens; this has been demonstrated both experimentally, such as in Ueki et al. (2022) demonstration of HEPA removal of infectious SARS-CoV-2, and in real-world school settings where HEPA units significantly reduced the viral load in the room air (Falkenberg et al., 2023). In high-risk or poorly ventilated indoor environments, including healthcare facilities, transport hubs, classrooms, and crowded commercial venues, air disinfection by ultraviolet germicidal irradiation (UVGI) has also been proven to be an effective intervention, with research confirming its capability to inactivate SARS-CoV-2 when properly installed and operated (Cattai et al., 2023; Kitagawa et al., 2021).

The implementation of these mitigation strategies also requires careful attention to safety considerations. Conventional UV-C systems must be installed in a way that prevents direct human exposure, while Far-UVC technologies require strict adherence to regulatory safety limits to avoid potential eye and skin risks (International Commission on Illumination, 2020; WHO, 2023b) In addition to safety, contextual challenges may hinder adoption, particularly in regions with older buildings (Rieser et al., 2021), limited electrical capacity (Gaillard et al., 2023), or climates (T. Ahmed et al., 2021), where natural ventilation is impractical due to heat, humidity, or outdoor pollution. Maintenance demands, such as routine filter replacement, UV lamp cleaning, and technical oversight, can further strain facilities with limited financial or technical resources. Despite these challenges, these aerosol precautionary measures are particularly critical in suppressing the risk of airborne transmission in densely populated areas or settings with vulnerable populations, offering non-intrusive mitigation options that support public cooperation. Making such interventions visible and consistently maintained can further strengthen public trust and promote the collective action needed to manage airborne infectious threats.

Nevertheless, this study still highlights the critical role of personal control measures in reducing the risk of airborne transmission of virus-laden aerosols that cannot be fully replaced by environmental control measures. Therefore, it remains essential and critical for the government to put in additional efforts to educate and communicate with the public and communities regarding the importance and necessity to implement personal control measures to safeguard oneself and others constantly and broadly. Moreover, implementing proper educational materials in the curricula of K-12 schools, higher education institutes, and other environmental education settings also helps to shift people's knowledge and attitude to reinforce the personal control measures.

Closing the gender gap in environmental concerns and behaviours at the collective level. This study shows that females are

more receptive than males to adapt changes in attitudes and behaviours, particularly concerning their willingness to engage in the environmental control of virus-laden aerosols. Closing the gender gap in environmental concerns and behaviours at the collective level is thus essential and urgent to ensure a smooth paradigm shift in disease control. This in turn requires addressing numerous intertwined issues, such as gender inequality, economic scarcity, power distance, and collectivism (Chan et al., 2019). To address these issues, it requires a multifaceted approach encompassing education and awareness enhancement, economic and political empowerment, community engagement, and cultural transformation, as elaborated below:

1. *Education and awareness enhancement*: It is necessary to design specific educational programmes and curricula for students at all learning stages to foster understanding of environmental issues and awareness regarding the importance of clean and pathogen-free air. This can be achieved through various learning approaches, such as ecocritical instruction (Saiful and Shein, 2025), ecocritical dialogues (Khasanah et al., 2025; Saiful, 2025), or project-based learning (Melton et al., 2022) or the inclusion of an ecocriticism course in higher education (Saiful and Setyorini, 2022) that addresses air-related issues. These efforts will develop a sense of responsibility among all members of society (Chawla and Cushing, 2007).
2. *Economic and political empowerment*: It is important to make extra efforts to ensure gender equity in the decision-making processes, especially those related to environmental governance and resource management (Bayeh, 2016), with possible measures such as quotas for women's representation in leadership positions.
3. *Community engagement*: It is also important to foster partnerships between local communities, civil society and professional organizations, and government agencies that address the needs for all genders (Figueiredo and Perkins, 2013).
4. *Capacity building*: It is crucial to implement women-friendly strategies in disease control and prevention, such as (i) leveraging existing women's organizations, involving women with relevant professional knowledge and skills in social initiatives (McHugh, 2012), (ii) empowering women with sufficient scientific knowledge and an open mindset to accept new information and are willing to get involved in or even leading related disease control policy or decision making, and (iii) creating opportunities for women to take actions (Bullock and Tegbaru, 2019)
5. *Cultural transformation*: It is helpful to promote positive role models and narratives to prominently feature female expertise and voices in news media (Hubner, 2023) that depict women as active agents of change in environmental stewardship and sustainable development, to amplify their perspectives in the paradigm shift processes.

Addressing these issues can help the global societies attain collective awareness regarding airborne diseases effectively and enable the essential actions to drive and accomplish the paradigm shift.

Foster pro-environment masculine–feminine balanced traits at the individual level. In the survey conducted in this study, the participants were asked to self-report their gender, thus it could encompass self-identification beyond strictly biological sex, allowing for expressions of feminine or masculine traits. Within such a gender identity framework, our result readily aligns with the existing general perception that females tend to exhibit greater concern for environmental issues, social welfare, and the overall well-being of others than males (Stern et al., 1993). This inclination toward social-altruistic, environmental concerns and ecological cooperation may be accounted for by generally greater levels of empathy in women (Arnocky and Stroink, 2010), either due to their inherent characteristics (Christov-Moore et al., 2014) or traits cultivated through gender role socialization (Arnocky and Stroink, 2010). In addition to empathy, other conventionally attributed feminine values and traits, such as caring, openness, altruism, cooperation, and pro-environmental behavioural intention (Tien and Huang, 2023) may also contribute to the observation of higher willingness of women to alter their behaviours to engage in precautionary measures against virus-laden aerosols particularly the environmental control measures, as shown in Fig. 5. Nevertheless, to facilitate the paradigm shift to implement precautionary measures against virus-laden aerosols at the global level, it is profoundly imperative to encourage above-mentioned and other pro-environmental inner traits in all genders, even if some have been conventionally attributed to feminine traits. Fostering the development of pro-environmental inner traits, such as empathy, altruism, and collaboration, can effectively promote pro-environmental behaviours.

Each individual, in fact, exhibits a blend of masculine and feminine traits, and it has been found that androgynous individuals, featured by high levels of both masculine and feminine traits, exhibit strong pro-environment attitudes and behaviours (Phillips and Englis, 2022). A variety of approaches may be employed to cultivate environmental awareness and consciousness in individuals with predominantly masculine traits. These include practices such as self-awareness and reflection (Frantz et al., 2005), role-play (Chen and Martin, 2015), increased contact with nature in outdoor spaces (Liu et al., 2022), volunteering (Liarakou et al., 2011), and educational games (Morganti et al., 2017). Engaging in these activities may help individuals attain a masculine-feminine balanced character conducive to pro-environmental behaviours. Additionally, it is equally crucial to dismantle the stereotype that environmental concern is exclusively feminine, as some men may avoid pro-environmental actions to maintain a macho image (Brough et al., 2016; Desrochers and Zelenski, 2023).

Engaging precautions facilitate SDGs to attain a more sustainable future. Effective education and communication of scientific knowledge of airborne transmission play multi-faceted, vital roles in facilitating the necessary paradigm shift of disease control to reduce the risk of airborne transmission of infectious respiratory diseases. Aligned with the guidelines of the "Clean Air in Buildings Challenge" initiated by the Environmental Protection Agency, USA, prioritizing community engagement, communication and education serves as a crucial practice for building owners and operators to mitigate risks associated with airborne viruses and other contaminants indoors (Environmental Protection Agency, 2022).

Furthermore, developing effective educational outreach materials, such as the comics and animation of the virus-laden aerosols studied in the present work, not only helps raising public's awareness and willingness to engage in the aerosol precautionary measures, but also contributes to facilitating a number of key sustainable development goals (SDGs) outlined by the United Nations (Fig. 6). For instance, implementing aerosol precautions can effectively reduce the risk of infectious diseases spread via aerosol transmission pathway, thus facilitating the "*good health and well-being*" of global citizens (SDG 3). To safeguard the public, both governments and citizens need to act proactively, an essential Inner Development Goal (Inner Development

Fig. 6 Paradigm shift towards virus-laden aerosols can be expedited by IDGs, which in turn facilitate SDGs for a sustainable future. The pro-environmental inner traits and skills, outlined in the context of the 5 dimensions of IDGs, may facilitate the smooth paradigm shift and accomplish 9 (out of 17) SDGs.

Goals, 2025) trait for addressing urgent public health challenges and preventing future pandemics. By creating and disseminating effective and sound educational materials or curriculum to convey key knowledge of airborne transmission of pathogens, it helps attain "*quality education* (SDG 4)" to all global citizens such that individuals, governmental agencies, society communities can all be well informed, allowing them to have sufficient knowledge to make righteous decision or policy to protect oneself from airborne diseases, and benefit the global society.

This study identifies a significant gender gap in terms of the willingness and behaviours change to engage in aerosol precautions. By making endeavours to close the gender gap at the collective level, and re-establish a masculine-feminine balanced inner traits conducive to pro-environmental behaviours at the individual level among all genders, it helps attain the "*gender equality*" (SDG 5) from the inside out.

Furthermore, by implementing aerosol precautionary measures, airborne pathogens in the air can be effectively removed and/or deactivated, thus contributing to improving the sanitation of the air we share. Since many water bodies were found contaminated by viruses and other forms of pathogens from the wastewater of hospitals or household environments (Wang et al., 2024; Zamhuri et al., 2022), reducing airborne diseases indirectly reduces the chance of contaminating the water body, thus contributing to the "*clean water and sanitation*" (SDG 6).

To fully implement the aerosol precautionary measures, it necessitates the close cooperation of related industries to develop and manufacture effective and innovative products, such as effective ventilation systems, novel filtration materials for mask making, portable air purification devices, and effective UV disinfection devices. As a result, implementing the aerosol precaution also facilitates "*industry, innovation and infrastructure*" (SDG 9).

Furthermore, the mortality rates of COVID-19 in poor and low-wealth counties were reported to be nearly twice those in rich countries (Lynch and Sachs, 2021). By implementing aerosol precautionary measures, it may help reduce the mortality rates in the poor and low-wealth counties, thereby "*reducing inequalities*' (SDG 10). By implementing aerosol precautions, it helps create healthier buildings, public spaces and living environments to establish truly "*sustainable cities and communities*" (SDG 11).

Breathing clean air is a fundamental human right. As declared by The United Nations General Assembly (UN General Assembly 3rd Committee, 2017), "everyone on the planet has a right to a healthy environment, including clean air, water, and a stable climate". It is urgent and essential for disease control and prevention agencies, governments, and global decision-making agencies worldwide to revise the disease control and prevention guidelines and mindfully allocate resources to implement the aerosol precautions for all to ensure clean, pathogen-free air, thus ensuring the "*justice and strong institutions*" (SDG 16) to fulfil the fundamental right to breathe clean air. In 2024, the WHO and EU have updated and released guidelines in managing indoor facilities and suppressing airborne transmission (WHO, 2024a, 2024b; Ruiz et al., 2024).

Finally, by effectively disseminating sound knowledge regarding airborne transmission of virus-laden aerosols, it helps bring individuals, communities, and countries together to reach a

consensus and form "*partnerships for the goals*" (SDG 17) of preventing airborne disease transmission. According to the United Nations (2025), the overall progress on the SDGs is severely falling behind. By implementing the precautionary measures against virus-laden aerosols, 9 out of 17 SDGs can be facilitated.

Development of pro-environment inner traits and skills not only facilitates the essential paradigm shift but also expedites attainment of related SDGs. To accomplish the essential paradigm shift in disease control at the individual, regional, national, and global levels, it necessitates all global citizens to be informed and comprehend the importance of clean and pathogen-free air we share on this planet. In addition to the pro-environmental inner traits, other inner traits and skills, such as those outlined in the framework of the Inner Development Guide (IDG) (Inner Development Goals, 2025, with relevant IDG skills designated in *italic* in the following paragraphs), also contribute to expediting the paradigm shift and attaining a healthy and sustainable environment on the planetary level.

For instance, it is crucial for people to raise their *self-awareness* with respect to the air quality in their immediate environment. Also, since the airborne transmission pathway has been largely underestimated in the past few decades, cultivating an *openness and learning mindset* (Duchi et al., 2020; Tang et al., 2017) and divergent thinking (Giancola et al., 2024) enable individuals to be receptive to multidisciplinary scientific knowledge regarding virus-laden aerosols. The development of *critical thinking* helps people evaluate and adopt proper precautionary actions against virus-laden aerosols in their environments to safeguard themselves and others from infection. The concept of shared air (Peng et al., 2022) nurtures *systems thinking*, which is crucial to establishing a holistic perspective on the significance of clean air for personal and planetary well-being (Fleury-Bahi et al., 2017) and one's sense of *connectedness* with others and the environment (Frantz et al., 2005). Development of these inner traits, which include fostering a pro-environment masculine–feminine balanced characteristics across all genders, in turn facilitates the cultivation of an *inner compass* and reinforces *empathy and compassion* toward others' suffering from COVID-19 (Inner Development Goals, 2025). Development of these IDG skills may help guide the essential paradigm shifts from people's inner *perspective skills* towards pro-environmental attitudes and behaviours (Barbaro and Pickett, 2016; De Groot et al., 2021; Duong and Pensini, 2023), eventually inspiring people to *leading and enabling changes*, in this case, the prevention of airborne transmission of pathogen-laden aerosols, to establish a clean, pathogen-free, and sustainable air environment (Di Fabio and Kenny, 2021).

Moreover, as airborne transmission of virus-laden aerosols involves multi-disciplinary knowledge and expertise, it is crucial for people from different disciplines, occupations, cultures, and countries to keep *humility* and cultivate an *inclusive mindset and intercultural competence*, and *communication skills* (Evely et al., 2010; Videras et al., 2012), to *co-create a long-term orientation and visioning* of a clean and pathogen-free atmospheric environment. This tendency can be further understood through the cultural contexts of participants from different countries, as culture fundamentally shapes how people respond to public health crises like COVID-19 (Lu et al., 2021). Certain countries represented in our sample, including Indonesia, the Philippines, Malaysia, and Taiwan, are characterized as culturally "tight," exhibiting strong social norms and high expectations for compliance (Gelfand et al., 2011, 2021; Uz, 2015). Because cultural tightness is associated with greater adherence to collective-level interventions during COVID-19 (Dong et al., 2021), participants' preference for environmental control measures may reflect shared orientations toward collective action and community-level protection. Developing and strengthening *communication* and *collaboration skills* may further cultivate the attitude and behaviour transformations necessary for broad acceptance and implementation of aerosol precautions with *conscious use of resources*, ultimately supporting a smooth paradigm shift in disease control and prevention at the collective, planetary level.

Finally, engaging the aerosol precautions with *integrity and authenticity*, *proactivity*, *courage* and *creativity* in problem-solving when confronting various environmental settings, while maintaining *hope and optimism* and *resilience* warrants the necessary attitude and behaviour changes at both individual and collective levels, to accomplish the paradigm shift towards a sustainable, pathogen-free living environment for all.

Limitations and future research

This study examined the effectiveness of text, explainer comics, and animation in enhancing knowledge of virus-laden aerosols and promoting willingness to adopt five preventive measures across countries, occupations, and genders. All media formats significantly improved knowledge, with explainer comics and animation outperforming plain text. Moreover, animation shows a relatively stronger effect on increasing willingness to adopt precautions. Media effectiveness on willingness varied by country, reflecting cultural influences. While no single medium was found universally effective, animation appears most effective for females. Across all groups, environmental control measures, such as air filtration and UV disinfection, were generally preferred.

The key findings reported in this study provide crucial insights for disease control and prevention agencies and governmental authorities to refine the science education strategies and curriculum related to airborne transmission diseases, enhancing the efficiency and effectiveness in pandemic and epidemic control, and preventing future pandemics. Additionally, the analysis indicates a higher willingness among participants to adopt environmental over personal control measures, emphasizing the need to optimize environmental control technologies and, in the meantime, to reinforce community education and communication to highlight the importance and effectiveness of personal control measures. A multicultural and multimodal approach in science communication emerges as a highly promising strategy to facilitate the paradigm shifts and positive responses across diverse cultural contexts, expediting the essential paradigm shift in disease control and prevention.

Future research could draw more explicitly on cognitive-bias frameworks in narrative design (e.g., social, survival, and counterintuitive information; Little and Dunstone, 2025) and systematically test not only their effects on knowledge and willingness, but also on trust, emotional well-being, and perceived integrity of science communication.

Finally, we mark the significance of adopting precautions to boost 9 out of 17 SDGs for a more sustainable future, while highlighting the importance of numerous inner traits and skills outlined in the IDG framework that serve as pivotal factors in catalysing the implementation of precautions, facilitating a paradigm shift in disease control and prevention. Finally, we underscore the importance of providing quality education and communication materials to effectively convey key scientific knowledge to all global citizens, fostering the necessary paradigm shift, and ultimately a clean, pathogen-free, and sustainable environment for all at both the individual and planetary level.

Data availability

All data are available in a public database, Survey Research Data Archive, housed in Academia Sinica (accession https://srda.sinica.edu.tw/search/metadata/detail/E11201).

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Conceptualization: Paichi Pat Shein, Chia C. Wang, Jepri Ali Saiful, and Yuh-Yuh Li. Methodology: Paichi Pat Shein, Yuh-Yuh Li, Jepri Ali Saiful, and Chia C. Wang. Investigation: Paichi Pat Shein, Jepri Ali Saiful, Yuh-Yuh Li, Yahaya M. Normi, Yuni Gayatri, Septian Galuh Winata, Muhammad Anas, Azren Aida Asmawi, Ahmad Syarkowi, Wei-Lun Tsai, Mohd Basyaruddin Abdul Rahman, and Chia C. Wang. Visualization: Chia C. Wang, Paichi Pat Shein, Yuh-Yuh Li. Funding acquisition: Chia C. Wang and Paichi Pat Shein. Project administration: Paichi Pat Shein. Supervision: Paichi Pat Shein and Chia C. Wang. Writing—original draft: Paichi Pat Shein, Jepri Ali Saiful, Yuh-Yuh Li and Chia C. Wang. Writing—review and editing: Paichi Pat Shein, Chia C. Wang, Jepri Ali Saiful, Yuh-Yuh Li, Yahaya M. Normi, Yuni Gayatri, Septian Galuh Winata, Muhammad Anas, Azren Aida Asmawi, Ahmad Syarkowi, Wei-Lun Tsai, and Mohd Basyaruddin Abdul Rahman.

Ethical approval

This study was conducted in accordance with the Declaration of Helsinki on ethical principles for research involving human participants, with particular reference to Article 23 (paragraph 3) concerning prior approval by a research ethics committee. As an international collaborative project involving participants from Indonesia, Malaysia, the Philippines, and Taiwan, ethical clearance was obtained from the competent review boards in each participating country. In Taiwan, the sponsoring country, approval was granted by the Institutional Review Board of National Cheng Kung University (NCKU) on 17 May 2022 (Approval No. NCKU HREC-E-111-096-2). In Indonesia, ethical approval was secured from the Ethics Committee of STIKES PEMKAB Jombang on 6 June 2022 (Approval No. 0522060004/KEPK/STIKES-PEMKAB/JBG/VI/2022). In the Philippines, the study was approved by the University of Makati Research Ethics Committee on 22 May 2023 (Approval No. 8/UMREC/2023). In Malaysia, approval was obtained from the Ethics Committee for Research Involving Human Subjects at Universiti Putra Malaysia on 17 June 2022 (Approval No. JKEUPM-2022-314). The scope of these approvals encompasses the study protocol, participant recruitment procedures, informed consent process, data collection instruments, cross-national data transfer arrangements, and safeguards for confidentiality and data protection.

Informed consent

All participants were provided with an informed consent form embedded within the online survey platform. In Taiwan, Indonesia, and Malaysia, consent was obtained beginning on 20 June 2022. Following completion of data collection in these three countries, the study continued in the Philippines, where participants provided consent starting on 25 May 2023. In all cases, consent was obtained only after formal ethical approval had been granted by the respective review committees in each participating country. Participation was entirely voluntary. Respondents were informed of their right to decline participation or withdraw at any stage without penalty. The consent form outlined the study's objectives, potential risks and anticipated benefits, and ensured that participants received sufficient information prior to enrolment. It further specified that personal data would be treated confidentially, used exclusively for research purposes, and could be withdrawn upon request without adverse consequences.

Competing interests

The authors declare no competing interests.

Additional information

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