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Examining the cultural influence on online stances towards COVID-19 preventive measures and their impact on incidence and mortality: A global stance detection analysis of tweets

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A R T I C L E I N F O

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A B S T R A C T

During the COVID-19 pandemic, nations implemented various preventive measures, triggering varying online responses. This study examines cultural influences on public online stances toward these measures and their impacts on COVID-19 cases/deaths. Stance detection analysis was used to analyze 16,428,557 Tweets regarding COVID-19 preventive measures from 95 countries, selected based on Hofstede's cultural dimensions. To ensure the variety of population, countries were chosen based on Twitter data availability and a minimum sample size of 385 tweets, achieving a 95% confidence level with a 5% margin of error. The weighted regression analysis revealed that the relationship between culture and online stances depends on the cultural congruence of each measure. Specifically, power distance positively predicted stances for all measures, while indulgence had a negative effect overall. Effects of other cultural indices varied across measures. Individualism negatively affected face coverings stances. Uncertainty avoidance influenced lockdown and vaccination stances negatively but had a positive effect on social distancing stances. Long-term orientation negatively affected lockdown and social distancing stances but positively influenced quarantine stances. Cultural tightness only negatively affected face coverings and quarantine stances. Online stances toward face coverings mediated the relationship between cultural indices and COVID-19 cases/deaths. As such, public health officials should consider cultural profiles and use culturally congruent communication strategies when implementing preventive measures for future pandemics. Furthermore, leveraging digital tools is vital in navigating and shaping online stances to enhance the effectiveness of these measures.

1. Introduction

The COVID-19 pandemic, characterized by its high transmissibility, has led to significant global health challenges and a substantial number of fatalities. As a crucial strategy to combat the spread of the virus, various countries have adopted and implemented preventive measures. Research indicates significant variations in COVID-19 cases and fatalities across nations with different cultural backgrounds. For instance, cultures higher in individualism[1] and cultural looseness[2] tend to have higher incidence and mortality rates of COVID-19 (Gelfand et al., 2021; Maaravi et al., 2021). Power distance,[3] individualism, and indulgence have also been found to predict COVID-19 case rates in different regions (Gokmen et al., 2021; Messner, 2020).

Notwithstanding these findings, the underlying mechanisms driving

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[1] Individualism, as the opposite to collectivism, is the degree to which people in a society are integrated into groups (Hofstede, 2011).

[2] Cultural looseness is the opposite of cultural tightness, which refers to a construct with strong social norms and sanctions for inappropriate behavior (Gelfand et al., 2006).

[3] Power distance is defined as the extent to which the less powerful members of organizations and institutions accept and expect that power is distributed unequally (Hofstede, 2011).

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Table 1
List of 95 countries used for analysis.

Albania (AL)	Argentina (AR)	Australia (AU)	Austria (AT)	Bangladesh (BD)
Belgium (BE)	Bolivia (BO)	Brazil (BR)	Bulgaria (BG)	Canada (CA)
Chile (CL)	China (CN)	Colombia (CO)	Costa Rica (CR)	Croatia (HR)
Czech Republic (CZ)	Denmark (DK)	Ecuador (EC)	Egypt (EG)	El Salvador (SV)
Estonia (EE)	Ethiopia (ET)	Fiji (FJ)	Finland (FI)	France (FR)
Georgia (GE)	Germany (DE)	Ghana (GH)	Greece (GR)	Guatemala (GT)
Hong Kong (HK)	Hungary (HU)	India (IN)	Indonesia (ID)	Iran (IR)
Iraq (IQ)	Ireland (IE)	Israel (IL)	Italy (IT)	Jamaica (JM)
Japan (JP)	Jordan (JO)	Kazakhstan (KZ)	Kuwait (KW)	Latvia (LV)
Luxembourg (LU)	Malaysia (MY)	Malta (MT)	Mexico (MX)	Morocco (MA)
Namibia (NA)	Nepal (NP)	Netherlands (NL)	New Zealand (NZ)	Nigeria (NG)
Macedonia (MK)	Norway (NO)	Pakistan (PK)	Panama (PA)	Peru (PE)
Philippines (PH)	Poland (PL)	Portugal (PT)	Qatar (QA)	Bosnia and Herzegovina (BA)
Romania (RO)	Russia (RU)	Saudi Arabia (SA)	Senegal (SN)	Serbia (RS)
Sierra Leone (SL)	Singapore (SG)	Slovakia (SK)	Slovenia (SI)	South Africa (ZA)
South Korea (KR)	Spain (ES)	Suriname (SR)	Sweden (SE)	Switzerland (CH)
Syria (SY)	Taiwan (TW)	Thailand (TH)	Trinidad and Tobago (TT)	Turkey (TR)
Uganda (UG)	Ukraine (UA)	United Arab Emirates (AE)	United Kingdom (GB)	United States (US)
Uruguay (UY)	Venezuela (VE)	Vietnam (VN)	Zambia (ZM)	Zimbabwe (ZW)

Table 2
Evaluation of pre- and post-fine-tuned RoBERTa for stance detection.

	Pre-fine-tuned RoBERTa			Post-fine-tuned RoBERTa		
	Precision	Recall	F1-Score	Precision	Recall	F1-Score
Against	0.77	0.92	0.84	0.89	0.92	0.90
Neither	0.62	0.67	0.65	0.93	0.83	0.88
Favor	0.80	0.58	0.67	0.87	0.92	0.89
Accuracy	0.73			0.89		

these trends warrant further exploration. One crucial determinant influencing COVID-19 cases and deaths is people's responses to preventive measures. Governments worldwide have implemented various preventive measures, including economic shutdowns, mask mandates, quarantines, and social distancing, to slow the virus spread. A comprehensive review of 348 articles demonstrates the importance and effectiveness of preventive measures in reducing the virus's spread and mortality rates (Perra, 2021). But the effectiveness of these measures depends on individuals' willingness to adhere to them. Therefore, it is crucial to investigate how cultural factors influence individuals' responses to preventive measures, thereby impacting COVID-19 cases and deaths.

Scattered research has explored the influence of cultural dimensions on responses to a limited range of preventive measures. For example, studies conducted in the United States and Canada revealed associations between collectivism and adherence to stay-at-home and mask-wearing (Card, 2022; Kemmelmeier & Jami, 2021). Higher uncertainty avoidance[4] linked to increased vaccine hesitancy (Lu, 2023) but quicker adoption of social distancing measures (Ashraf et al., 2022) and fewer gatherings in public spaces (Huynh, 2020). Countries with stronger long-term orientation[5] implemented less strict social distancing measures (Ashraf et al., 2022) and had lower acceptance of lockdown (Ma et al., 2022). However, these findings are fragmented, lacking a comprehensive understanding of how cultural dimensions collectively impact online opinion on various preventive measures. Furthermore, traditional methodologies like surveys and archival databases make it challenging to establish clear connections between online responses and COVID-19 cases/deaths at the country level.

Examining existing knowledge, we contend that a consistent pattern emerges, in which people's responses tend to align with prevailing cultural values and norms (Zou et al., 2009). The foundation of this argument is rooted in the Cultural Theory within the domain of policy preference studies, anchored by the seminal works of Thompson et al.

(1990) and the contributions of Douglas and Wildavsky (1983), and Wildavsky (1987). According to the Cultural Theory, cultural worldviews are individuals' general beliefs in social relationships and perspectives towards unfolding events. In specific situations, they influence individuals' attitudes and perspectives toward events (Dake, 1992). It is through these prisms that cultural values and beliefs significantly influence policy preferences, as public policy is an institutional tool to address societal issues and shape social relationships. Such preferences for particular policies are not the result of simplistic benefit-cost calculation; instead, they stem from a more profound contemplation of how policies resonate with or disrupt their chosen lifestyle or "way of life" (Jenkins-Smith & Herron, 2009; Kahan et al., 2010; Lodge et al., 2010; Silva & Jenkins-Smith, 2007; Swedlow, 2011). Accordingly, Cultural Theory postulates that these ingrained cultural biases form the backbone of policy preferences, resulting in what (Wildavsky, 1987) termed as culturally constrained rationalities.

Further, Cultural Theory's resonance within the policy realm also intersects with Social and Cognitive Psychology Theories. Culture, functioning as a cognitive lens, plays a pivotal role in interpreting public policies, providing crucial cues for public comprehension Hoppe (2010). Therefore, cultural perspectives precede factual information, influencing the formulation of beliefs about policy outcomes. In other words, people's collective perceptions of these policies' impacts are deeply embedded in their cultural worldviews. This acceptance or rejection of empirical claims pertaining to controversial policies is thus influenced by a range of psychological mechanisms and reflects the populace's vision of an ideal society (Douglas & Wildavsky, 1982). In this way, cultural values serve as heuristic guides in the rational processing of public policy information. They provide guidelines for people to accept or not accept certain ways of doing things in specific circumstances (Feather, 1995). This cognitive processing works through cultural schemes stored in the human brain, allowing individuals to efficiently categorize, process, and interpret communications that align with their cultural backgrounds (D'Andrade, 1992). Moreover, Cultural Theory also posits that cultural worldviews can be geographically pinpointed (e.g. (Ney & Verweij, 2014),), laying the theoretical and methodological foundation for utilizing Hofstede's cultural dimensions as predictive

[4] Uncertainty avoidance indicates to what extent a culture programs its members to feel either uncomfortable or comfortable in unstructured situations (Hofstede, 2011).

[5] Long-term orientation refers to a society's tendency to foster virtues oriented towards future rewards, in particular, perseverance and thrift. It's a dimension that contrasts with a closer focus on immediate or short-term gains and the honoring of traditions and social obligations (Hofstede, 2011).

Table 3
Weighted regression of face covering stance with hofstede culture.

Hofstede Culture	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	3.36 (3.09–3.62); $p <$ 0.001	3.30 (3.00–3.60); $p <$ 0.001	3.31 (3.01–3.61); $p <$ 0.001	3.31 (3.00–3.61); $p <$ 0.001	3.31 (3.00–3.61); $p <$ 0.001	3.30 (2.99–3.60); $p <$ 0.001
Power Distance	0.24 (0.00–0.00); $p =$ 0.023	0.30 (0.00–0.01); $p =$ 0.013	0.31 (0.00–0.01); $p =$ 0.012	0.27 (0.00–0.01); $p =$ 0.038	0.27 (0.00–0.01); $p =$ 0.038	0.30 (0.00–0.01); $p =$ 0.020
Uncertainty Avoidance	−0.03 (−0.00 to 0.00); $p = 0.638$	−0.02 (−0.00 to 0.00); $p = 0.768$	−0.04 (−0.00 to 0.00); $p = 0.591$	−0.00 (−0.00 to 0.00); $p = 0.965$	−0.00 (−0.00 to 0.00); $p = 0.970$	−0.02 (−0.00 to 0.00); $p = 0.774$
Individualism	−0.52 (−0.01 to −0.00); $p < 0.001$	−0.48 (−0.01 to −0.00); $p = 0.002$	−0.50 (−0.01 to −0.00); $p = 0.002$	−0.509 (−0.01 to −0.00); $p = 0.002$	−0.51 (−0.01 to −0.00); $p = 0.002$	−0.48 (−0.01 to −0.00); $p = 0.003$
Masculinity	−0.02 (−0.00 to 0.00); $p = 0.319$	0.01 (−0.00 to 0.00); 0.92	0.01 (−0.00 to 0.00); $p = 0.890$	−0.00 (−0.00 to 0.00); $p = 0.968$	−0.00 (−0.00 to 0.00); $p = 0.965$	0.01 (−0.00 to 0.00); $p = 0.921$
Long-Term Orientation	−0.06 (−0.00 to 0.00); $p = 0.319$	−0.11 (−0.00 to 0.00); $p = 0.131$	−0.10 (−0.00 to 0.00); $p = 0.169$	−0.114 (−0.00 to 0.00); $p = 0.130$	−0.11 (−0.00 to 0.00); $p = 0.130$	−0.11 (−0.00 to 0.00); $p = 0.138$
Indulgence	−0.37 (−0.01 to −0.00); $p < 0.001$	−0.38 (−0.01 to −0.00); $p < 0.001$	−0.38 (−0.01 to −0.00); $p < 0.001$	−0.351 (−0.01 to −0.00); $p < 0.001$	−0.35 (−0.01 to −0.00); $p < 0.001$	−0.38 (−0.01 to −0.00); $p < 0.001$
Population Size Estimate	.	−0.02 (−0.03 to 0.02); $p = 0.778$	−0.03 (−0.03 to 0.02); $p = 0.690$	−0.03 (−0.03 to 0.02); $p = 0.751$	−0.03 (−0.03 to 0.02); $p = 0.751$	−0.02 (−0.03 to 0.02); $p = 0.782$
Percent Migrants	.	0.03 (−0.04 to 0.06); $p = 0.721$	0.04 (−0.04 to 0.06); $p = 0.663$	0.03 (−0.04 to 0.06); $p = 0.743$	0.03 (−0.04 to 0.06); $p = 0.743$	0.03 (−0.04 to 0.06); $p = 0.728$
Gini Coefficient	.	−0.09 (−0.05 to 0.01); $p = 0.199$	−0.10 (−0.05 to 0.01); $p = 0.174$	−0.10 (−0.05 to 0.01); $p = 0.161$	−0.11 (−0.05 to 0.01); $p = 0.159$	−0.09 (−0.05 to 0.01); $p = 0.210$
GDP Per Capita	.	0.02 (−0.05 to 0.05); $p = 0.867$	0.04 (−0.04 to 0.06); $p = 0.803$	0.02 (−0.05 to 0.05); $p = 0.875$	0.02 (−0.05 to 0.05); $p = 0.875$	0.02 (−0.05 to 0.05); $p = 0.871$
Political Authoritarianism	.	0.09 (−0.02 to 0.08); $p = 0.213$	0.08 (−0.02 to 0.08); $p = 0.251$	0.08 (−0.02 to 0.08); $p = 0.264$	0.08 (−0.02 to 0.08); $p = 0.265$	0.09 (−0.02 to 0.08); $p = 0.221$
All-Cause Mortality Rate	.	−0.04 (−0.06 to 0.04); $p = 0.63$	−0.03 (−0.06 to 0.04); $p = 0.745$	−0.03 (−0.06 to 0.04); $p = 0.737$	−0.03 (−0.06 to 0.04); $p = 0.739$	−0.04 (−0.06 to 0.04); $p = 0.638$
Population Density	.	.	−0.04 (−0.08 to 0.04); $p = 0.527$	.	.	.
Containment Health	.	.	.	0.05 (−0.03 to 0.06); $p = 0.504$	.	.
Economic Support	.	.	.	.	0.05 (−0.03 to 0.07); $p = 0.493$	.
Government Stringency	.	.	.	.	.	−0.00 (−0.05 to 0.04); $p = 0.971$
Observations	77	74	74	73	73	73
R^2	0.83	0.85	0.85	0.85	0.85	0.85
Adjusted R^2	0.81	0.82	0.82	0.82	0.82	0.82
Residual *SE*	10.41 (70)	10.43 (61)	10.48 (60)	10.56 (59)	10.56 (59)	10.60 (59)
F Statistic	55.85 (6, 70); $p <$ 0.001	28.49 (12, 61); $p <$ 0.001	26.08 (13, 60); $p <$ 0.001	25.67 (13, 59); $p <$ 0.001	25.68 (13, 59); $p <$ 0.001	25.44 (13, 59); $p <$ 0.001

Note: The analysis is to evaluate the association between the Hofstede Culture and the face-covering stances for 77 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AU, AT, BD, BE, BO, BR, BG, CA, CL, CN, CO, HR, CZ, DK, EG, SV, EE, FI, FR, GE, DE, GH, GR, HK, HU, IN, ID, IR, IQ, IE, IT, JP, JO, KZ, LV, LU, MY, MT, MX, MA, NL, NZ, NG, MK, NO, PK, PE, PH, PL, PT, BA, RO, RU, SA, RS, SG, SK, SI, ZA, KR, ES, SE, CH, TW, TH, TT, TR, UA, AE, GB, US, UY, VE, VN, ZM.

tools for public response in an online milieu.

In addition, Cultural Norm Theory offers further insights into the diverse responses observed across cultures. This theory posits that distinct cultural norms influence normative behaviors, leading to varied levels of adherence to specific behaviors (Chiu et al., 2010; Fischer et al., 2009; Wan et al., 2007; Zou et al., 2009). For example, individualistic cultures, which endorse self-oriented norms, typically promote behaviors that emphasize personal independence and autonomy. Conversely, collectivistic cultures advocate others-oriented norms, which support behaviors focused on social connectedness, communal responsibilities, and social obligations (Hofstede, 1983; Hui & Triandis, 1986; Markus & Kitayama, 2014; Wan et al., 2007). These norms can lead individualistic societies to prioritize self-centric norms, whereas collectivistic societies are inclined towards group-centric norms (Triandis, 1995). Research indicates that the cultural values associated with these norms impact societal expectations about which social behaviors are considered desirable or acceptable. For example, socially desired traits in individualistic cultures like independence and assertiveness are not endorsed as socially desirable in collectivistic cultures, as found in Japan (Sugihara & Katsurada, 2002) and China (Chia et al., 1994). Therefore, in cultures where independence is highly valued, public health mandates like mask-wearing and social distancing may be perceived as impositions on personal freedom, potentially leading to more negative attitudes. In contrast, in societies where community welfare and collective responsibility are emphasized, there tends to be greater adherence to such measures, viewing them as necessary for the common good. These underlying cultural predispositions not only shape immediate reactions to public health directives but also influence the long-term acceptance and effectiveness of these strategies, thereby impacting the overall success of the response to health crises.

With this understanding as our backdrop, it is hypothesized that people's responses to preventive measures in times of crises, such as the COVID-19 pandemic, will vary across cultures, depending on how these interventions correspond with the cultural values and norms of each society. Consequently, cultural factors' impact on preventive behaviors has downstream effects on public health outcomes, such as case counts and mortality rates from COVID-19. This prompts an exploration via mediation analyses to uncover which preventive measures link the path between cultural constructs and the pandemic's health outcomes, from the onset of the COVID-19 pandemic on March 11, 2020, when the World Health Organization officially declared the pandemic, until December 1, 2021, when preventive measures began to be lifted.

Our research significantly contributes to advancing the understanding of the alignment of preventive measures with nation-level cultural values and norms and its subsequent impact on COVID-19 cases and deaths. This nuanced insight holds substantial value for governments and policymakers in formulating and implementing culturally appropriate policies to manage public health crises effectively. It also

Table 4
Weighted regression of lockdown stance with hofstede culture.

Hofstede Culture	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	3.31 (2.89–3.74); $p <$ 0.001	3.52 (3.10–3.95); $p <$ 0.001	3.56 (3.14–3.98); $p <$ 0.001	3.55 (3.11–4.00); $p <$ 0.001	3.55 (3.10–4.00); $p <$ 0.001	3.51 (3.05–3.97); $p <$ 0.001
Power Distance	0.33 (0.00–0.01); $p =$ 0.049	0.51 (0.00–0.01); $p =$ 0.005	0.55 (0.00–0.01); $p <$ 0.001	0.45 (0.00–0.01); $p =$ 0.031	0.46 (0.00–0.01); $p =$ 0.030	0.53 (0.00–0.01); $p =$ 0.013
Uncertainty Avoidance	−0.40 (−0.01 to −0.00); $p < 0.001$	−0.55 (−0.01 to −0.00); $p < 0.001$	−0.62 (−0.01 to −0.01); $p < 0.001$	−0.53 (−0.01 to −0.00); $p < 0.001$	−0.54 (−0.01 to −0.00); $p < 0.001$	−0.55 (−0.01 to −0.00); $p < 0.001$
Individualism	−0.13 (−0.00 to 0.00); $p = 0.495$	−0.29 (−0.00 to 0.00); $p = 0.148$	−0.36 (−0.01 to 0.00); $p = 0.069$	−0.33 (−0.01 to 0.00); $p = 0.130$	−0.32 (−0.01 to 0.00); $p = 0.138$	−0.27 (−0.01 to 0.00); $p = 0.213$
Masculinity	0.16 (−0.00 to 0.01); $p = 0.104$	0.20 (0.00–0.01); $p =$ 0.024	2.00 (0.00–0.01); $p =$ 0.026	0.18 (0.00–0.01); $p =$ 0.067	0.19 (0.00–0.01); $p =$ 0.063	0.21 (0.00–0.01); $p =$ 0.031
Long-Term Orientation	−0.07 (−0.00 to 0.00); $p = 0.520$	−0.25 (−0.01 to −0.00); $p = 0.023$	−0.21 (−0.00 to −0.00); $p = 0.052$	−0.27 (−0.01 to −0.00); $p = 0.022$	−0.26 (−0.01 to −0.00); $p = 0.023$	−0.25 (−0.01 to −0.00); $p = 0.030$
Indulgence	−0.43 (−0.01 to −0.00); $p < 0.001$	−0.55 (−0.01 to −0.00); $p < 0.001$	−0.55 (−0.01 to −0.00); $p < 0.001$	−0.50 (−0.01 to −0.00); $p = 0.003$	−0.50 (−0.01 to −0.00); $p = 0.003$	−0.56 (−0.01 to −0.00); $p < 0.001$
Population Size Estimate	.	−0.19 (−0.09 to −0.00); $p = 0.042$	−0.22 (−0.10 to −0.01); $p = 0.022$	−0.19 (−0.09 to −0.00); $p = 0.047$	−0.19 (−0.92 to −0.00); $p = 0.047$	−0.19 (−0.09 to −0.00); $p = 0.047$
Percent Migrants	.	0.19 (−0.01 to 0.12); $p = 0.112$	0.22 (−0.01 to 0.12); $p = 0.084$	0.20 (−0.01 to 0.12); $p = 0.113$	0.20 (−0.01 to 0.12); $p = 0.114$	0.19 (−0.02 to 0.12); $p = 0.141$
Gini Coefficient	.	−0.26 (−0.07 to −0.01); $p = 0.011$	−0.27 (−0.07 to −0.01); $p = 0.006$	−0.28 (−0.07 to −0.01); $p = 0.012$	−0.28 (−0.74 to −0.01); $p = 0.014$	−0.25 (−0.07 to −0.01); $p = 0.014$
GDP Per Capita	.	−0.02 (−0.07 to 0.06); $p = 0.938$	0.02 (−0.06 to 0.07); $p = 0.925$	−0.04 (−0.07 to 0.06); $p = 0.835$	−0.04 (−0.07 to 0.06); $p = 0.851$	−0.01 (−0.07 to 0.06); $p = 0.975$
Political Authoritarianism	.	−0.08 (−0.10 to 0.04); $p = 0.363$	−0.11 (−0.11 to 0.03); $p = 0.243$	−0.09 (−0.11 to 0.04); $p = 0.334$	−0.09 (−0.10 to 0.04); $p = 0.342$	−0.08 (−0.10 to 0.04); $p = 0.374$
All-Cause Mortality Rate	.	0.41 (0.05–0.19); $p =$ 0.001	0.44 (0.06–0.19); $p <$ 0.001	0.42 (0.05–0.19); $p =$ 0.001	0.42 (0.05–0.19); $p =$ 0.001	0.41 (0.05–0.19); $p =$ 0.002
Population Density	.	.	−0.15 (−0.17 to 0.01); $p = 0.081$	.	.	.
Containment Health Index	.	.	.	0.08 (−0.05 to 0.09); $p = 0.606$	.	.
Economic Support Index	.	.	.	.	0.06 (−0.06 to 0.09); $p = 0.663$	.
Government Stringency	.	.	.	.	.	−0.02 (−0.07 to 0.06); $p = 0.852$
Observations	77	74	74	73	73	73
R^2	0.53	0.69	0.7	0.69	0.69	0.69
Adjusted R^2	0.49	0.63	0.64	0.62	0.62	0.62
Residual *SE*	20.72 (70)	18.02 (61)	17.71 (60)	18.28 (59)	18.30 (59)	18.32 (59)
F Statistic	13.03 (6, 70); $p <$ 0.001	11.24 (12, 61); $p <$ 0.001	10.98 (13, 60); $p <$ 0.001	10.10 (13, 59); $p <$ 0.001	10.08 (13, 59); $p <$ 0.001	10.04 (13, 59); $p <$ 0.001

Note: The analysis is to evaluate the association between the Hofstede Culture and the lockdown stances for 77 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AU, AT, BD, BE, BO, BR, BG, CA, CL, CN, CO, HR, CZ, DK, EG, SV, EE, FI, FR, GE, DE, GH, GR, HK, HU, IN, ID, IR, IQ, IE, IT, JP, JO, KZ, LV, LU, MY, MT, MX, MA, NL, NZ, NG, MK, NO, PK, PE, PH, PL, PT, BA, RO, RU, SA, RS, SG, SK, SI, ZA, KR, ES, SE, CH, TW, TH, TT, TR, UA, AE, GB, US, UY, VE, VN, ZM.

aids in developing targeted and impactful messaging strategies for individuals from diverse cultural backgrounds during the COVID-19 pandemic, post-pandemic period, and future public health emergencies. The pathways that act as intermediaries between culture and COVID-19 cases and deaths hold the potential as focal points for future public health preventive interventions.

In terms of methodology, our study introduces innovative approaches by leveraging AI technologies to analyze large-scale global data. This approach overcomes the limitations of traditional survey-based research, enhancing the representativeness and generalizability of our findings and creating the possibility to link national culture and people's sentiments with country-level public health data such as cases and deaths. To the best of our knowledge, this is the first study to offer a comprehensive examination of the online stance toward different preventive measures in a global context during the pandemic and their impacts on country-level public health outcomes.

2. Methods

2.1. Preventive measures

Our study investigates the five primary nationwide public health preventive measures: social distancing, vaccination, lockdown, quarantine/isolation, and face covering. Please refer to Appendix A in the supplementary materials for a detailed justification and comprehensive definitions of these measures.

2.1.1. Country and culture coverage

Initially, 119 countries were identified with available Hofstede's cultural indices and 68 countries with cultural tightness indices Gelfand et al. (2006). Considering the overlap between the datasets, a combined initial pool of 124 countries was yielded. To ensure statistical robustness and representativeness, we applied the required sample size criteria Israel (1992), calculating the minimum sample size "n" using the formula:

$$n = \frac{Z2 \cdot p \cdot (1 - p)}{E2}$$

where "*Z*" is the critical value for confidence, "*p*" is the estimated proportion, and "*E*" is the desired margin of error. São Tomé and Príncipe, with a population of 219,000, had the smallest population among all identified countries. Thus, it required a minimum sample size of 385. As a result, the minimum sample size threshold was set to 385 for each country to ensure statistical robustness and representativeness at a 95% confidence level with a 5% margin of error and accounting for variability Israel (1992). Applying this criterion, we kept 95 countries that met the specified sample size requirements in the analysis. The country names are provided in Table 1. For these countries, all their English

Table 5
Weighted regression of quarantine stance with hofstede culture.

Hofstede Culture	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	2.85 (2.43–3.27); $p <$ 0.001	2.93 (2.51–3.34); $p <$ 0.001	2.93 (2.50–3.35); $p <$ 0.001	2.93 (2.50–3.35); $p <$ 0.001	2.93 (2.50–3.35); $p <$ 0.001	2.92 (2.50–3.35); $p <$ 0.001
Power Distance	0.13 (−0.00 to 0.00); $p = 0.539$	0.48 (0.00–0.01); $p =$ 0.030	0.48 (0.00–0.01); $p =$ 0.033	0.50 (0.00–0.01); $p =$ 0.027	0.50 (0.00–0.01); $p =$ 0.027	0.50 (0.00–0.01); $p =$ 0.028
Uncertainty Avoidance	0.17 (−0.00 to 0.00); $p = 0.192$	0.04 (−0.002 to 0.00); $p = 0.762$	0.04 (−0.00 to 0.00); $p = 0.791$	0.03 (−0.00 to 0.00); $p = 0.813$	0.03 (−0.00 to 0.00); $p = 0.812$	0.04 (−0.00 to 0.00); $p = 0.797$
Individualism	−0.18 (−0.00 to 0.00); $p = 0.450$	−0.54 (−0.01 to −0.00); $p = 0.053$	−0.54 (−0.01 to −0.00); $p = 0.061$	−0.50 (−0.01 to 0.00); $p = 0.081$	−0.50 (−0.01 to 0.00); $p = 0.080$	−0.50 (−0.01 to 0.00); $p = 0.082$
Masculinity	0.18 (−0.0 to 0.01); $p = 0.143$	0.19 (0.00–0.01); $p =$ 0.085	0.19 (0.00–0.01); $p =$ 0.088	0.19 (0.00–0.01); $p =$ 0.090	0.19 (0.00–0.01); $p =$ 0.090	0.19 (0.00–0.01); $p =$ 0.089
Long-Term Orientation	0.24 (0.00–0.00); $p =$ 0.055	0.26 (0.00–0.01); $p =$ 0.04	0.26 (0.00–0.01); $p =$ 0.048	0.26 (0.00–0.01); $p =$ 0.045	0.26 (0.00–0.01); $p =$ 0.046	0.26 (0.00–0.01); $p =$ 0.048
Indulgence	−0.20 (−0.00 to 0.00); $p = 0.150$	−0.39 (−0.01 to −0.00); $p = 0.008$	−0.39 (−0.01 to −0.00); $p = 0.008$	−0.43 (−0.01 to −0.00); $p = 0.008$	−0.43 (−0.01 to −0.00); $p = 0.008$	−0.41 (−0.01 to −0.00); $p = 0.008$
Population Size Estimate	.	−0.35 (−0.09 to −0.01); $p = 0.010$	−0.35 (−0.09 to −0.01); $p = 0.012$	−0.34 (0.09 to −0.01); $p = 0.015$	−0.34 (−0.09 to −0.01); $p = 0.015$	−0.34 (−0.09 to −0.01); $p = 0.014$
Percent Migrants	.	−0.36 (−0.17 to −0.01); $p = 0.034$	−0.36 (−0.17 to −0.01); $p = 0.037$	−0.36 (−0.17 to −0.01); $p = 0.039$	−0.36 (−0.17 to −0.01); $p = 0.039$	−0.37 (−0.16 to −0.01); $p = 0.034$
Gini Coefficient	.	0.15 (−0.02 to 0.06); $p = 0.245$	0.15 (−0.02 to 0.06); $p = 0.252$	0.17 (−0.02 to 0.07); $p = 0.213$	0.17 (−0.02 to 0.07); $p = 0.214$	0.16 (−0.02 to 0.07); $p = 0.228$
GDP Per Capita	.	0.95 (0.06–0.21); $p =$ 0.001	0.95 (0.05–0.21); $p =$ 0.001	0.94 (0.05–0.21); $p =$ 0.001	0.94 (0.05–0.21); $p =$ 0.001	0.93 (0.05–0.21); $p =$ 0.002
Political Authoritarianism	.	−0.44 (−0.18 to −0.05); $p < 0.001$	−0.44 (−0.18 to −0.05); $p < 0.001$	−0.43 (−0.18 to −0.05); $p = 0.001$	−0.43 (−0.18 to −0.05); $p = 0.001$	−0.42 (−0.18 to −0.05); $p < 0.001$
All-Cause Mortality Rate	.	0.27 (0.00 $p = 0.049$ to 0.14);	0.27 (−0.00 to 0.14); $p = 0.054$	0.25 (−0.01 to 0.14); $p = 0.078$	0.25 (−0.01 to 0.14); $p = 0.077$	0.25 (−0.01 to 0.14); $p = 0.075$
Population Density	.	.	0.05 (−0.10 to 0.10); $p = 0.985$	.	.	.
Containment Health Index	.	.	.	−0.07 (−0.07 to 0.04); $p = 0.547$	.	.
Economic Support Index	.	.	.	.	−0.07 (−0.07 to 0.04); $p = 0.558$	.
Government Stringency	.	.	.	.	.	−0.06 (−0.07 to 0.04); $p = 0.576$
Observations	77	74	74	73	73	73
R^2	0.3	0.51	0.51	0.52	0.52	0.52
Adjusted R^2	0.24	0.42	0.41	0.41	0.41	0.41
Residual *SE*	18.02 (70)	16.11 (61)	16.24 (60)	16.32 (59)	16.33 (59)	16.33 (59)
F Statistic	5.07 (6, 70); $p <$ 0.001	5.38 (12, 61); $p <$ 0.001	4.89 (13, 60); $p <$ 0.001	4.87 (13, 59); $p <$ 0.001	4.86 (13, 59); $p <$ 0.001	4.86 (13, 59); $p <$ 0.001

Note: The analysis is to evaluate the association between the Hofstede Culture and the quarantine stances for 77 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AU, AT, BD, BE, BO, BR, BG, CA, CL, CN, CO, HR, CZ, DK, EG, SV, EE, FI, FR, GE, DE, GH, GR, HK, HU, IN, ID, IR, IQ, IE, IT, JP, JO, KZ, LV, LU, MY, MT, MX, MA, NL, NZ, NG, MK, NO, PK, PE, PH, PL, PT, BA, RO, RU, SA, RS, SG, SK, SI, ZA, KR, ES, SE, CH, TW, TH, TT, TR, UA, AE, GB, US, UY, VE, VN, ZM.

tweets were collected. For those countries that do not use English as their predominant language, the data were also crawled using their own languages.

2.2. Data collection and pre-processing

To collect public responses and discussions regarding various preventive measures globally, we developed automated data crawlers to collect data from Twitter, one of the largest and most widely used social media platforms. In total, 16,428,557 posts were crawled, capturing online discussions on the implemented preventive measures from.

March 11, 2020 (when such measures commenced globally and the date that the WHO declared as a global pandemic) (Cucinotta & Vanelli, 2020) until December 1, 2021 (when such measures began to be lifted). The collected dataset underwent a process of removing duplicates, repetitive characters, hash symbols, hyperlinks, user information, and other minor cleaning tasks. Tweets containing three words or fewer were excluded as they lacked sufficient information or context. Punctuations and emojis were preserved to enhance the contextual information used for stance analysis. After preprocessing, the dataset was reduced to 7,034,026 tweets, including 6,368,582 in English and 665, 444 in non-English languages. The post distribution for each measure was as follows: lockdown - 2,335,763 tweets (33·206%), face coverings - 1,358,993 tweets (19·320%), vaccination - 1,478,083 tweets (21·01%), quarantine - 1,396,902 tweets (19·859%), and social distancing - 464, 285 tweets (6·60%). More information can be found in Appendix A.

In the case of publicly available data from platforms like Twitter, the ethical landscape differs significantly from traditional survey research. In accordance with the Protection of Human Subjects 45 CFR 46 (NationalArchives, 2024), our study's engagement with publicly accessible Twitter data is exempt from ethical approval. This regulation specifically excludes publicly available information from constituting human subjects research. This is because there is no interaction with the individuals and the information is not private. Moreover, our study employed aggregate data analysis, which does not identify individual users or their personal data. Also, no individually identifying information will be made public in replication materials. The current research has adhered to Twitter's terms of service and data use policies, which users agree to upon creating their accounts, allowing for the public dissemination of their tweets.

2.3. Multi-language tweets

Non-English posts, and keywords were translated into English using M2M-100, an advanced multilingual translation model with 1.2 billion parameters (Fan et al., 2021) to expand the collection of the dataset. M2M-100 supports low-resource languages and achieves state-of-the-art performance in multi-language translation.

Table 6
Weighted regression of social distancing stance with hofstede culture.

Hofstede Culture	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	3.12 (2.74 to 3.49); $p < 0.001$	2.93 (2.59–3.27); $p < 0.001$	2.93 (2.59 to 3.27); $p < 0.001$	2.94 (2.60 to 3.29); $p < 0.001$	2.94 (2.60 to 3.29); $p < 0.001$	2.95 (2.60 to 3.30); $p < 0.001$
Power Distance	0.34 (0.00 to 0.01); $p = 0.065$	0.96 (0.00–0.01); $p < 0.001$	0.97 (0.00 to 0.01); $p < 0.001$	0.90 (0.00 to 0.01); $p < 0.001$	0.90 (0.00 to 0.01); $p < 0.001$	0.89 (0.00 to 0.01); $p < 0.001$
Uncertainty Avoidance	0.28 (0.00 to 0.01); $p = 0.021$	0.26 (0.001–0.01); $p = 0.012$	0.25 (0.00 to 0.01); $p = 0.027$	0.29 (0.00 to 0.01); $p = 0.011$	0.29 (0.00 to 0.01); $p = 0.011$	0.29 (0.00 to 0.01); $p = 0.010$
Individualism	0.26 (−0.00 to 0.00); $p = 0.210$	−0.08 (−0.00 to 0.00); $p = 0.681$	−0.09 (−0.00 to 0.00); $p = 0.647$	−0.13 (−0.00 to 0.00); $p = 0.533$	−0.13 (−0.00 to 0.00); $p = 0.531$	−0.14 (−0.00 to 0.00); $p = 0.518$
Masculinity	0.05 (−0.00 to 0.00); $p = 0.616$	−0.01 (−0.00 to 0.00); $p = 0.870$	−0.01 (−0.00 to 0.00); $p = 0.884$	−0.03 (−0.00 to 0.00); $p = 0.738$	−0.03 (−0.00 to 0.00); $p = 0.737$	−0.03 (−0.00 to 0.00); $p = 0.770$
Long-Term Orientation	−0.39 (−0.01 to −0.00); $p = 0.001$	−0.25 (−0.00 to −0.00); $p = 0.028$	−0.24 (−0.00 to −0.00); $p = 0.040$	−0.25 (−0.00 to −0.00); $p = 0.027$	−0.25 (−0.00 to −0.00); $p = 0.027$	−0.25 (−0.00 to −0.00); $p = 0.027$
Indulgence	−0.54 (−0.01 to −0.00); $p < 0.001$	−0.62 (−0.01 to −0.00); $p < 0.001$	−0.62 (−0.01 to −0.00); $p < 0.001$	−0.56 (−0.01 to −0.00); $p < 0.001$	−0.56 (−0.01 to −0.00); $p < 0.001$	−0.58 (−0.01 to −0.00); $p < 0.001$
Population Size Estimate	.	0.16 (−0.01 to 0.05); $p = 0.195$	0.15 (−0.01 to 0.05); $p = 0.238$	0.15 (−0.01 to 0.05); $p = 0.217$	0.15 (−0.01 to 0.05); $p = 0.217$	0.15 (−0.01 to 0.05); $p = 0.228$
Percent Migrants	.	−0.14 (−0.11 to 0.04); $p = 0.330$	−0.13 (−0.11 to 0.04); $p = 0.367$	−0.14 (−0.11 to 0.04); $p = 0.333$	−0.14 (−0.11 to 0.04); $p = 0.333$	−0.12 (−0.11 to 0.04); $p = 0.386$
Gini Coefficient	.	0.05 (−0.02 to 0.04); $p = 0.663$	0.04 (−0.03 to 0.04); $p = 0.683$	0.02 (−0.03 to 0.04); $p = 0.838$	0.02 (−0.03 to 0.04); $p = 0.840$	0.04 (−0.03 to 0.04); $p = 0.705$
GDP Per Capita	.	1.19 (0.10–0.21); $p < 0.001$	1.19 (0.10–0.21); $p < 0.001$	1.17 (0.09–0.21); $p < 0.001$	1.17 (0.09–0.21); $p < 0.001$	1.17 (0.09–0.21); $p < 0.001$
Political Authoritarianism	.	−0.03 (−0.07 to 0.06); $p = 0.785$	−0.03 (−0.07 to 0.06); $p = 0.764$	−0.04 (−0.08 to 0.05); $p = 0.715$	−0.04 (−0.08 to 0.05); $p = 0.716$	−0.04 (−0.08 to 0.05); $p = 0.721$
All-Cause Mortality Rate	.	0.10 (−0.04 to 0.09); $p = 0.410$	0.11 (−0.04 to 0.10); $p = 0.392$	0.12 (−0.04 to 0.10); $p = 0.331$	0.12 (−0.04 to 0.10); $p = 0.330$	0.12 (−0.04 to 0.10); $p = 0.350$
Population Density	.	.	−0.03 (−0.09 to 0.07); $p = 0.766$	.	.	.
Containment Health Index	.	.	.	0.10 (−0.04 to 0.08); $p = 0.468$	.	.
Economic Support Index	.	.	.	.	0.10 (−0.04 to 0.08); $p = 0.463$	.
Government Stringency	.	.	.	.	.	0.09 (−0.03 to 0.08); $p = 0.417$
Observations	77	74	74	73	73	73
R^2	0.36	0.68	0.68	0.68	0.68	0.68
Adjusted R^2	0.31	0.61	0.61	0.61	0.61	0.61
Residual *SE*	9.50 (70)	7.23 (61)	7.29 (60)	7.32 (59)	7.32 (59)	7.31 (59)
F Statistic	6.59 (6, 70); $p < 0.001$	10.65 (12, 61); $p < 0.001$	9.69 (13, 60); $p < 0.001$	9.64 (13, 59); $p < 0.001$	9.64 (13, 59); $p < 0.001$	9.67 (13, 59); $p < 0.001$

Note: The analysis is to evaluate the association between the Hofstede Culture and the social distancing stances for 77 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AU, AT, BD, BE, BO, BR, BG, CA, CL, CN, CO, HR, CZ, DK, EG, SV, EE, FI, FR, GE, DE, GH, GR, HK, HU, IN, ID, IR, IQ, IE, IT, JP, JO, KZ, LV, LU, MY, MT, MX, MA, NL, NZ, NG, MK, NO, PK, PE, PH, PL, PT, BA, RO, RU, SA, RS, SG, SK, SI, ZA, KR, ES, SE, CH, TW, TH, TT, TR, UA, AE, GB, US, UY, VE, VN, ZM.

2.4. Stance detection

Stance Detection, also referred to as Opinion Mining in certain contexts, is a Natural Language Processing (NLP) technique employed to determine the stance of a piece of text towards a specific target (AlDayel & Magdy, 2021). The typical classification involves categorizing the producer's stance into one of three classes: {Favor, Against, Neither}. Stance detection was employed to categorize Tweets into five categories: 1 (strongly against), 2 (against), 3 (neither), 4 (favor), and 5 (strongly favor).

To do so, we adopted the Robustly Optimized Bidirectional Encoder Representation Pretraining Approach (RoBERTa) (Liu et al., 2019), an advanced transformer-based model pre-trained on Twitter dataset and sentiment analysis task. In efforts to enhance the performance in analyzing these posts, we fine-tuned RoBERTa using 1900 annotated posts, specifically focusing on learning the context of COVID-19 preventive measures and the model's ability to predict the stance expressed in a given piece of text (AlDayel & Magdy, 2021).

The model's hyperparameters were tuned using Optuna, a hyperparameter optimization framework (Akiba et al., 2019). The labeled data was then used for training and testing based on a commonly used approach, with 80% tweets (1,520) for training and 20% tweets (380) for testing. To prevent biases, the training and testing were cross-validated through K-fold cross-validation (Wong & Yeh, 2019), where the training and testing sets were randomly shuffled and sampled.

After fine-tuning, the accuracy and F1 scores were evaluated, where the accuracy measures the overall correctness of the model's predictions. The F1 score combines precision and recall to provide a balanced measure of the model's performance. Precision represents the ratio of correctly predicted positive observations to the total predicted positives, emphasizing the accuracy of positive predictions. Recall quantifies the ratio of correctly predicted positive observations to all actual positives, highlighting the model's ability to capture relevant instances. The F1 score, being the harmonic mean of precision and recall, offers a consolidated assessment of the model's effectiveness in handling both false positives and false negatives (Yacouby & Axman, 2020). The model's stance scores were aggregated to obtain a continuous value from 1 to 5. In addition, the performance of the stance detection model was further assessed with human evaluation of unseen raw data to evaluate its ability to accurately classify the stance of unseen raw tweets.

2.5. Weighted regression analysis

To assess the influence of culture on online stance, weighted regression analyses were conducted with cultural indices of each nation as predictors, mean stance scores as dependent variables, and the total number of posts for each nation as weights to ensure a balanced analysis,

Table 7
Weighted regression of vaccination stance with hofstede culture.

(a) Hofstede Culture	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	2.89 (2.59–3.20); $p <$ 0.001	2.80 (2.45–3.16); $p <$ 0.001	2.83 (2.47–3.18); $p <$ 0.001	2.83 (2.47–3.20); $p <$ 0.001	2.83 (2.47–3.20); $p <$ 0.001	2.85 (2.49–3.21); $p <$ 0.001
Power Distance	0.50 (0.00–0.01); $p <$ 0.001	0.65 (0.00–0.01); $p <$ 0.001	0.66 (0.00–0.01); $p <$ 0.001	0.58 (0.00–0.01); $p <$ 0.001	0.58 (0.00–0.01); $p <$ 0.001	0.56 (0.00–0.01); $p <$ 0.001
Uncertainty Avoidance	−0.28 (−0.01 to −0.00); $p < 0.001$	−0.27 (−0.01 to −0.00); $p = 0.005$	−0.30 (−0.01 to −0.00); $p = 0.003$	−0.24 (−0.01 to −0.00); $p = 0.014$	−0.24 (−0.01 to −0.00); $p = 0.013$	−0.24 (−0.01 to −0.00); $p = 0.010$
Individualism	−0.14 (−0.00 to 0.00); $p = 0.322$	−0.14 (−0.00 to 0.00); $p = 0.458$	−0.18 (−0.00 to 0.00); $p = 0.345$	−0.18 (−0.00 to 0.00); $p = 0.349$	−0.18 (−0.00 to 0.00); $p = 0.351$	−0.21 (−0.00 to 0.00); $p = 0.280$
Masculinity	0.13 (0.00–0.01); $p =$ 0.090	0.17 (0.00–0.01); $p =$ 0.026	0.18 (0.00–0.01); $p =$ 0.023	0.14 (0.00–0.01); $p =$ 0.078	0.15 (0.00–0.01); $p =$ 0.077	0.13 (0.00–0.01); $p =$ 0.097
Long-Term Orientation	0.09 (−0.00 to 0.00); $p = 0.245$	0.02 (−0.00 to 0.00); $p = 0.857$	0.03 (−0.00 to 0.00); $p = 0.740$	0.01 (−0.00 to 0.00); $p = 0.941$	0.01 (−0.00 to 0.00); $p = 0.940$	0.02 (−0.00 to 0.00); $p = 0.825$
Indulgence	−0.34 (−0.00 to −0.00); $p < 0.001$	−0.36 (−0.01 to −0.00); $p = 0.001$	−0.37 (−0.01 to −0.00); $p < 0.001$	−0.31 (−0.00 to −0.00); $p = 0.014$	−0.31 (−0.00 to −0.00); $p = 0.014$	−0.31 (−0.00 to −0.00); $p = 0.009$
Population Size Estimate	.	−0.06 (−0.04 to 0.02); $p = 0.543$	−0.08 (−0.04 to 0.02); $p = 0.407$	−0.06 (−0.04 to 0.02); $p = 0.513$	−0.06 (−0.04 to 0.02); $p = 0.522$	−0.05 (−0.04 to 0.02); $p = 0.575$
Percent Migrants	.	−0.14 (−0.09 to 0.02); $p = 0.225$	−0.13 (−0.09 to 0.02); $p = 0.251$	−0.13 (−0.09 to 0.02); $p = 0.237$	−0.13 (−0.09 to 0.02); $p = 0.242$	−0.10 (−0.08 to 0.03); $p = 0.392$
Gini Coefficient	.	−0.18 (−0.06 to 0.00); $p = 0.053$	−0.19 (−0.06 to −0.00); $p = 0.038$	−0.21 (−0.07 to −0.00); $p = 0.033$	−0.21 (−0.07 to −0.00); $p = 0.034$	−0.19 (−0.06 to −0.00); $p = 0.041$
GDP Per Capita	.	0.24 (−0.02 to 0.09); $p = 0.200$	0.26 (−0.02 to 0.09); $p = 0.169$	0.21 (−0.02 to 0.09); $p = 0.254$	0.21 (−0.02 to 0.09); $p = 0.254$	0.22 (−0.02 to 0.09); $p = 0.227$
Political Authoritarianism	.	0.06 (−0.03 to 0.07); $p = 0.501$	0.04 (−0.04 to 0.06); $p = 0.672$	0.04 (−0.04 to 0.06); $p = 0.652$	0.04 (−0.04 to 0.06); $p = 0.628$	0.07 (−0.03 to 0.07); $p = 0.446$
All-Cause Mortality Rate	.	−0.02 (−0.07 to 0.06); $p = 0.895$	0.01 (−0.07 to 0.07); $p = 0.958$	0.01 (−0.07 to 0.07); $p = 0.913$	0.01 (−0.07 to 0.07); $p = 0.914$	0.01 (−0.06 to 0.07); $p = 0.905$
Population Density	.	.	−0.08 (−0.11 to 0.03); $p = 0.309$	.	.	.
Containment Health Index	.	.	.	0.11 (−0.03 to 0.09); $p = 0.320$	.	.
Economic Support Index	.	.	.	.	0.11 (−0.03 to 0.09); $p = 0.334$	.
Government Stringency	.	.	.	.	.	0.14 (−0.01 to 0.09); $p = 0.130$
Observations	77	74	74	73	73	73
R^2	0.7	0.74	0.75	0.75	0.75	0.75
Adjusted R^2	0.67	0.69	0.69	0.69	0.69	0.7
Residual *SE*	12.94 (70)	12.74 (61)	12.73 (60)	12.84 (59)	12.85 (59)	12.70 (59)
F Statistic	26.66 (6, 70); $p <$ 0.001	14.68 (12, 61); $p <$ 0.001	13.65 (13, 60); $p <$ 0.001	13.41 (13, 59); $p <$ 0.001	13.40 (13, 59); $p <$ 0.001	13.82 (13, 59); $p <$ 0.001

Note: The analysis is to evaluate the association between the Hofstede Culture and the vaccination stances for 77 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AU, AT, BD, BE, BO, BR, BG, CA, CL, CN, CO, HR, CZ, DK, EG, SV, EE, FI, FR, GE, DE, GH, GR, HK, HU, IN, ID, IR, IQ, IE, IT, JP, JO, KZ, LV, LU, MY, MT, MX, MA, NL, NZ, NG, MK, NO, PK, PE, PH, PL, PT, BA, RO, RU, SA, RS, SG, SK, SI, ZA, KR, ES, SE, CH, TW, TH, TT, TR, UA, AE, GB, US, UY, VE, VN, ZM.

considering some countries inherently contribute more tweets, and the inclusion of weights serves to mitigate potential disparities in the dataset. Hofstede's cultural indices and cultural tightness were analyzed separately because the latter had fewer countries. The analysis included 95 countries for Hofstede's cultural indices and 55 for cultural tightness. Proportional cases were used to measure the stance score, considering the varying number of Twitter users across countries, to ensure reliability and accuracy. Statistical analyses were performed using SPSS Statistics 27.

2.6. Covariates

In this study, covariates were carefully selected to dissect the intricate relationships between societal attributes and public health responses, particularly in the context of COVID-19. These covariates were chosen not only for their direct relevance to public health outcomes but also for their potential to influence the cultural dimensions underpinning online stances toward pandemic measures. By incorporating these variables, our analysis goes beyond surface correlations, allowing us to isolate and understand the specific impact of cultural factors on the public's online reactions to COVID-19 interventions. The inclusion of these covariates ensures that our findings on the cultural impact are robust and not confounded by: 1. Economic Development: measured by Gross Domestic Product (GDP) per capita in current US dollars (World Bank, 2020), to account for the financial capacity of nations to implement health measures. 2. Inequality: Captured through Gini coefficients (World Bank, latest year available), reflecting societal disparities that may affect health outcomes and adherence to preventive measures. 3. Population Density: Log-transformed population per square kilometer (World Bank, 2020), indicating the challenges in social distancing and virus transmission rates. 4. Political Authoritarianism: Assessed by the Political Regime Characteristics scale from the Center for Systemic Peace (earliest date available from 2018), to consider the influence of governance on policy enforcement and public compliance. 6. All-Cause Mortality Rate: (World Bank, 2020) included as an indicator of overall health and susceptibility of the population to COVID-19.7. Percent Migrants: Percentage of migrants in the population (UN Population Division, 2020), to consider the inclusivity and reach of health measures. 8. Population Size: Estimated total population (United Nations Population Division 2020), impacting the scale and logistics of response efforts. 9. COVID-19 government interventions: The extent of governmental measures to combat the pandemic (OxCGRT project), crucial for assessing response effectiveness. To ensure the accuracy and reliability of the results, we focused on the year 2020 for all control factors, aligning them with our dataset. This decision improved the precision and validity of our findings by reducing potential confounding variables. Covariates' data source is available in Appendix E2.

In our study, the Religious Diversity Index (RDI) was initially

Table 8
Weighted regression of face covering stance with cultural tightness.

Cultural Tightness	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Constant	3.03 (2.86–3.20); $p < 0.001$	3.24 (3.12–3.36); $p < 0.001$	3.24 (3.11–3.37); $p < 0.001$	3.23 (3.12–3.34); $p < 0.001$	3.23 (3.12–3.34); $p < 0.001$	3.23 (3.11–3.35); $p < 0.001$	3.14 (2.85–3.42); $p < 0.001$
Cultural Tightness	−0.19 (−0.00 to 0.00); $p = 0.163$	−0.38 (−0.00 to −0.00); $p < 0.001$	−0.38 (−0.00 to −0.00); $p < 0.001$	−0.44 (−0.01 to −0.00); $p < 0.001$	−0.44 (−0.01 to −0.00); $p < 0.001$	−0.44 (−0.01 to −0.00); $p < 0.001$	−0.22 (−0.00 to −0.00); $p = 0.005$
Power Distance	.	.	.	.	.	.	0.38 (0.00–0.01); $p = 0.015$
Individualism	.	.	.	.	.	.	−0.51 (−0.01 to −0.00); $p = 0.001$
Population Size Estimate	.	0.18 (−0.00 to 0.08); $p = 0.063$	0.18 (−0.00 to 0.08); $p = 0.066$	0.11 (−0.02 to 0.06); $p = 0.249$	0.11 (−0.02 to 0.06); $p = 0.250$	0.13 (−0.02 to 0.07); $p = 0.203$	.
Percent Migrant	.	−0.03 (−0.17 to 0.15); $p = 0.864$	−0.03 (−0.18 to 0.15); $p = 0.866$	−0.16 (−0.22 to 0.09); $p = 0.372$	−0.16 (−0.22 to 0.09); $p = 0.370$	−0.12 (−0.21 to 0.11); $p = 0.519$	.
Gini Index	.	−0.17 (−0.08 to −0.00); $p = 0.041$	−0.17 (−0.09 to 0.01); $p = 0.116$	−0.13 (−0.07 to 0.00); $p = 0.082$	−0.13 (−0.07 to 0.00); $p = 0.082$	−0.11 (−0.07 to 0.01); $p = 0.196$	.
GDP	.	−0.79 (−0.19 to −0.07); $p < 0.001$	−0.79 (−0.19 to −0.07); $p < 0.001$	−0.67 (−0.17 to −0.06); $p < 0.001$	−0.67 (−0.17 to −0.06); $p < 0.001$	−0.68 (−0.17 to −0.05); $p < 0.001$	.
Political Authoritarianism	.	0.21 (0.01–0.17); $p = 0.034$	0.21 (0.01–0.17); $p = 0.037$	0.17 (−0.01 to 0.15); $p = 0.079$	0.17 (−0.01 to 0.15); $p = 0.078$	0.22 (0.01–0.17); $p = 0.030$	.
Mortality Rate	.	−0.21 (−0.14 to −0.02); $p = 0.011$	−0.21 (−0.14 to −0.02); $p = 0.015$	−0.09 (−0.10 to 0.03); $p = 0.292$	−0.09 (−0.10 to 0.03); $p = 0.295$	−0.12 (−0.12 to 0.03); $p = 0.202$	.
Population Density	.	.	0.00 (−0.31 to 0.31); $p = 0.992$	.	.	.	
Containment Health	.	.	.	0.22 (0.02–0.14); $p = 0.006$	.	.	.
Economic Support	.	.	.	.	0.22 (0.02–0.14); $p = 0.006$	.	.
Stringency	.	.	.	.		0.17 (−0.00 to 0.13); $p = 0.065$	.
Observations	55	53	53	52	52	52	53
R^2	0.04	0.81	0.81	0.84	0.84	0.83	0.76
Adjusted R^2	0.02	0.79	0.78	0.82	0.82	0.8	0.74
Residual *SE*	25.6 (53)	12.18 (45)	12.32 (44)	11.42 (43)	11.41 (43)	11.97 (43)	12.96 (49)
F Statistic	2.00 (1, 53); $p < 0.163$	28.07 (7, 45); $p < 0.001$	24.01 (8, 44); $p < 0.001$	28.99 (8, 43); $p < 0.001$	29.06 (8, 43); $p < 0.001$	25.88 (8, 43); $p < 0.001$	50.98 (3, 49); $p < 0.001$

Note: The analysis is to evaluate the association between the Cultural Tightness and the face-covering stances for 55 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AT, BD, BE, BG, CA, CL, HR, CZ, DK, EG, EE, FI, FR, DE, GR, HU, IN, ID, IR, IE, IT, JP, JO, LV, LU, MT, MX, MA, NL, NG, MK, PK, PE, PH, PL, PT, BA, RO, RU, RS, SK, SI, ZA, KR, ES, SE, TR, UG, UA, GB, US, VN, ZW.

considered as a covariate to account for cultural variations based on religion. However, due to strong correlations between RDI and other cultural dimensions, which led to high variance inflation factors (VIF), RDI was excluded from our analyses to mitigate multicollinearity issues, as detailed in Table 4. This decision reflects the significant overlap between religious and cultural variables in our dataset. More detailed analysis results can be found in the Appendix.

2.7. Mediation analysis

Mediation analyses were performed to estimate the direct effects of cultural indices on COVID-19 cases/rates and their indirect effects through online stances toward preventive measures. Separate analyses were conducted for COVID-19 cases and deaths. Mediation analyses were performed using the PyProcessMacro, a Python package of Andrew F. Hayes' Process Macro.

3. Results

3.1. Overview

This section presents our findings from a comprehensive analysis of over 16 million tweets from 95 countries, aimed at understanding the cultural influences on public stances towards COVID-19 preventive measures. The results section initiates with an analysis of the RoBERTa model's stance detection performance, demonstrating significant improvements in precision, recall, and F1-score after fine-tuning, which confirms its suitability for analyzing cultural influences on public responses to COVID-19 preventive measures. Then stance detection analysis was employed to examine the online responses to COVID-19 preventive measures, structured by Hofstede's cultural dimensions. Our approach evaluates how these cultural dimensions correlate with public attitudes across different preventive strategies, such as face coverings, lockdowns, and social distancing. The analysis also explores the mediating role of public stances towards face coverings in relation to COVID-19 outcomes. This structured examination provides insights into the complex interplay between culture and public health communication, guiding our understanding of global responses to the pandemic.

3.2. Stance detection performance evaluation

First, the performance difference between the pre-trained and fine-tuned RoBERTa model for stance detection was analyzed. Table 2 indicates RoBERTa's performance of pre- and post-fine-tuning. Three common evaluation metrics were used including precision, recall and F1-score. Precision, also known as Positive Predictive Value, measures the proportion of true positive predictions in the total predicted positives, essentially quantifying the accuracy of the model in identifying relevant instances. Recall, or Sensitivity, evaluates the proportion of actual positives that the model correctly identifies, reflecting the model's ability to capture relevant cases. The F1-Score, a harmonic mean of Precision and Recall, balances these two metrics. It is particularly useful when seeking a single measure for scenarios where an equilibrium between Precision and Recall is desired. As shown in the results, the pre-trained RoBERTa model was unable to provide very accurate stance detection on our datasets. This could be because the tweets about COVID-19 preventive measures have a specific context for expressing users' stances that differ from the general tweets. After our

Table 9
Weighted regression of lockdown stance with cultural tightness.

Cultural Tightness	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Constant	3.14 (3.00–3.27); $p < 0.001$	3.10 (2.98–3.22); $p < 0.001$	3.07 (2.95–3.12); $p < 0.001$	3.11 (2.98–3.23); $p < 0.001$	3.10 (2.98–3.23); $p < 0.001$	3.10 (2.98–3.22); $p < 0.001$	2.90 (2.59–3.21); $p < 0.001$
Cultural Tightness	−0.01 (−0.00 to 0.00); $p = 0.943$	−0.03 (−0.00 to 0.00); $p = 0.766$	0.05 (−0.00 to 0.00); $p = 0.679$	−0.08 (−0.00 to 0.00); $p = 0.499$	−0.08 (−0.00 to 0.00); $p = 0.523$	−0.08 (−0.00 to 0.00); $p = 0.525$	−0.11 (−0.00 to 0.00); $p = 0.385$
Power Distance	.	.	.	.	.	.	0.72 (0.00–0.01); $p = 0.003$
Individualism	.	.	.	.	.	.	0.06 (−0.00 to 0.00); $p = 0.800$
Population Size Estimate	.	0.28 (0.02–0.11); $p = 0.006$	0.25 (0.01–0.10); $p = 0.013$	0.24 (0.01–0.10); $p = 0.023$	0.25 (0.01–0.11); $p = 0.021$	0.25 (0.01–0.11); $p = 0.018$	.
Percent Migrant	.	−0.36 (−0.33 to 0.06); $p = 0.165$	−0.38 (−0.34 to 0.05); $p = 0.130$	−0.35 (−0.33 to 0.06); $p = 0.176$	−0.35 (−0.33 to 0.06); $p = 0.177$	−0.34 (−0.33 to 0.07); $p = 0.195$	.
Gini Index	.	−0.45 (−0.09 to −0.04); $p < 0.001$	−0.65 (−0.13 to −0.05); $p < 0.001$	−0.43 (−0.09 to −0.03); $p < 0.001$	−0.43 (−0.09 to −0.03); $p < 0.001$	−0.39 (−0.09 to −0.02); $p = 0.002$	.
GDP	.	−0.25 (−0.10 to 0.03); $p = 0.302$	−0.38 (−0.11 to 0.01); $p = 0.125$	−0.21 (−0.09 to 0.04); $p = 0.381$	−0.22 (−0.09 to 0.04); $p = 0.375$	−0.22 (−0.09 to 0.04); $p = 0.375$	.
Political Authoritarianism	.	0.14 (−0.04 to 0.14); $p = 0.236$	0.07 (−0.07 to 0.11); $p = 0.590$	0.12 (−0.05 to 0.13); $p = 0.328$	0.12 (−0.04 to 0.13); $p = 0.315$	0.15 (−0.03 to 0.14); $p = 0.205$	.
Mortality Rate	.	−0.26 (−0.13 to −0.01); $p = 0.019$	−0.29 (−0.13 to −0.02); $p = 0.009$	−0.21 (−0.12 to 0.01); $p = 0.101$	−0.21 (−0.12 to 0.01); $p = 0.094$	−0.21 (−0.12 to 0.01); $p = 0.104$	.
Population Density	.	.	−0.27 (−0.51 to 0.02); $p = 0.069$	.	.	.	.
Containment Health	.	.	.	0.14 (−0.04 to 0.11); $p = 0.326$	.	.	.
Economic Support	.	.	.	.	0.12 (−0.04 to 0.10); $p = 0.370$	.	.
Stringency	.	.	.	.	.	0.13 (−0.05 to 0.12); $p = 0.386$	.
Observations	55	53	53	52	52	52	53
R^2	0.00	0.67	0.70	0.68	0.68	0.68	0.44
Adjusted R^2	−0.02	0.62	0.64	0.62	0.62	0.62	0.40
Residual *SE*	25.82 (53)	16.07 (45)	15.65 (44)	16.26 (43)	16.29 (43)	16.30 (43)	20.08 (49)
F Statistic	0.01 (1, 53); $p = 0.943$	13.10 (7, 45); $p < 0.001$	12.53 (8, 44); $p < 0.001$	11.33 (8, 43); $p < 0.001$	11.27 (8, 43); $p < 0.001$	11.25 (8, 43); $p < 0.001$	12.65 (3, 49); $p < 0.001$

Note: The analysis is to evaluate the association between the Cultural Tightness and the lockdown stances for 55 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AT, BD, BE, BG, CA, CL, HR, CZ, DK, EG, EE, FI, FR, DE, GR, HU, IN, ID, IR, IE, IT, JP, JO, LV, LU, MT, MX, MA, NL, NG, MK, PK, PE, PH, PL, PT, BA, RO, RU, RS, SK, SI, ZA, KR, ES, SE, TR, UG, UA, GB, US, VN, ZW.

fine-tuning, it is clear that the performance has been significantly increased. As a result, the fine-tuned RoBERTa model was adopted as the candidate model.

3.3. Cultural impacts on each Measure's stances

Tables 3–7 provide the analysis results of the association between the Hofstede culture and the stances of face covering, lockdown, quarantine, social distancing, and vaccination respectively. Tables 8–12 provide the analysis results of the association between the cultural tightness and the stances of face covering, lockdown, quarantine, social distancing, and vaccination respectively. Our first model, Model 1 included Hofstede's cultural indices without controls (Tables 3–7). Results indicate that certain cultural dimensions had consistent impacts across different preventive measures. Power distance positively predicted online stance of face coverings (β = 0·24, $p = 0·023$, $n = 77$), lockdown (β = 0·33, $p = 0·049$, $n = 77$), social distancing (β = 0·34, $p = 0·065$, $n = 77$) and vaccination (β = 0·50, $p < 0·001$, $n = 77$). Indulgence negatively predicted online stance of face coverings (β = −0·37, $p < 0·001$, $n = 77$), lockdown (β = −0·43, $p < 0·001$, $n = 77$), social distancing (β = −0·54, $p < 0·001$, $n = 77$), and vaccination (β = −0·34, $p < 0·001$, $n = 77$). Appendix C shows these stances at different cultural dimension levels for bubble plots.

However, other cultural indices had diverse impacts on different preventive measures. Individualism only negatively predicted face coverings stance (β = −0·52, $p < 0·001$, $n = 77$) but was not significantly related to other preventive measures. Uncertainty avoidance and long-term orientation had mixed impacts on various measures. Uncertainty avoidance negatively predicted stance toward lockdown (β = −0·40, $p < 0·001$, $n = 77$) and vaccination (β = −0·28, $p < 0·001$, $n = 77$), but positively predicted the stance of social distancing measures (β = 0·28, $p = 0·021$, $n = 77$). Long-term orientation negatively predicted the stances of social distancing (β = −0·39, $p = 0·001$, $n = 77$) but positively predicted quarantine stance (β = 0·24, $p = 0·055$, $n = 77$).

In the second model - Model 2, which included Hofstede's cultural indices above and beyond the covariances.

(Tables 3–7), a robust and consistent results pattern in the first model without controls was observed. For model 1, the results additionally revealed that long-term orientation negatively predicted stance scores for lockdown (β = 0·25, $p = 0·023$, $n = 74$). Power distance's positive association (β = 0·48, $p = 0·030$, $n = 74$) and indulgence's negative association (β = −0·39, $p = 0·008$, $n = 74$) with quarantine stance were also significant. Models 3–6 replicated the second model's results, respectively, including population density, and measures of COVID-19 government interventions of containment health index, economic support index, and government stringency (Tables 3–7; Appendix C for bubble plots).

Next, the main effects of cultural tightness was tested. In the first model, cultural tightness negatively predicted online stances of quarantine (β = −0·47, $p < 0·001$, $n = 55$) and social distancing (β = −0·33, $p = 0·015$, $n = 55$). In the second model, which included controls of covariances, cultural tightness negatively predicted the stance of face coverings (β = 0·38, $p < 0·001$, $n = 53$) and quarantine (β = −0·61, $p < 0·001$, $n = 53$). Models 3–7 replicated the results of the second model, respectively, including population density, and measures of COVID-19 government interventions of containment health index, economic support index, and government stringency (Tables 8–12; Appendix C for bubble plots).

Table 10
Weighted regression of quarantine stance with cultural tightness.

Cultural Tightness	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Constant	3.25 (3.15–3.35); $p < 0.001$	3.29 (3.142–3.44); $p < 0.001$	3.33 (3.17–3.48); $p < 0.001$	3.29 (3.13–3.45); $p < 0.001$	3.29 (3.13–3.45); $p < 0.001$	3.30 (3.14–3.46); $p < 0.001$	3.15 (2.86–3.44); $p < 0.001$
Cultural Tightness	−0.47 (−0.00 to −0.00); $p < 0.001$	−0.61 (−0.00 to −0.00); $p < 0.001$	−0.65 (−0.01 to −0.00); $p < 0.001$	−0.61 (−0.01 to −0.00); $p < 0.001$	−0.61 (−0.01 to −0.00); $p < 0.001$	−0.59 (−0.00 to −0.00); $p < 0.001$	−0.54 (−0.00 to −0.00); $p < 0.001$
Power Distance	.	.	.	.	.	.	0.38 (−0.00 to 0.01); $p = 0.102$
Individualism	.	.	.	.	.	.	0.02 (−0.00 to 0.00); $p = 0.929$
Population Size Estimate	.	−0.09 (−0.07 to 0.04); $p = 0.578$	−0.11 (−0.07 to 0.04); $p = 0.522$	−0.10 (−0.07 to 0.04); $p = 0.569$	−0.10 (−0.07 to 0.04); $p = 0.566$	−0.08 (−0.07 to 0.04); $p = 0.641$	.
Percent Migrant	.	−0.25 (−0.30 to 0.14); $p = 0.482$	−0.22 (−0.28 to 0.15); $p = 0.530$	−0.28 (−0.34 to 0.15); $p = 0.476$	−0.29 (−0.33 to 0.15); $p = 0.471$	−0.20 (−0.30 to 0.18); $p = 0.617$	.
Gini Index	.	−0.06 (−0.06 to 0.04); $p = 0.651$	0.12 (−0.04 to 0.08); $p = 0.489$	−0.06 (−0.06 to 0.04); $p = 0.669$	−0.06 (−0.06 to 0.04); $p = 0.670$	−0.08 (−0.06 to 0.04); $p = 0.600$	.
GDP	.	0.06 (−0.07 to 0.09); $p = 0.866$	0.16 (−0.06 to 0.10); $p = 0.635$	0.08 (−0.08 to 0.10); $p = 0.824$	0.09 (−0.08 to 0.10); $p = 0.817$	−0.00 (−0.09 to 0.09); $p = 0.991$	.
Political Authoritarianism	.	0.16 (−0.06 to 0.16); $p = 0.348$	0.15 (−0.06 to 0.15); $p = 0.381$	0.15 (−0.07 to 0.16); $p = 0.424$	0.15 (−0.07 to 0.16); $p = 0.428$	0.18 (−0.06 to 0.17); $p = 0.325$	.
Mortality Rate	.	−0.03 (−0.08 to 0.07); $p = 0.851$	0.05 (−0.06 to 0.09); $p = 0.731$	−0.01 (−0.10 to 0.09); $p = 0.974$	−0.00 (−0.09 to 0.09); $p = 0.986$	−0.08 (−0.12 to 0.08); $p = 0.675$	.
Population Density	.	.	0.32 (−0.07 to 0.62); $p = 0.113$	.	.	.	.
Containment Health	.	.	.	0.03 (−0.07 to 0.08); $p = 0.842$	.	.	.
Economic Support	.	.	.	.	0.04 (−0.06 to 0.08); $p = 0.822$	.	.
Stringency	.	.	.	.	.	−0.08 (−0.10 to 0.06); $p = 0.653$	.
Observations	55	53	53	52	52	52	53
R^2	0.22	0.36	0.39	0.36	0.36	0.36	0.37
Adjusted R^2	0.20	0.26	0.28	0.24	0.24	0.24	0.33
Residual *SE*	16.72 (53)	16.44 (45)	16.15 (44)	16.81 (43)	16.81 (43)	16.78 (43)	15.47 (49)
F Statistic	14.67 (1, 53); $p <$ 0.001	3.56 (7, 45); $p <$ 0.001	3.56 (8, 44); $p =$ 0.003	2.98 (8, 43); $p =$ 0.009	2.99 (8, 43); $p =$ 0.009	3.02 (8, 43); $p =$ 0.009	9.49 (3, 49); $p <$ 0.001

Note: The analysis is to evaluate the association between the Cultural Tightness and the quarantine stances for 55 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AT, BD, BE, BG, CA, CL, HR, CZ, DK, EG, EE, FI, FR, DE, GR, HU, IN, ID, IR, IE, IT, JP, JO, LV, LU, MT, MX, MA, NL, NG, MK, PK, PE, PH, PL, PT, BA, RO, RU, RS, SK, SI, ZA, KR, ES, SE, TR, UG, UA, GB, US, VN, ZW.

3.4. Association between cultures and COVID-19 cases/deaths mediated by stance

To identify the potential pathways from culture to COVID-19 cases and deaths, mediation analyses were further conducted to identify which preventive measures mediate the relationship between various cultural indices and online stances toward them.

Online stance toward face coverings mediated the relationship between indulgence and COVID-19 cases per million (Fig. 1), with effect size 0·02 (0·01 to 0·03, $P = 0{\cdot}002$) for the total effect, 0·00 (−0·00 to 0·00, $P = 0{\cdot}677$) for the natural direct effect of indulgence, and 0·00 (0·00 to 0·00) for the indirect effect. Face covering stance accounted for 2·4% of the relative effect of indulgence on COVID-19 cases.

Public stances toward face coverings mediated the relationship between cultural tightness and COVID-19 cases per million (Fig. 2), with effect size −0·00 (−0·01 to 0·01, $P = 0{\cdot}813$) for the total effect, −0·00 (−0·00 to 0·00, $P = 0{\cdot}577$) for the natural direct effect of cultural tightness, and 0·00 (0·00 to 0·00) for the indirect effect. Face-covering stance accounted for 3·1% of the relative effect of cultural tightness on COVID-19 cases.

Online stances toward face coverings mediated the relationship between power distance and COVID-19 deaths per million (Fig. 3), with effect size −0·02 (−0·03 to −0·02, $P = 0{\cdot}000$) for the total effect, −0·00 (−0·00 to 0·00, $P = 0{\cdot}498$) for the natural direct effect of power distance, and −0·00 (−0·00 to −0·00) for the indirect effect. Face covering stance accounted for 3·3% of the relative effect of power distance on COVID-19 deaths.

4. Discussion

The COVID-19 pandemic has revealed diverse online opinions on preventive measures globally. It is crucial to comprehend the underlying factors driving this variation, the differential effects on various preventive measures, and their implications for public health outcomes. This knowledge informs effective interventions for future crises and facilitates tailored strategies to promote widespread adherence to guidelines, ensuring public health and societal resilience in the face of challenges.

Using AI technologies to collect data from 95 countries, we find clear links between cultures, online stance on preventive measures, and COVID-19 cases/deaths from March 11, 2020, to December 1, 2021. Our findings demonstrate distinct cultural impacts on online stances, with each measure having unique cultural predictors. Some stances mediate the link between culture and COVID-19 cases/deaths. This supports our theory that cultural values and norms influence policy acceptance by shaping the interpretation of communicated information based on culturally consistent categories in the cognitive schemes.

Two cultural predictors consistently emerged: power distance (positive) and indulgence (negative). These effects remained robust after accounting for various covariates. These findings indicate a strong alignment between power distance and all preventive measures, while indulgence shows a misalignment. In high power distance cultures, authority is accepted (Hofstede, 2011), resulting in positive responses to government-enforced measures. In contrast, low power distance cultures tend to be skeptical of authority, leading to negative stance toward government directives. Similarly, indulgence represents a society that freely satisfies basic human desires (Hofstede, 2011), resulting in

Table 11
Weighted regression of social distancing stance with cultural tightness.

Cultural Tightness	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Constant	3.30 (3.18–3.42); $p < 0.001$	3.11 (2.97–3.25); $p < 0.001$	3.07 (2.93–3.21); $p < 0.001$	3.13 (2.99–3.27); $p < 0.001$	3.13 (2.99–2.37); $p < 0.001$	3.15 (3.02–3.29); $p < 0.001$	2.93 (2.58–3.28); $p < 0.001$
Cultural Tightness	−0.33 (−0.00 to 0.00); $p = 0.015$	−0.15 (−0.00 to 0.00); $p = 0.182$	−0.04 (−0.00 to 0.00); $p = 0.721$	−0.08 (−0.00 to 0.00); $p = 0.492$	−0.08 (−0.00 to 0.00); $p = 0.490$	−0.06 (−0.00 to 0.00); $p = 0.584$	−0.42 (−0.00 to −0.00); $p = 0.002$
Power Distance	.	.	.	.	.	.	0.74 (0.00–0.01); $p = 0.004$
Individualism	.	.	.	.	.	.	0.31 (−0.00 to 0.01); $p = 0.210$
Population Size Estimate	.	0.80 (0.11–0.19); $p < 0.001$	0.78 (0.10–0.19); $p < 0.001$	0.88 (0.12–0.21); $p < 0.001$	0.88 (0.12–0.21); $p < 0.001$	0.89 (0.12–0.21); $p < 0.001$	.
Percent Migrant	.	−0.28 (−0.32 to 0.11); $p = 0.343$	−0.20 (−0.28 to 0.14); $p = 0.487$	−0.07 (−0.26 to 0.20); $p = 0.820$	−0.07 (−0.26 to 0.20); $p = 0.816$	−0.05 (−0.24 to 0.20); $p = 0.868$	.
Gini Index	.	−0.11 (−0.06 to 0.02); $p = 0.309$	−0.34 (−0.11 to −0.01); $p = 0.023$	−0.14 (−0.06 to 0.01); $p = 0.200$	−0.14 (−0.06 to 0.01); $p = 0.200$	−0.22 (−0.08 to 0.00); $p = 0.060$	.
GDP	.	0.06 (−0.06 to 0.07); $p = 0.813$	−0.24 (−0.10 to 0.04); $p = 0.406$	−0.15 (−0.09 to 0.05); $p = 0.606$	−0.15 (−0.09 to 0.05); $p = 0.609$	−0.24 (−0.10 to 0.04); $p = 0.407$	.
Political Authoritarianism	.	−0.00 (−0.10 to 0.10); $p = 0.979$	−0.01 (−0.10 to 0.09); $p = 0.950$	0.07 (−0.07 to 0.13); $p = 0.590$	0.07 (−0.07 to 0.13); $p = 0.594$	0.02 (−0.09 to 0.10); $p = 0.902$	.
Mortality Rate	.	−0.48 (−0.21 to −0.08); $p < 0.001$	−0.50 (−0.21 to −0.09); $p < 0.001$	−0.65 (−0.28 to −0.11); $p < 0.001$	−0.65 (−0.28 to −0.11); $p < 0.001$	−0.68 (−0.29 to −0.12); $p < 0.001$	.
Population Density	.	.	−0.37 (−0.71 to −0.03); $p = 0.032$	.	.	.	.
Containment Health	.	.	.	−0.24 (−0.15 to 0.01); $p = 0.090$	.	.	.
Economic Support	.	.	.	.	−0.24 (−0.15 to 0.01); $p = 0.091$	.	.
Stringency	.	.	.	.	.	−0.32 (−0.18 to −0.01); $p = 0.030$	.
Observations	55	53	53	52	52	52	53
R^2	0.11	0.65	0.69	0.68	0.68	0.69	0.34
Adjusted R^2	0.09	0.60	0.63	0.62	0.61	0.63	0.30
Residual *SE*	12.00 (53)	8.12 (45)	7.79 (44)	8.02 (43)	8.03 (43)	7.85 (43)	10.67 (49)
F Statistic	6.30 (1, 53); $p = 0.015$	12.04 (7, 45); $p < 0.001$	12.06 (8, 44); $p < 0.001$	11.17 (8, 43); $p < 0.001$	11.16 (8, 43); $p < 0.001$	11.89 (8, 43); $p < 0.001$	8.43 (3, 49); $p < 0.001$

Note: The analysis is to evaluate the association between the Cultural Tightness and the social distancing stances for 55 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AT, BD, BE, BG, CA, CL, HR, CZ, DK, EG, EE, FI, FR, DE, GR, HU, IN, ID, IR, IE, IT, JP, JO, LV, LU, MT, MX, MA, NL, NG, MK, PK, PE, PH, PL, PT, BA, RO, RU, RS, SK, SI, ZA, KR, ES, SE, TR, UG, UA, GB, US, VN, ZW.

resistance to preventive measures that restrict enjoyment. Conversely, societies with restraint norms exert greater control over gratification (Hofstede, 2011), promoting compliance with nationwide preventive measures.

The other cultural indicators were not significantly related to all preventive measures examined. However, consistent patterns emerged regarding the alignment between specific behaviors or motivations required by the measures and cultural values or the influence range of cultural norms. Positive associations were observed when there was alignment, while negative associations were observed when there was misalignment. The following section will delve into the distinctive patterns of each cultural value and norm's impact on each preventive measure.

First, individualism showed a negative association specifically with online stances on face coverings but not with other measures. These effects were replicated when controlling for the other covariates. Studies have consistently shown that individualistic cultures prioritize self-interest, autonomy, and self-centric norms, while collectivistic cultures emphasize social connectedness, fulfilling obligations, and others- or group-centric norms (Triandis, 2018). Furthermore, wearing masks can prevent COVID-19's spread and only works effectively when practiced collectively. This measure requires individuals to prioritize the common good or the interests of others over their own comfort and desires, aligning with collectivistic values (Hofstede, 2011). Conversely, it conflicts with individualistic values prioritizing individual needs and desires (Hofstede, 2011). Consequently, individuals from more collectivistic cultures tend to exhibit more favorable attitudes toward face coverings.

Second, country-level uncertainty avoidance negatively predicted online opinions of lockdown and vaccination measures. Implementing lockdowns and vaccinations in response to the COVID-19 pandemic can create feelings of insecurity (Sonuga-Barke & Fearon, 2021), which are less tolerated in uncertainty-avoidant cultures (Hofstede, 2011). For example, vaccine hesitancy often stems from concerns about potential side effects and risks (Karafillakis & Larson, 2017), aligning with uncertainty avoidance, i.e., discomfort with ambiguous or uncertain situations (Hofstede, 2011). Similarly, lockdown measures have endangered numerous jobs, workforces, and businesses (Allas et al., 2020) while simultaneously amplifying health risks (Ambika et al., 2021), which are less acceptable in uncertainty-avoidant cultures (Hofstede, 2011).

Conversely, our findings reveal a positive link between uncertainty avoidance and online opinions of social distancing measures. This can be attributed to the notion that keeping distance from potentially virus-carrying individuals reduces anxiety and uncertainty, while also minimizing the risk of transmission (Xie et al., 2020). The alignment between individuals' motivation to practice social distancing and the cultural value of uncertainty avoidance helps clarify this positive association.

Third, our study reveals distinct associations between long-term orientation and online opinions of different preventive measures. A positive link was observed between long-term orientation and online stances toward quarantine, but a negative link with online stances toward social distancing and lockdown measures. According to the contrast between long-term and short-term orientations (Hofstede, 2011), cultures with short-term orientations are more inclined to implement reactive measures and enforce actions for quick results (Ashraf et al., 2022), such as social distancing and lockdown. Conversely, long-term orientation values qualities like thrift and perseverance (Hofstede, 2011). However, lockdown, as a mandatory

Table 12
Weighted regression of vaccination stance with cultural tightness.

Cultural Tightness	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Constant	2.92 (2.79–3.06); $p < 0.001$	2.93 (2.82–3.04); $p < 0.001$	2.96 (2.85–3.06); $p < 0.001$	2.93 (2.83–3.02); $p < 0.001$	2.93 (2.83–3.02); $p < 0.001$	2.91 (2.82–3.01); $p < 0.001$	2.80 (3.49–3.11); $p < 0.001$
Cultural Tightness	−0.02 (−0.00 to 0.00); $p = 0.890$	−0.11 (−0.00 to 0.00); $p = 0.290$	−0.18 (−0.00 to 0.00); $p = 0.077$	−0.24 (−0.00 to 0.00); $p = 0.014$	−0.24 (−0.00 to 0.00); $p = 0.014$	−0.26 (−0.00 to 0.00); $p = 0.007$	−0.08 (−0.00 to 0.00); $p = 0.478$
Power Distance	.	.	.	.	.	.	0.56 (0.00–0.01); $p = 0.008$
Individualism	.	.	.	.	.	.	−0.17 (−0.00 to 0.00); $p = 0.404$
Population Size Estimate	.	0.39 (0.04–0.11); $p < 0.001$	0.42 (0.04–0.12); $p < 0.001$	0.25 (0.01–0.08); $p = 0.008$	0.26 (0.02–0.08); $p = 0.007$	0.27 (0.02–0.09); $p = 0.003$	.
Percent Migrant	.	−0.28 (−0.27 to 0.06); $p = 0.217$	−0.20 (−0.23 to 0.09); $p = 0.367$	−0.37 (−0.28 to 0.01); $p = 0.064$	−0.36 (−0.28 to 0.01); $p = 0.067$	−0.31 (−0.25 to 0.03); $p = 0.109$	.
Gini Index	.	−0.39 (−0.10 to −0.04); $p < 0.001$	−0.244 (−0.08 to −0.01); $p = 0.024$	−0.35 (−0.09 to −0.04); $p < 0.001$	−0.35 (−0.09 to −0.04); $p < 0.001$	−0.26 (−0.08 to −0.02); $p = 0.001$	.
GDP	.	−0.29 (−0.09 to 0.02); $p = 0.159$	−0.21 (−0.08 to 0.03); $p = 0.288$	−0.14 (−0.07 to 0.03); $p = 0.440$	−0.14 (−0.07 to 0.03); $p = 0.433$	−0.13 (−0.06 to 0.03); $p = 0.467$	.
Political Authoritarianism	.	0.32 (0.03–0.17); $p = 0.007$	0.47 (0.07–0.22); $p < 0.001$	0.24 (0.01–0.13); $p = 0.017$	0.25 (0.02–0.14); $p = 0.012$	0.37 (0.06–0.17); $p < 0.001$	.
Mortality Rate	.	−0.43 (−0.19 to −0.07); $p < 0.001$	−0.40 (−0.18 to −0.07); $p < 0.001$	−0.20 (−0.12 to 0.00); $p = 0.050$	−0.20 (−0.12 to −0.00); $p = 0.047$	−0.19 (−0.12 to −0.00); $p = 0.047$	.
Population Density	.	.	0.30 (0.04–0.42); $p = 0.019$	.	.	.	.
Containment Health	.	.	.	0.39 (0.06–0.17); $p < 0.001$	.	.	.
Economic Support	.	.	.	.	0.39 (0.06–0.17); $p < 0.001$	.	.
Stringency	.	.	.	.	.	0.45 (0.08–0.19); $p < 0.001$	.
Observations	55	53	53	52	52	52	53
R^2	0.00	0.76	0.79	0.83	0.83	0.84	0.51
Adjusted R^2	−0.02	0.73	0.75	0.80	0.80	0.82	0.48
Residual *SE*	23.07 (53)	12.21 (45)	11.60 (44)	10.45 (43)	10.46 (43)	10.12 (43)	16.73 (49)
F Statistic	0.02 (1, 53); $p = 0.890$	20.59 (7, 45); $p < 0.001$	20.71 (8, 44); $p < 0.001$	26.89 (8, 43); $p < 0.001$	26.84 (8, 43); $p < 0.001$	29.08 (8, 43); $p < 0.001$	16.87 (3, 49); $p < 0.001$

Note: The analysis is to evaluate the association between the Cultural Tightness and the vaccination stances for 55 countries, spanning from March 11, 2020, to December 1, 2021. Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AT, BD, BE, BG, CA, CL, HR, CZ, DK, EG, EE, FI, FR, DE, GR, HU, IN, ID, IR, IE, IT, JP, JO, LV, LU, MT, MX, MA, NL, NG, MK, PK, PE, PH, PL, PT, BA, RO, RU, RS, SK, SI, ZA, KR, ES, SE, TR, UG, UA, GB, US, VN, ZW.

measure to curb the spread of COVID-19, often incurs substantial costs (Allen, 2022) and is not aligned with the long-term focus of these cultures.

Simultaneously, countries with long-term orientation value adaptability to the circumstances in addressing social struggles (Ibarra-Vega, 2020), while those with low long-term orientation prioritize steadiness and stability in tackling immediate problems (Hofstede, 2011). Quarantine primarily operates individually, based on specific circumstances such as infection or close contact with COVID-19 patients. Conversely, lockdown and social distancing measures are uniformly applied to all citizens, regardless of individual circumstances. Therefore, individuals from long-term oriented cultures may prefer flexible and adaptive public health solutions, like individual quarantine, rather than strict lockdown mandates. Conversely, individuals from short-term-oriented cultures are more likely to support stability-focused measures like lockdown and social distancing.

Fourth, a negative association was observed between cultural tightness and online stances of face coverings, quarantine, and social distancing. No significant impact was found on stances regarding lockdown or vaccination. Lockdown and vaccination are preventive measures implemented region-wide and are often mandatory. Many countries have enforced mandatory mass lockdown policies, and jurisdictions worldwide have established vaccination requirements, including proof of vaccination in schools, workplaces, and public places. Cultural tightness vs. looseness reflects the strictness of norms and the presence of punishments for deviance within a culture (Gelfand et al., 2021). Therefore, in the context of mandatory policies with penalties for non-compliance, the influence of cultural norms becomes limited, and institutional mechanisms play a significant role.

Conversely, face covering, quarantine (especially self-quarantine), and social distancing measures involve individual level actions, providing deviant individuals the opportunity to conceal their non-compliance or not strictly adhere to the requirements (Bodas & Peleg, 2020). For these cases, the influence of social norms becomes crucial in shaping people's responses, and thus, cultural tightness can negatively predict their online opinions. The effect on social distancing was insignificant when controlling other covariates, possibly because this measure encompasses individual-level behaviors, like keeping distance in public places, and mandatory restrictions, like avoiding large gatherings.

A key strength of this research is its investigation of the mechanisms linking cultural values and norms to COVID19 cases and deaths using a mediation framework. This analysis was facilitated by employing AI technologies for collecting large-scale online data during the pandemic, allowing for examining cultural variables, online stances, and public health outcomes at the country level. Our findings indicate that online stances toward face coverings mediated the positive path from indulgence and the negative path from cultural tightness to COVID-19 cases. Indulgent cultures, emphasizing personal freedom and gratification, had more COVID-19 cases, potentially due to lower compliance with face coverings. Conversely, cultural tightness, reflecting strong social norms and rule adherence, is negatively associated with COVID-19 cases, potentially attributed to higher compliance with face coverings. Furthermore, online stances toward face coverings mediated the negative association between power distance and COVID-19 deaths. Higher power distance cultures, characterized by respect for authority and hierarchical structures, showed decreased COVID-19 deaths, potentially attributed to varying levels of compliance with face coverings.

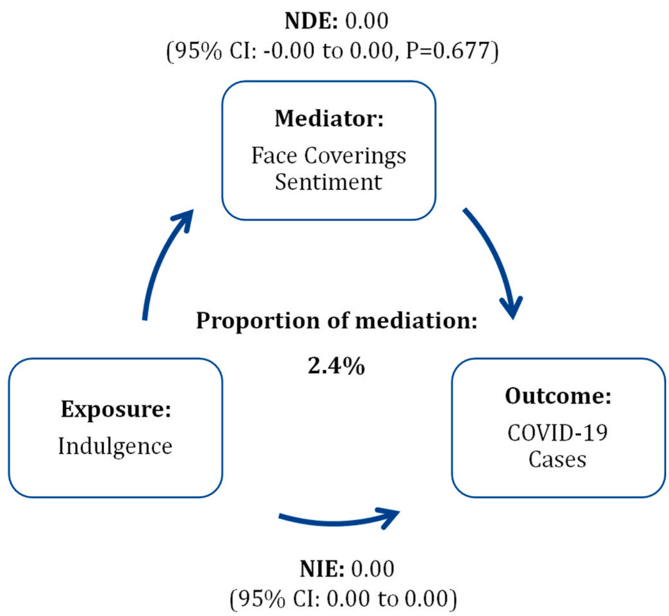

Fig. 1. Mediation Analysis Path Model Diagram for X: Indulgence, M: Face Covering Sentiment, and Y: COVID-19 Cases. Abbreviations: CI, confidence interval. NDE, Natural Direct Effect. NIE, Natural Indirect Effect. Note: Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AU, AT, BD, BE, BO, BR, BG, CA, CL, CN, CO, HR, CZ, DK, EG, SV, EE, FI, FR, GE, DE, GH, GR, HK, HU, IN, ID, IR, IQ, IE, IT, JP, JO, KZ, LV, LU, MY, MT, MX, MA, NL, NZ, NG, MK, NO, PK, PE, PH, PL, PT, BA, RO, RU, SA, RS, SG, SK, SI, ZA, KR, ES, SE, CH, TW, TH, TT, TR, UA, AE, GB, US, UY, VE, VN, ZM.

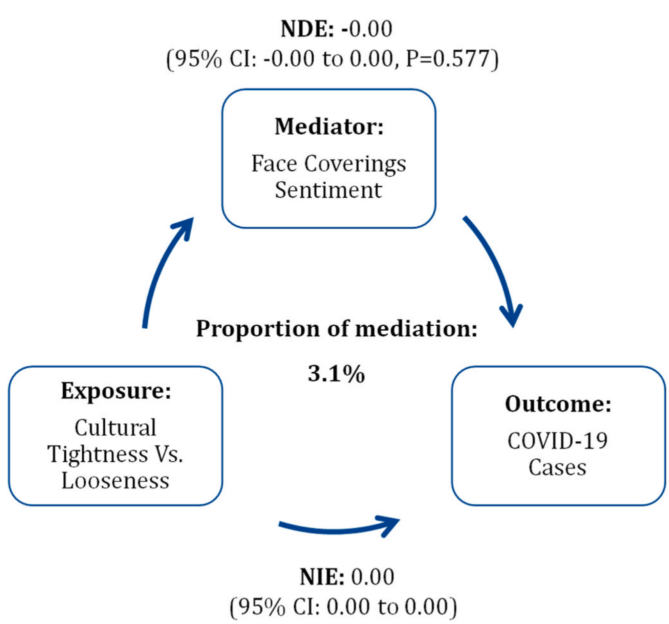

Fig. 2. Mediation Analysis Path Model Diagram for X: Cultural Tightness, M: Face Covering Sentiment, and Y: COVID-19 Cases. Abbreviations: CI, confidence interval. NDE, Natural Direct Effect. NIE, Natural Indirect Effect. Note: Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AT, BD, BE, BG, CA, CL, HR, CZ, DK, EG, EE, FI, FR, DE, GR, HU, IN, ID, IR, IE, IT, JP, JO, LV, LU, MT, MX, MA, NL, NG, MK, PK, PE, PH, PL, PT, BA, RO, RU, RS, SK, SI, ZA, KR, ES, SE, TR, UG, UA, GB, US, VN, ZW.

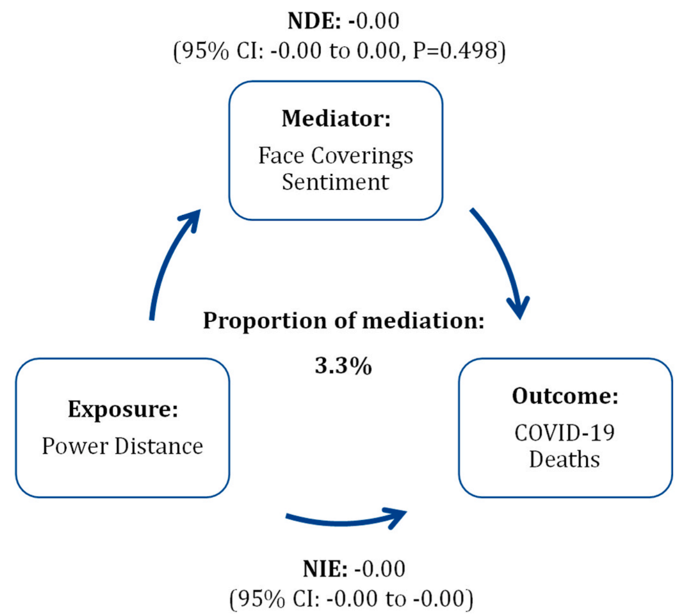

Fig. 3. Mediation Analysis Path Model Diagram for X: Power Distance, M: Face Covering Sentiment, and Y: COVID-19 Death. Abbreviations: CI, confidence interval. NDE, Natural Direct Effect. NIE, Natural Indirect Effect. Note: Data collection in Singapore was conducted from 05 to 10–22 to 28-12-22, with analysis including countries represented by the following acronyms: AL, AR, AU, AT, BD, BE, BO, BR, BG, CA, CL, CN, CO, HR, CZ, DK, EG, SV, EE, FI, FR, GE, DE, GH, GR, HK, HU, IN, ID, IR, IQ, IE, IT, JP, JO, KZ, LV, LU, MY, MT, MX, MA, NL, NZ, NG, MK, NO, PK, PE, PH, PL, PT, BA, RO, RU, SA, RS, SG, SK, SI, ZA, KR, ES, SE, CH, TW, TH, TT, TR, UA, AE, GB, US, UY, VE, VN, ZM.

The mediation results support our theoretical model's validity, emphasizing the alignment between cultural dimensions and online stances toward preventive measures. Power distance, indulgence, and cultural tightness share conceptual commonalities, particularly concerning the tension between satisfying individual needs and complying with regulations (Uz, 2015). Face coverings have consistently shown the highest effectiveness as a non-pharmaceutical intervention in reducing COVID-19 cases and deaths (Agyapon-Ntra & McSharry, 2023). This underscores the importance of online stances towards face coverings as a key determinant of preventive measure efficacy.

From a public health and policy perspective, this study has significant implications for pandemic management. First, understanding the distinct associations between cultural factors and online stances towards preventive measures enables public health officials to tailor strategies and interventions that align with cultural values and norms. This ultimately helps mitigate the pandemic's impact on public health. For instance, individualism negatively predicted face covering stance. Therefore, public health officials should adopt an individualistic communication approach to promote adherence to face-covering measures, such as "protect yourself" rather than "protect others." Another example is the negative associations between cultural tightness and online stances toward social distancing, quarantine, and face coverings, but not for mandated measures like lockdown and vaccination. Thus, public health officials in looser cultures should consider implementing stricter penalties for non-compliance with these affected measures.

Regarding cultural values that exhibit paradoxical impacts on online stances toward preventive measures, nuanced communication strategies are necessary. As uncertainty avoidance negatively predicted online opinions of lockdown and vaccination but positively predicted social distancing stance, distinct communication strategies are required for each measure. For example, policymakers in uncertainty-avoidant societies should focus on addressing concerns and alleviating fears related to lockdown and vaccination, both psychologically and financially. However, promoting social distancing may not require significant resources. Similarly, there was a positive impact of long-term orientation on online opinions about quarantine and a negative impact on social distancing and lockdown. Thus, in long-term-oriented societies, emphasizing long-term interests and adaptability in implementing social distancing and lockdown measures is recommended, while highlighting the short-term interests and historical traditions of quarantine is recommended in short-term-oriented countries.

Second, the identified mediating pathways offer insights into how culture impacts COVID-19 cases and deaths. These findings highlight key areas for policymakers of diverse cultural backgrounds to focus on in future pandemics, including effectively managing and guiding online responses to preventive measures upon their official announcements. To mitigate the pandemic's impact in reducing cases and deaths, public health officials should proactively mobilize digital tools and promote culturally appropriate messaging across official websites, online campaigns, and social media platforms.

5. Conclusion

In conclusion, our study provides strong evidence that culture significantly influences COVID-19 cases and deaths by shaping online opinions toward preventive measures. The results have shown that culture's impact is inconsistent across different measures. Interestingly, the same cultural value can positively associate with certain measures while negatively associating with others. These findings emphasize the importance of investigating policies' cultural congruence and relevance when exploring how culture shapes online opinions. Our research has practical implications for policymakers, emphasizing the necessity of considering cultural factors when designing public health strategies during pandemics. By aligning interventions with cultural values and effectively communicating preventive measures, policymakers can enhance greater public compliance and mitigate the spread of infectious diseases. Moreover, our study highlights the crucial role of online responses as mediators in the relationship between culture and COVID-19 cases and deaths. To effectively manage pandemic crises, public health officials must harness digital tools and navigate online opinions.

5.1. Limitations and future work

In recognizing the limitations of our study, it is important to note that our analysis is based solely on online responses from the Twitter platform, which may not fully capture the breadth of societal opinions. Although Twitter's user base is diverse, it is not perfectly representative of the entire population. For example, the user demographic has shown a slight lean towards the Democratic Party in the U.S. before Elon Musk's acquisition of Twitter (Center, 2019). To further enhance the generalizability and depth of future research, future research can incorporate additional data sources, including other social media platforms and survey data, to provide a more rounded and representative analysis of public attitudes towards COVID-19 preventive measures. This multifaceted approach will seek to mitigate the limitations of relying solely on Twitter data and broaden our understanding of societal responses to health crises.

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CRediT authorship contribution statement

Wen Shan: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Conceptualization. **Jovan Chew Yu Quan:** Software, Methodology, Data curation. **Zhengkui Wang:** Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Anurag Sharma:** Writing – review & editing, Methodology, Conceptualization. **Aik Beng Ng:** Writing – review & editing, Supervision, Resources, Methodology. **Simon See:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2024.101679.

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