Strengthening national capacities for pandemic preparedness: a cross-country analysis of COVID-19 cases and deaths

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Key words

Pandemic preparedness; national indices; COVID-19; surveillance systems; health system

Abbreviated running title

Pandemic preparedness indicators associated with better early performance

Key Messages

1. Countries with higher GHSI and IHR-SPAR index scores experienced fewer COVID-19 cases and deaths, though only for the first 8 weeks after the country's first case;
2. For the GHSI, a significant association between country ranking and COVID-19 cases and deaths is limited to countries with populations below 69.4 million;
3. For both the GHSI and IHR-SPAR, countries with a higher sub-index score in human resources for pandemic preparedness reported fewer COVID-19 cases and deaths;
4. UHC-SCI and WGI scales were not associated with COVID-19 outcomes.

Word Count

3948 words

Ethical Approval

Ethical approval for this type of study is not required by our institute.

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Declaration of Interests

All authors declare no competing interests.

Contributors

DBD and DB conceived and designed the study and DBD is the principle investigator. KG, DH, LYH, JL, CP, TTT, IV, and FV contributed to the protocol and design of the study. SB, LC, RF, BN, JP, PS, and NT contributed to the data collection of the study. AK conducted the statistical analysis. DBD, AK, DB, KG, DH, LYH, JL, CP, TTT, IV, FV, EY, SB, LC, RF, BN, JP, PS and NT contributed to the preparation of the report. All authors critically reviewed and approved the final version.

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4. UHC-SCI and WGI scales were not associated with COVID-19 outcomes.

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ABSTRACT

The International Health Regulation—State Party Annual Reporting (IHR-SPAR) and the Global Health Security Index (GHSI)) have been developed to aid in strengthening national capacities for pandemic preparedness. We examine the relationship between country-level rankings on these two indices, along with two additional indices (the Universal Health Coverage Service Coverage Index and World Bank Worldwide Governance Indicator (n=195)) and compared them to the country-level reported COVID-19 cases and deaths (Johns Hopkins University (JHU) COVID-19 Dashboard) through 17 June 2020. Ordinary least squares regression models were used to compare weekly reported COVID-19 case and death rates per million in the first 12 weeks of the pandemic between countries classified as low, middle, and high ranking on each index, while controlling for country socio-demographic information. Countries with higher GHSI and IHR-SPAR index scores experienced fewer reported COVID-19 cases and deaths, but only for the first 8 weeks after the country's first case. For the GHSI, this association was further limited to countries with populations below 69.4 million. For both the GHSI and IHR-SPAR, countries with a higher sub-index score in human resources for pandemic preparedness reported fewer COVID-19 cases and deaths in the first 8 weeks after the country's first reported case. The UHC-SCI and WGI country-level rankings were not associated with COVID-19 outcomes. The associations between GHSI and IHR-SPAR scores and COVID-19 outcomes observed in this study demonstrate that these two indices, although imperfect, may have value, especially in countries with a population under 69.4 million people for the GHSI. Preparedness indices may have value; however, they should continue to be evaluated as policymakers seek to better prepare for future global public health crises.

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Introduction

Over the last two decades, the global community has repeatedly confronted important infectious disease outbreaks, including SARS-CoV, H1N1, Ebola, Zika, MERS-CoV and the current SARS-CoV2 pandemic. Comprehensive analyses have recognized the need to improve national health security capabilities and better coordinate regional and global efforts to anticipate and prepare for outbreaks (Sands et al., 2016; Morse et al., 2012; World Health Organization, 1995; Fineberg, 2014). In 2005, the World Health Assembly adopted the revised International Health Regulations (IHR (2005)), which legally came into force in 2007. The IHR (2005), building upon previous iterations, provides a stronger framework for the World Health Organization (WHO) and member states to support country preparedness capacity development regarding public health risks and emergencies which can have devastating impacts on human health and economies, as demonstrated by the COVID-19 pandemic global impact with over 2.8 million lives and over 255 million full-time jobs lost (World Health Organization, n.d.; Gostin, 2004; International Labor Organization, 2021; Johns Hopkins University, 2021). Under the IHR (2005), member states are required to report potential public health emergencies of international concern to WHO, ensure their national health surveillance and response capacities meet certain functional criteria, have a set timeframe in which to meet these standards, and annually report this to WHO (World Health Organization, n.d.). In turn, WHO makes recommendations on measures that can be taken during public health emergencies of international concern, and is responsible for providing technical assistance and financing to member states to enhance their national surveillance and response capacities (World Health Organization, n.d.).

Since the adoption of the IHR (2005), a number of efforts have been launched to assess the progress countries have made building national capacity to respond to potential infectious disease threats (Broberg, 2020). This includes annual reporting on IHR capacities through the State Party Annual Reporting (IHR-

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SPAR) as well as the Joint External Evaluation (JEE) mechanisms. In addition, an independent group of organizations developed the Global Health Security Index (GHSI) to provide an external assessment of similar state capacities (Nuclear Threat Initiative et al., n.d.). These assessments may be used to inform national action plans, policies, and resource allocations that strengthen national capacities for health security (Nuclear Threat Initiative and Johns Hopkins Center for Health Security, 2019). Table 1 provides a detail description of the three pandemic preparedness indices.

Effective responses to epidemics and pandemics also likely depend on more than preparation, early detection, and the initial response to public health crises, which compose the underlying framework of existing preparedness indices (Broberg, 2020; Wilson et al, 2008). We therefore also examined whether a country's level of universal health coverage, as measured by WHO's Universal Health Coverage Service Coverage Index (UHC-SCI), was associated with COVID-19 outcomes. The UHC-SCI measures a country's progress towards Sustainable Development Goal (SDG) 3's target 3.8.1, which is to provide coverage of essential health services (World Health Organization, 2019a). Additionally, we examined if a country's political stability, government effectiveness, and control of corruption was associated with COVID-19 outcomes. The existing preparedness indices are more limited in their measures of these factors, which are captured by the World Bank Worldwide Governance indicator (WGI) (Kraay et al., 2010). Table 1 provides a detailed description of the three national pandemic preparedness indices, alongside the UHC-SCI and WGI.

Overall, the majority of countries have low or moderate levels of preparedness capacities as measured by IHR-SPAR, with high-scoring countries in Europe and low-scoring countries in Africa and Southeast Asia (World Health Organization, 2019b). Although the IHR-SPAR has been credited with setting clear benchmarks for improving national capabilities in the area of health security, it is limited by biases that may arise from country self-reporting (Sands et al., 2016; Gostin and Katz, 2016; Kandel et al., 2020). While JEE and IHR-SPAR scores are highly correlated, JEE scores have been found to be consistently

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lower on average than self-reported scores under IHR-SPAR, likely because it is an external assessment of a country's IHR capacities (Tsai and Katz, 2018). The GHSI shows that, collectively, international preparedness for epidemics and pandemics remains very weak (Nuclear Threat Initiative et al., n.d.). Although the GHSI methodology is comprehensive, questions remain about the skew of indicators towards priorities of high-income countries, the validity of some indicators, the scoring system and its weighting, and how the GHSI adds value to existing assessments of global health security (Razavi et al., 2020).

Two published studies have evaluated the association between preparedness indices (collectively JEE, GHSI and UHC-SCI) and COVID-19 burden. These counter-intuitively find that countries with higher preparedness scores have experienced a higher burden of cases and death (Aitken et al., 2020; Crosby et al., 2020). The objective of our study is to measure the associations between the preparedness indices and country-level daily data on COVID-19 sourced from the Johns Hopkins University (JHU) COVID-19 Dashboard. Our research adds to the limited literature and further investigates the relationship between preparedness indicators and pandemic outbreaks, making several methodological improvements on previous studies. We examine the temporal relationship and population size effects between the preparedness indices and country-level outcomes, and disaggregate the preparedness indices into sub-scales to determine which sub-scales are associated with the country-level outcomes. In addition, our study examines the association of the WGI with COVID-19. As the global community and policy makers examine how to better prepare for future pandemics and prevent the severe public health and socio-economic toll of the COVID-19 pandemic from happening again, studies on the existing tools that benchmark country-level pandemic preparedness are now more important than ever.

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Methods

Country-level daily data on COVID-19 were sourced from the Johns Hopkins University (JHU) COVID-19 Dashboard. A first research team worked to collect data on reported COVID-19 cases and deaths, extracted from 22 January 2020 through 17 June 2020.

A second research team separately collected the most recent year data for each index: 2019 for GHSI, 2019 or 2018 for IHR-SPAR, 2017 for UHC-SCI, and 2019 for WGI. Because the JEE data had more than 50% of its variables missing, the JEE index was excluded from the final analysis, leaving four indices: GHSI, IHR-SPAR, UHC-SCI and WGI.

Sovereign states and non-sovereign territories (herein "countries" for simplicity) were included if their reported COVID-19 cases and deaths were reported in the JHU database and if they were ranked by at least 1 of the indices; a total of 195 countries met our inclusion criteria. Countries that did not meet inclusion criteria were North Korea, Turkmenistan, and small island countries from the Caribbean and the Atlantic and Pacific oceans (See Supplementary Table 1 for selected data per included country). For each included country, the first day a case (herein "index case date") was identified from the JHU data repository and confirmed through independent follow-up of internet searches in national media/official government websites. The search was done in English, Mandarin, Spanish, and Hindi.

Starting with the 6th day after the index case date (T0), we divided the total number of COVID-19 cases and deaths over the immediate 7-day look-back window by the total country population and multiplied by 1 million to determine 7-day rolling daily rates of cases and deaths per million country population. A country-week level outcome data file that included a maximum of 12 possible weekly rates of cases and deaths per million for each country was created by selecting the 6th day after T0 and multiples of 7 thereafter, up until 12-weeks, or however long country data existed in the JHU repository up until 17 June 2020. This process yielded a total of 2,310 weeks of outcomes data.

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Data Analysis

The small amount of country-level missing data in item-level and total preparedness index predictors (1.5-10.3%; see Supplementary Table 2) was imputed using multiple imputation (MI; 10 imputations) by predictive mean matching in exactly one procedure that controlled for population size, region of the world and 2017 Gross National Income (GNI) from the World Bank. For scales that included a total score predictor (GHSI, SPAR, UHC) the total score was imputed sequentially in the same procedure after items were imputed. For WGI, where a total score predictor was not available, individual items were imputed and the total score was computed after the imputation procedure within each of the 10 MI datasets. To standardize metrics across each of the 4 different indices and to allow for possible non-linear associations between index scores and rates of COVID-19 cases and deaths, each index score was transformed from a continuous variable to a 3-category rank-order variable (corresponding to low, middle, and high scores) based on the within-imputation tertile cut-points of the total country-level (n=195) data. This exact process was repeated for the 6 sub-indicator preparedness indices for GHSI, and 13 for IHR-SPAR.

The final analytic dataset was created by merging the country level predictor data (ncountry=195) onto the country-week level outcomes data (nweek=2,310) and repeating this process for each of the 10 imputations. To examine the individual associations of each index with weekly rates of COVID-19 cases and death rates per million pooled across the entire 12-week study period, we used discrete-time MI ordinary least squares (MI-OLS) regression analysis with country-week as the unit of analysis. The logic of this approach is identical to that of discrete-time survival analysis. To examine whether associations between indices and outcomes varied over time, three consecutive pooled 4-week MI-OLS models were separately estimated in parallel to the 12-week models. In total, 12-week and 4-week MI-OLS models were estimated for each of the 4 total indices and only 12-week models were estimated for each of the sub-indicator indices within each total index.

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MI-OLS models included four country-level socio-demographic covariates: (1) a set of 6 dummy variables corresponding to 7 regions of the world (North America, South America, Europe, Africa, Middle East, Central and South Asia, and East Asia and Oceania); (2) a single continuous variable based on the decile-transformed rank order of per capita income (values=1-10) as defined by 2017 Gross National Income from the World Bank; (3) two continuous variables for the age distribution in the total population (%≥65 and %=15-64, with %≤14 as the reference category); and (4) a single continuous variable based on the decile-transformed rank order of total country size (values=1-10) as defined by 2018 population from the World Bank World Development Indicators. Two methodological controls were also included in the MI-OLS models: the first being a set of 11 dummy variables denoting the country-week interval in the final analytic dataset (values=1-12) and the second being another set of 11 dummy variables to distinguish the 12 consecutive weeks during which each country experienced their index case and thus began reporting outcomes data. This second methodological control adjusted for cohort effects as countries entered the analysis at different historical points in time while the first methodological control pooled, or averaged, incident weekly COVID-19 outcomes over the 12-week study period (see Supplementary Table 3).

Since COVID-19 outcomes were standardized across countries by converting summary totals into rates per million population, and since countries with large populations (i.e. China) contributed as many weeks of data to the analytic file (nweek=12) as smaller countries (i.e. Andorra), we examined whether observed associations between preparedness indices and reported COVID-19 outcomes varied based on country population by testing for an interaction of the continuous control variable for population rank order and the GHSI and IHR-SPAR.

Additionally, a sensitivity analysis was attempted using data from countries which reported testing rates. However, this disproportionately excluded countries with a smaller population and lower income countries in the Caribbean, Latin America and African nation states. This also excluded data at the

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beginning of the pandemic, as reporting of testing data typically lagged case and death data by a few weeks for countries across the world. For these reasons, these data are not included in our reporting.

Results

This study included data from 195 countries, which represent 99.5% of the population in the world as of 2018. Almost all included countries reported at least 12 weeks of COVID-19 case and death data (93.8%, range=5-12 weeks). Africa reported the lowest proportion of countries with 12 weeks of data (85.5%); the remaining 5 world regions reported at least 90.0% of countries with 12 weeks. All countries in South America and Europe reported 12 weeks of data (nweek=2,310).

Table 2 shows that overall, for the weeks 1-12 pooled model, both GHSI and IHR-SPAR demonstrated a significant association of higher index preparedness scores with lower rates of reported COVID-19 cases per million. This statistically significant finding is also observed for reported deaths per million (Table 3). This significance is mainly driven by weeks 1-4, and 5-8 after the reported index case date, and diminishes in weeks 9-12. UHC-SCI and WGI have no notable significance in correlation with our reported COVID-19 outcomes in the weeks 1-12 pooled model. Although not statistically significant, it is worth noting the directional reversal, in the association of both the UHC-SCI and WGI—countries that rank lower on these indices experience fewer reported COVID-19 cases and deaths per million. For the WGI, this finding reverses in weeks 9-12, becoming significant (countries that rank lower on WGI experience a higher reported burden of cases during weeks 9-12 after the index case date). This is not observed for reported deaths.

In a deeper analysis of tables 2 and 3, we found that a country's population size significantly interacted with the associations of the reported rates of COVID-19 cases and deaths with the GHSI ($F2=12.7-21.9$, $p<0.001$) but not with IHR-SPAR ($F2=0.2-1.6$, $p=0.198-0.790$). Table 4 (top panel) shows our sub-group analysis of the overall association of GHSI and reported COVID-19 outcomes among different groupings

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of countries with similar populations, all based on decile cut-points. This demonstrates the overall finding for GHSI was consistent across all countries in the world except for those with the largest populations (i.e. the tenth decile, countries with a population >69.5 million people), accounting for n=175 countries (Table 4, bottom panel).

Supplementary Tables 4 and 5 shows analyses of the sub-indicators of GHSI and IHR-SPAR, demonstrating which sub-indicators within their respective index are statistically significant in their association with lower ranking and increased burden cases and deaths. For the GHSI, early detection is significantly associated with reported cases burden, while health system is significantly associated with reported deaths (Supplementary Table 4). The IHR-SPAR (Supplementary Table 5) shows that legislation and financing, coordination, food safety, human resources, national health emergency framework, points of entry, and radiation emergencies all demonstrate significantly associated with reported cases and deaths.

Discussion

Our study finds that countries ranking higher in the GHSI and IHR-SPAR experienced a lower burden of reported COVID-19 cases and deaths per million during their first 12 weeks of the pandemic. Upon stratification of our analyses, a more nuanced picture emerges. Indeed, a time-dependent relationship exists between the GHSI and IHR-SPAR scores and COVID-19 outcomes; significance and predictability are higher during weeks 1-4 and 5-8 and diminish in weeks 9-12. This tailing off of the association may occur because during the initial 8 weeks of the pandemic, governments can prepare through investments, policies, and infrastructure already in-place, which are measured by the preparedness indices. These factors include capacity in the preparedness, containment, and early mitigation phases of the response (Prevent Epidemics, 2020). However, after the 8th week, other factors that are not included in the indices may become more significant. There is evidence, for example, from previous outbreaks that trust in government may be important factor explaining why people vary in their compliance with public health

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measures (Prevent Epidemics, 2020; Blair Et al., 2017; Zhu et al., 2020). This finding may also be supported by a recent analysis of the 2018 IHR-SPAR data from 182 countries, which concluded that, although governments are generally well-equipped to detect outbreaks, they are poorly prepared to prevent and respond to them (Kandel et al., 2020). This may also help explain why the WGI demonstrated a significant association with outcomes in weeks 9-12 of our analysis; countries ranking lower in governance indicators had more reported cases.

When we stratify the GHSI by country population size, the significant associative value of the GHSI is observed only for the 175 countries that have a population below 69.4 million people, and not for the 20 largest countries in the world. Although speculative, this may be because countries with very large populations (most populous 20 countries) experience more heterogeneity among cities and regions (Alesina and Spolaore 2003), face more complex issues with managing hierarchical health bureaucracies at scale (Axelsson et al 2007), are more socio-economically diverse, and many experience greater internal migration flows than countries with smaller populations (Bell and Charles-Edwards 2013). Very large countries may need a modified GHSI or several GHSI scores (i.e. sub-national scores) rather than a single composite score.

Our sub-analysis of the GHSI demonstrated that 2 sub-scales out of 6, ‘early detection’ and ‘health system’, were highly associated with reported COVID-19 outcomes. This affirms that the GHSI indicators for preparedness and response (which are in accord with the elements of the IHR 2005) and health system capacity are valid. Our finding suggests that countries that had lower capacity for early detection (which includes laboratory systems, real-time surveillance and reporting, a limited epidemiology workforce, and limited data integration between the human, animal, and environmental health sectors) were more likely to experience a higher reported burden of cases in the initial 8 weeks of the pandemic. Similarly, countries that were ranked lower on the health system sub-scale (which includes health capacity in clinics, hospitals, and community care centers; limited medical countermeasures and

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personnel deployment; low healthcare access; decreased communications with healthcare workers during a public health emergency; limited infection control practices and availability of equipment; and decreased capacity to test and approve new countermeasures) would experience more reported COVID-19 deaths in the initial 8 weeks of the pandemic; that is, the strength of a country's health system is inversely associated with reported deaths attributed to COVID-19 in the initial 8 weeks of the pandemic.

The significant sub-scales in the IHR-SPAR, although self-reported, assess whether countries have standard operating procedures, protocols, and guidelines in place to ensure public health and medical safety, including scenario planning and communication and coordination efforts. These are all likely applicable and translatable to the initial 8-12 weeks of a country's COVID-19 response. For the sub-scale with highest significance, human resource, countries that rank higher have a policy and coordination framework among training institutions, do human resource capacity mapping, and provide continuous training in relevant public health emergency areas, including field epidemiology. This is highly relevant to the initial COVID-19 response, since health workers and field epidemiologists are on the front lines of the pandemic. These countries experienced both a lower reported case and death burden than those ranking lower on this sub-scale.

We also examined other circumstances that may contribute to a country's pandemic response, such as progress towards UHC, service capacity, access to healthcare, and effective governance structures, as measured by the UHC-SCI and WGI; however, none of these showed significant relationships with outcomes. The counter-intuitive pattern of correlation (i,e, that lower ranking countries experienced fewer reported cases and deaths) suggests that these indices may be measuring other factors that are not relevant or specific to pandemic preparedness, as they were not developed for this purpose.

Our study has 3 main public policy implications. The first is that preparedness indices may be time sensitive to the different stages of a pandemic; current indices better characterize performance in the

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initial 8 weeks (i.e. preparedness, containment, early mitigation phases). Policy makers may need additional indices to assess and benchmark preparedness for public health emergencies beyond the initial 8 weeks (i.e. mitigation, suppression, and recovery phases). Second, countries should carefully examine and consider increasing investment in human resources for pandemic preparedness. Our findings show that countries which ranked highest in human resource for pandemic preparedness, as measured by the GHSI and IHR-SPAR, had lower reported COVID-19 cases and deaths in the initial 8 weeks. Finally, specific to the GHSI, a single composite score for countries with a population greater than 69.5 million may not reflect the country's level of preparedness, and population size and diversity should likely be accounted for in further iterations.

The overall findings of our study are opposite those of two other analyses, which concluded that countries that ranked higher in the GHSI experienced a higher burden of deaths and cases per million (Aitken et al., 2020; Crosby et al., 2020). This may be explained by the different methodology of our study. First, our study examined the association between a country's preparedness index score and COVID-19 outcomes at different weekly intervals, rather than the combined average case and deaths over an entire time period. Second, we simultaneously identified and controlled for possible cohort effects, as countries that experienced their index case date at similar historical points may follow similar "within cohort" COVID-19 experiences and different "among cohort" COVID-19 experiences than other countries whose index case occurred before or afterward.

Limitations

Our study is an observational study utilizing data that likely has a high degree of variability, considering the COVID-19 pandemic continues to evolve and progress. Our two main outcome variables, reported cases per million and deaths per million, have several limitations. "Cases" are the number of infections reported by each country, and early in the pandemic, each country regularly changed the testing strategy and number tested based testing capacity. This likely made reporting of infections (i.e. cases) vary

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considerably both among countries and within countries. This is a potential threat to the validity of any associations discovered. Reported death rates may be a more stable comparison among countries. In this regard, our findings that reported death rates follow the same association with indices as reported cases is encouraging. We also acknowledge that, regarding index case date, many countries are now discovering that what was first reported as the index case date is likely not the index date and is likely not a reliable indicator of the date of first introduction of SARS-CoV-2 within the country. Additionally, we did not report or directly control for country-week testing rates because of the high-level of missing testing data among countries in the JHU dataset and the high level of incomplete testing data among countries that reported testing data to JHU. To incorporate testing data requires eliminating approximately half of the countries and ultimately this study decided to present observed associations with maximum external validity.

Of necessity, the preparedness indices do not account for contextual issues such as population diversity, health care systems, service load, and patterns of co-morbidity. All are likely to increase the risk of new infectious pathogens being introduced and subsequently spread. We also did not include the JEE in the final analysis due to its small sample size. The JEE is important, since it is the only index that externally validates country reported IHR capacities. Finally, we recognize that using the indices as an explanatory tool may not be consistent with the original intent of the indices; namely, as tools for countries to gauge their level of pandemic preparedness and adjust investments and policies accordingly.

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Conclusion

As global and national policy makers re-examine how to assess, measure and benchmark country-level preparedness to better manage and prevent crises such as COVID-19, tools such as the GHSI and IHR-SPAR, although imperfect, may still have value and can be improved upon. Our findings suggest there are complexities in the ways in which these indices correlate with reported COVID-19 outcomes or fail to. We propose that future iterations of these global preparedness indices should consider different stages of an outbreak, and should possibly include sub-national scores, especially for larger countries. Better preparedness indices may help individual countries, policy makers, and the international community, better prepare for the next pandemic.

Ethical Approval

Ethical approval for this type of study is not required by our institute.

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Declaration of Interests

All authors declare no competing interests.

Contributors

DBD and DB conceived and designed the study and DBD is the principle investigator. KG, DH, LYH, JL, CP, TTT, IV, and FV contributed to the protocol and design of the study. SB, LC, RF, BN, JP, PS, and NT contributed to the data collection of the study. AK conducted the statistical analysis. DBD, AK, DB, KG, DH, LYH, JL, CP, TTT, IV, FV, EY, SB, LC, RF, BN, JP, PS and NT contributed to the preparation of the report. All authors critically reviewed and approved the final version.

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References

Aitken T, Chin KL, Liew D, and Ofori-Asenso R. (2020). Rethinking pandemic preparation: Global Health Security Index (GHSI) is predictive of COVID-19 burden, but in the opposite direction. *The Journal of Infection* **81**(2): 318-356.

Alesina A and Spolaore E. *The Size of Nations*. Boston: MIT Press, Boston 2003.

Axelsson R, Marchildon GP, and Repullo-Labrador JF. Effect of decentralization on managerial dimension of health systems. In: RB Saltman, Bakauskaite V, Vrangbaek K (eds). *Decentralization in Health Care: Strategies and outcomes*. World Health Organisation, on behalf of the European Observatory on Health Systems and Policies. New York: Open University Press, 2007.

Bell M and Charles-Edwards E. *Cross-national comparisons of internal migration: an update of global patterns and trends*. Population Division Technical Paper 2013/1. New York: United Nations, Department of Economic and Social Affairs, Population Division, 2013.

Blair RA, Morse BS, and Tsai LL. (2017). Public health and public trust: Survey evidence from the Ebola Virus Disease epidemic in Liberia. *Social Science & Medicine (1982)* **172**: 89-97.

Broberg M. (2020). A Critical Appraisal of the World Health Organization's International Health Regulations (2005) in Times of Pandemic: It Is Time for Revision. *European Journal of Risk Regulation* (April): 1-8.

Crosby S, Dieleman JL, Kiernan S, and Bollyky TJ. (2020). *All Bets Are Off for Measuring Pandemic Preparedness*, Think Global Health. [Online] Available at: https://www.thinkglobalhealth.org/article/all-bets-are-measuring-pandemic-preparedness (Accessed 1 July 2020).

ACCEPTED MANUSCRIPT

Fineberg HV. (2014). Pandemic preparedness and response--lessons from the H1N1 influenza of 2009. *The New England Journal of Medicine* **370**(14): 1335-42.

Gostin LO. (2004). International infectious disease law: revision of the World Health Organization's International Health Regulations. *JAMA* **291**(21): 2623-7.

Gostin LO and Katz R. (2016). The International Health Regulations: The Governing Framework for Global Health Security. *The Milbank Quarterly* **94**(2): 264-313.

Hogan DR, Stevens GA, Hosseinpoor AR, and Boerma T. (2018). Monitoring universal health coverage within the Sustainable Development Goals: development and baseline data for an index of essential health services. *The Lancet Global Health* **6**(2): e152-e68.

International Labor Organization. *ILO: Uncertain and uneven recovery expected following unprecedented labor market crisis*. https://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_766949/lang--en/index.htm (1 April 2021, date last accessed)

Johns Hopkins University. *COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU)*. https://coronavirus.jhu.edu/map.html (1 April 2021, date last accessed)

Kandel N, Chungong S, Omaar A, and Xing J. (2020). Health security capacities in the context of COVID-19 outbreak: an analysis of International Health Regulations annual report data from 182 countries. *Lancet (London, England)* **395**(10229): 1047-53.

ACCEPTED MANUSCRIPT

Kraay A, Kaufmann D, and Mastruzzi M. (2010). *The worldwide governance indicators: methodology and analytical issues*, Policy Research Working Paper no. 5431, The World Bank. [Online]. Available at: http://documents1.worldbank.org/curated/en/630421468336563314/pdf/WPS5430.pdf (Accessed 1 July 2020).

Morse SS, Mazet JA, Woolhouse M, Parrish CR, Carroll D, Karesh WB, Zambrana-Torrelio C, Lipkin WI, and Daszak P. (2012). Prediction and prevention of the next pandemic zoonosis. *Lancet (London, England)* **380**(9857): 1956-65.

Nuclear Threat Initiative and Johns Hopkins Center for Health Security. (2019). *Global Health Security Index: Building Collective Action and Accountability*, Nuclear Threat Initiative and Johns Hopkins Center for Health Security. [Online]. Available at: https://www.ghsindex.org/wp-content/uploads/2019/10/2019-Global-Health-Security-Index.pdf (Accessed 1 July 2020).

Nuclear Threat Initiative, Johns Hopkins Center for Health Security, and The Economic Intelligence Unit. (n.d.). *Global Health Security Index*. Nuclear Threat Initiative, Johns Hopkins Center for Health Security, The Economic Intelligence Unit. [Online]. Available at: https://www.ghsindex.org/ (Accessed 1 July 2020).

Prevent Epidemics. (2020). *COVID-19 Playbook*, Vital Strategies. [Online]. Available at: https://preventepidemics.org/wp-content/uploads/2020/04/COV040_COVID19Playbook_v2-1.pdf (Accessed 1 July 2020).

Razavi A, Erondu N, and Okereke E. (2020). The Global Health Security Index: what value does it add? *BMJ Global Health* **5**(4): e002477.

ACCEPTED MANUSCRIPT

Sands P, Mundaca-Shah C, and Dzau VJ. (2016). The Neglected Dimension of Global Security--A Framework for Countering Infectious-Disease Crises. *The New England Journal of Medicine* **374**(13): 1281-7.

Tsai FJ and Katz R. (2018). Measuring Global Health Security: Comparison of Self- and External Evaluations for IHR Core Capacity. *Health Security* **16**(5): 304-10.

Wilson K, von Tigerstrom B, and McDougall C. (2008). Protecting global health security through the International Health Regulations: requirements and challenges. *CMAJ* **179**(1): 44-8.

World Health Organization. (n.d.). *International Health Regulations*, World Health Organization. [Online]. Available at: https://www.who.int/health-topics/international-health-regulations#tab=tab_1 (Accessed 22 July 2020).

World Health Organization. (1995). *Revision and updating of the International Health Regulations*, World Health Assemby 48, Document 7.

World Health Organization. (2019a). *Primary Health Care on the Road to Universal Health Coverage: 2019 Global Monitoring Report Conference Edition*, World Health Organization. [Online]. Available at: https://www.who.int/healthinfo/universal_health_coverage/report/uhc_report_2019.pdf (Accessed 1 July 2020).

World Health Organization. (2019b). *Thematic Paper on the Status of Country Preparedness Capacities*, Background report commissioned by the Global Preparedness Monitoring Board (GPMB). [Online]. Available at: https://apps.who.int/gpmb/assets/thematic_papers/tr-2.pdf (Accessed 1 July 2020).

ACCEPTED MANUSCRIPT

Zhu Y, Fu K-W, Grépin KA, Liang H, and Fung IC-H. (2020). Limited Early Warnings and Public Attention to Coronavirus Disease 2019 in China, January–February, 2020: A Longitudinal Cohort of Randomly Sampled Weibo Users. *Disaster Medicine and Public Health Preparedness* (April): 1-4.

Table 1. Summary of National Pandemic Preparedness Indices.

Index	Background	Scale scoring system and subcomponents
International Health Regulations - State Party Self-Assessment Annual Report (IHR-SPAR)	The International Health Regulations (2005) composed a legally binding set of regulations that provides a framework for managing public health threats that have the potential to cross borders – later articulated as global health security. The State Party Self-Assessment Annual Report (SPAR), was initially introduced in 2010 as a questionnaire for country reporting to the WHO as a mandatory component of the IHR Monitoring and Evaluation Framework. After the IHR review in 2018, the IHR SPAR was revised to become more concise and evidence based. It requires member states to self-report annually on their progress toward meeting IHR core capacities. SPAR is divided into 13 categories that aim to assess preparedness for a wide range of events, including zoonotic outbreaks, food safety events, chemical events, and radiation emergencies.	Scores are self-reported on a scale from 1 to 5. These scores are then transformed into percentages. The overall score is computed as a simple arithmetic mean of the 13 indicator scores. The IHR SPAR assesses legislation and financing; IHR coordination and national IHR focal point functions; zoonotic events and the human-animal interface; food safety; laboratory; surveillance; human resources; national health emergency framework; health service provision; risk communication; points of entry; chemical events; and radiation emergencies.
Joint External Evaluation (JEE)	To respond to the limitations of the SPAR, following the Ebola outbreak in 2016, the WHO established the JEE process as a voluntary component of the IHR Monitoring and Evaluation framework. The tool was revised in 2017. National assessments are derived from initial self-evaluation, corroborated with subsequent external evaluation. JEE assessments evaluate preparedness every	Scores range from 1 to 5. The JEE does not report an overall country score (i.e. "Country Mission Report"). Scores are externally evaluated, with initial self-assessment supplied by each country. The JEE assess national legislation, policy and financing; IHR coordination, communication and advocacy; antimicrobial resistance; zoonotic

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	3-5 years across 19 categories in a wide range of core IHR areas.	diseases; food safety; biosafety and biosecurity; immunization; national laboratory system; (real-time) surveillance; reporting; human resources/workforce development; (emergency) preparedness; emergency response operations; linking public health and security authorities; medical countermeasures and personnel deployment; risk communication; points of entry; chemical events; and radiation emergencies.
Global Health Security Index (GHSI)	The GHS Index is a project of the Nuclear Threat Initiative and the Johns Hopkins Center for Health Security and was developed with The Economist Intelligence Unit. It was developed to comprehensively assess health security across 195 state parties that make up the IHR, the GHSI measures both a country's preparedness to prevent, detect, and respond to biological threats as well as elements that could exacerbate country risks for epidemics or pandemics, such as political, social, and economic stability and the strength of a country's healthcare system and health workforce. The GHSI is an external assessment which uses only publicly available data through 140 qualitative and quantitative questions, organized across six categories, in an effort to encourage mutual transparency, accountability, and improvement across countries (Nuclear Threat Initiative et al., n.d.).	Scores range from 0 to 100. The overall score is a weighted sum of the six categories, with weights determined by an international panel of experts. Scores are externally evaluated using only publicly available information. The GHSI assesses prevention of the emergence or release of pathogens; early detection and reporting of epidemics of potential international concern; rapid response to and mitigation of the spread of an epidemic; sufficient and robust health sector to treat the sick and protect health workers; commitments to improving national capacity, financing, and adherence to norms; and overall risk environment and country vulnerability to biological threats.
Worldwide Governance Indicators (WGI)	The World Bank developed the WGI to assesses governance of over 200 countries and territories through six composite dimensions of voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption (Kraay et al., 2010).	Scores range from -2·5 to 2·5. The WGI does not report an overall country score. Scores are externally evaluated. The WGI assess voice and accountability; political stability and absence of violence/terrorism; government effectiveness; regulatory quality; rule of

		law; and control of corruption.
Universal Health Coverage Service Index (UHC-SCI)	The UHC Service Coverage Index (SCI) arose out of a need to create a formal monitoring mechanism to assess country progress in attaining Sustainable Development Goal 3.8.1, coverage of essential health services among the general and most disadvantaged population. The SCI is used to advance primary healthcare as the mechanism to achieve UHC (World Health Organization, 2019a). It also attempts to capture other elements of the SDGs, such as gender and equity challenges, through tracking and disaggregating data by sex, household wealth, and geographic location when possible (World Health Organization, 2019a). The SCI assesses the average coverage of essential services in four areas of healthcare services: reproductive, maternal, newborn, and child health; infectious diseases; noncommunicable diseases; and service capacity and access (World Health Organization, 2019a).	Scores range from 0 to 100. The overall score is computed as the geometric mean of 16 proxy indicators of health service coverage organized across four areas of healthcare services: reproductive, maternal, newborn and child health; infectious diseases, noncommunicable diseases; and service capacity and access. Scores are externally evaluated. The SCI is compiled using existing, publicly available data and estimates reported by countries, however, differences across countries in definition of indicator data, data collection, and data availability results in the need to impute missing data and report changes in SCI over broader time intervals (World Health Organization, 2019a; Hogan et al., 2018). Further, despite the SCI's advantages of collecting simple, feasible, and relevant indicators for country use, the available indicators also limited to assessing contact coverage rather than effective coverage; omitting important health areas for which there does not exist robust indicators; and obscuring differences in country health needs, which drive their provision of health services (World Health Organization, 2019a).

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Table 2: Univariate associations of 4 cross-national global scales and total weekly estimated COVID-19 cases per million population based on OLS models, pooled across the first 12 weeks after index case ($n_{country}$=195; n_{week}=2,310).

	12-week Pooled[1]				*Weeks 1-4 (n_{week}=780)*				*Weeks 5-8 (n_{week}=775)*				*Weeks 9-12 (n_{week}=755)*			
			95% CI				95% CI				95% CI				95% CI	
	β	*P*	Lower	Upper	B	*P*	Lower	Upper	β	*P*	Lower	Upper	β	*P*	Lower	Upper
GHSI																
Low	109.5*	<0.001	59.0	160.0	160.3*	<0.001	74.1	246.5	117.2*	0.001	46.4	187.9	52.4	0.162	-21.1	125.8
Middle	65.5*	<0.001	29.3	101.7	112.6*	<0.001	53.0	172.2	57.1*	0.046	1.0	113.3	27.8	0.361	-31.9	87.5
High (reference)	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··
IHR-SPAR																
Low	108.1*	<0.001	66.3	150.0	148.9*	<0.001	81.1	216.7	119.6*	<0.001	54.5	184.7	59.4	0.110	-13.5	132.3
Middle	-30.2	0.063	-62.0	1.7	20.8	0.441	-32.1	73.6	-26.6	0.302	-77.1	23.9	-84.4*	0.002	-138.9	-29.9
High (reference)	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··
UHC-SCI																
Low	-1.0	0.985	-105.2	103.3	-29.6	0.709	-192.8	133.5	-48.5	0.459	-180.7	83.6	82.8	0.105	-17.3	182.8
Middle	-60.0	0.220	-161.2	41.1	-65.0	0.379	-219.7	89.6	-88.3	0.136	-207.7	31.2	-26.7	0.448	-96.1	42.8
High (reference)	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··
WGI																
Low	31.7	0.242	-21.5	84.8	-1.7	0.969	-89.2	85.8	-11.6	0.784	-94.7	71.5	107.1*	0.018	18.3	195.8
Middle	5.3	0.793	-34.0	44.6	-40.5	0.219	-105.2	24.2	-14.6	0.641	-75.8	46.7	69.6*	0.036	4.4	134.8
High (reference)	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··	0.0	··	··	··

Note. * Indicates significance at the p<.05 level. Estimates reflect multiply-imputed (MI-10 imputations), pooled country-week level data. MI-OLS models included 2 methodological controls: a first set of 11 dummy variables corresponding to weeks 2-12 after the first week of outcomes data per country (F_{11}=0.4-0.4, p=.968-.971); and a second set of 11 dummy variables corresponding to weeks 2-12 after the first week of data in the analytic sample (week 1= January 13-20 -

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Thailand, China, and Japan; F11=3.3-4.9, p=.000-.000; see Supplementary Table 3). MI-OLS models also included4 demographic controls: two continuous variables for country age structure (i.e., % population ≥65 and 15-64; F_2=5.0-7.5, p=0.000-0.006); a single continuous decile-transformed, world-based rank of country population (F_1=9.7-33.6, p=0.000-0.002); a single continuous decile-transformed, world-based rank of 2017 per capita GNI-PPP (F_1=6.3-31.3, p=0.000-0.025); and region of the world (F_6=5.7-31.3, p=0.000-0.000).
1. Variance inflation factor scores for preparedness scales (range=1.9-5.1) were below the threshold of 10, indicating that multicollinearity among scale predictors and control variables was not present in the MI-OLS models.

Table 3: Univariate associations of 4 cross-national global scales and total weekly estimated COVID-19 deaths per million population based on OLS models, pooled across the first 12 weeks after index case ($n_{country}$=195; n_{week}=2,310).

	12-week Pooled[1]				*Weeks 1-4 (n_{week}=780)*				*Weeks 5-8 (n_{week}=775)*				*Weeks 9-12 (n_{week}=755)*			
			95% CI				95% CI				95% CI				95% CI	
	β	*P*	Lower	Upper	β	*P*	Lower	Upper	β	*P*	Lower	Upper	β	*P*	Lower	Upper
GHSI																
Low	6.6*	<0.001	4.1	9.2	8.4*	<0.001	4.3	12.4	11.6*	<0.001	7.2	16.0	0.0	0.984	-3.3	3.2
Middle	2.1*	0.033	0.2	4.1	3.4*	0.034	0.3	6.6	4.7*	0.005	1.5	8.0	-1.7	0.232	-4.6	1.1
High (reference)	0.0	..	..	..	0.0	..	..	..	0.0	..	..	..	0.0	..	..	..
IHR-SPAR																
Low	5.2*	<0.001	2.8	7.6	8.0*	<0.001	4.2	11.9	8.4*	<0.001	4.5	12.4	-0.8	0.616	-4.0	2.4
Middle	0.0	0.989	-1.9	1.9	2.6	0.084	-0.4	5.6	0.9	0.549	-2.2	4.0	-3.6*	0.005	-6.1	-1.1
High (reference)	0.0	..	..	..	0.0	..	..	..	0.0	..	..	..	0.0	..	..	..
UHC-SCI																
Low	-3.8	0.078	-8.0	0.4	-0.3	0.927	-7.0	6.4	-3.6	0.314	-10.7	3.5	-7.6*	0.001	-12.1	-3.0
Middle	-3.7*	0.049	-7.4	0.0	-1.5	0.580	-7.1	4.1	-4.8	0.113	-10.8	1.2	-4.8*	0.002	-7.7	-1.8
High (reference)	0.0	..	..	..	0.0	..	..	..	0.0	..	..	..	0.0	..	..	..
WGI																
Low	-1.1	0.468	-4.0	1.8	-0.6	0.817	-5.5	4.3	-1.5	0.553	-6.5	3.5	-1.2	0.535	-5.1	2.6

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Middle	-1.1	0.316	-3.2	1.1		-1.3	0.472	-4.9	2.3	-2.2	0.237	-5.9	1.5	0.1	0.923	-2.7	3.0
High (reference)	0.0	··	··	··		0.0	··	··	··	0.0	··	··	··	0.0	··	··	··

Note: * Indicates significance at the p<.05 level. Estimates reflect multiply-imputed (MI-10 imputations), pooled country-week level data. . MI-OLS models included 2 methodological controls: a first set of 11 dummy variables corresponding to weeks 2-12 after the first week of outcomes data per country (F11=0.4-0.4, p=.968-.971); and a second set of 11 dummy variables corresponding to weeks 2-12 after the first week of data in the analytic sample (week 1= January 13-20 - Thailand, China, and Japan; F11=3.3-4.9, p=.000-.000; see Supplementary Table 3). MI-OLS models also included 4 demographic controls: two continuous variables for country age structure (i.e., % population ≥65 and 15-64; F_2=5.0-7.5, p=0.000-0.006); a single continuous decile-transformed, world-based rank of country population (F_1=9.7-33.6, p=0.000-0.002); a single continuous decile-transformed, world-based rank of 2017 per capita GNI-PPP (F_1=6.3-31.3, p=0.000-0.025); and region of the world (F_6=5.7-31.3, p=0.000-0.000).

1. Variance inflation factor scores for preparedness scales (range=1.9-5.1) were below the threshold of 10, indicating that multicollinearity among scale predictors and control variables was not present in the MI-OLS models.

Table 4: Individual association of a cross-classification of GHSI and country population size with total weekly estimated COVID-19 cases per million population based on OLS models, pooled across the first 12 weeks after index case ($n_{country}$=195; n_{week}=2,310).

			Cases				Deaths			
					95% CI				95% CI	
Panel 1	%	SE	β	*P*	Lower	Upper	β	*P*	Lower	Upper
GSHI ranking within country population [1]										
Population: > 19.5 Million										
Low	5.7	0.2	192.2*	0.002	72.9	311.5	13.9*	<0.001	7.1	20.8
Middle	9.8	0.2	210.8*	<0.001	91.8	329.9	14.3*	<0.001	7.3	21.3
High	14.4	0.2	227.0*	<0.001	105.1	348.8	16.8*	<0.001	9.9	23.6
Population: =2.8 - 19.5 Million										
Low	11.6	0.2	210.9*	<0.001	113.8	308.0	14.7*	<0.001	9.0	20.4
Middle	12.5	0.2	156.2*	<0.001	64.2	248.2	12.7*	<0.001	7.3	18.1
High	16.6	0.2	67.2	0.1	-17.2	151.6	7.0*	0.0	2.0	12.0
Population: < 2.8 Million										
Low	15.5	0.2	205.4*	<0.001	113.1	297.6	15.4*	<0.001	10.4	20.4
Middle	11.3	0.2	162.2*	<0.001	69.9	254.6	6.9*	0.009	1.7	12.0
High (reference)	2.6	0.1	0.0	··	0.0	0.0	0.0	··	0.0	0.0
Panel 2										
Population: <=69.4 Million [2]										

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Low	35.8	0.3	120.7*	<0.001	66.2	175.2	7.6*	<0.001	4.6	10.6
Middle	33.3	0.3	79.9*	<0.001	37.1	122.7	3.1*	0.007	0.9	5.3
High (reference)	30.8	0.3	0.0	··	0.0	0.0	0.0	··	0.0	0.0

Note. %=Percent distribution of the 9-category cross-classification of GHSI ranking within country population; SE=standard error of the percent point estimate. Estimates reflect multiply-imputed (MI-10 imputations), pooled country-week level data. MI-OLS models included the same 6 controls as Tables 2 and 3. The interaction of GHSI and country population in predicting cases and deaths was significant (F2=12.7-21.9, p<0.001). The interaction of IHR-SPAR and country population in predicting cases and deaths was not significant (F2=0.2-1.6, p=0.198-0.790).

1. GHSI differences were not significantly associated with cases and deaths among the highest population countries (F_2=0.5-1.5, p=.587-.220), but were separately significant among the middle (F_2=12.7-12.9; p=.001-.001) and lowest (F_2=5.3-20.1; p=.008-.001) population countries.

2. GHSI 1 Population Category (panel 2) excludes countries in the highest decile of country population in the world. Model estimates represent 30.3% of the world population.

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