Ranking Effectiveness of Non-Pharmaceutical Interventions Against COVID-19: A Review

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In this review, we examine 34 studies based on experimental data that estimate and compare the effectiveness of 12 non-pharmaceutical government interventions against COVID-19 based on cases, deaths, and/or transmission rates to assess their overall effectiveness. The studies reviewed are based on daily country-level data and cover four to 200 countries and regions worldwide with varying time intervals, spanning the period between December 2019 and August 2021. We found that the overall most effective interventions are restrictions on gatherings, workplace closing, public information campaigns, and school closing, while the least effective are close public transport, contact tracing, and testing policy.

Povzetek: Predstavljen je pregled 34 objav, ki analizirajo uspešnost ukrepov proti kovidu.

1 Introduction

Looking back at the first months of 2020, it is clear that the pandemic COVID-19 caught the world unprepared. Initially, it was unclear how contagious the virus was, how quickly it would spread, how to protect against it, and how to prevent hospital overload. To combat the spread of the virus, governments began introducing various non-pharmaceutical interventions (NPIs). It quickly became clear that some NPIs had a stronger impact on containing the pandemic than others. As a result, researchers around the world have begun to study the effectiveness of NPIs in different geopolitical regions. Despite the vaccine being developed in the last half of 2020, the spread of COVID-19 and the number of infections are still a major burden to society. As of May 2022, there have been 6.25 million COVID-19-related deaths worldwide [1].

In this paper we extend our earlier work [2]. We review related work on the effectiveness of NPIs implemented in different countries and over different time periods, with the goal of assessing and ranking their overall effectiveness. There is some similar work in the literature [3, 4, 5], but in this work we only consider studies in which conclusive evidence of the effectiveness of at least two NPIs was found. In addition, we do not include simulation-based studies. Unlike the two reviews mentioned above, our review includes time intervals from the third and fourth waves and, to the best of our knowledge, is the most up-to-date review in this regard.

The rest of this paper is structured as follows. Section 2 presents methodology for selecting the papers and ranking the effectiveness of the NPIs. In section 3, we present and analyse the results. Section 4 describes the limitations of our study. We conclude the paper in section 5.

2 Methodology

The first step in our research was to establish the criteria for selecting the papers to be included and to create a unified ranking system that would allow us to compare the rankings of NPIs in related work.

2.1 Eligibility criteria

In this review, we considered 12 NPIs from the Oxford COVID-19 Government Response Tracker (OxCGRT) [6]: school closing (C1), workplace closing (C2), cancel public events (C3), restrictions on gatherings (C4), close public transport (C5), stay at home requirements (C6), restrictions on internal movement (C7), international travel controls (C8), public information campaigns (H1), testing policy (H2), contact tracing (H3), and facial coverings (H6). The letters C and H correspond to *containment and closure policies* and *health system policies*, respectively. The 12 selected NPIs were chosen because they have been implemented most frequently and therefore cover the majority of all measures implemented worldwide.

We searched for papers written in English and published up to May 2022. We searched Google Scholar for published studies and MedRxiv for preprints. For a study to be included in this review, it had to meet the following criteria:

- studies the effect on COVID-19 related deaths, cases or transmission rate,
- compares NPIs that map to at least two OxCGRT NPIs,
- is based on experimental data and not based on forecasts/simulatons, and
- was conducted on a geographical region level (one or more), meaning that studies that only focus on selected

groups of people (e.g. people from Universities only) [7, 8] were not included.

All papers included in this review are listed in Table 3 along with their respective study settings. In the cases where the study used NPI information from a database other than OxCGRT, the NPIs first had to be mapped from the other database to the OxCGRT, based on the descriptions of the interventions in both of the documentations. If multiple NPIs corresponded to one OxCGRT NPI, their scores were averaged. In contrast, if a single NPI corresponded to more than one OxCGRT NPI, its score was applied to all corresponding OxCGRT NPIs.

2.2 Ranking the effectiveness

To rank the effectiveness of the NPIs, we used a scale of one to four, with one and four representing the most and least effective NPIs studied, respectively. The effectiveness scores from each study were first ranked and then divided into four equally sized bins, with the most effective NPIs in bin one and the least effective NPIs in bin four. The bin number corresponds directly to the value on our effectiveness scale. Note that in some studies, some of the bins may be empty, resulting in this value not being assigned to an NPI.

In the Bendavid et al. study [9], the estimated impacts were reported separately for each country studied. In this case, the values were first averaged across countries and then ranked.

In the work of Askitas et al. [26], the NPIs were classified descriptively only. C1, C2, C3, and C4 were found to be the most effective NPIs and were given a value of one. The effect of C6 was judged to decrease over time and was therefore given a value of two. C8 was judged to be less effective and was given a value of three, while C5 and C7 were judged to be negligibly effective and were given a value of four.

Li et al. [10] calculated the estimated effects one, two, and three weeks after the implementation. In this case, the scores were averaged across all three cases.

In the work of Liu et al. [11], the effectiveness of NPIs was estimated in two scenarios, where NPIs are implemented at their maximum stringency or at any stringency. The NPIs were then described as either strong, moderate, or weak in both of the scenarios. The NPIs graded strong in at least any stringency scenario were assigned value one, NPIs graded strong in maximum stringency scenario only were assigned value two. All NPIs graded moderate were assigned value three, and all NPIs graded weak were assigned value four.

In the study by Wibbens et al. [12], the effectiveness of NPIs was assessed at different intensity levels. They were first rated separately at the highest intensity and at an intermediate intensity. Then, their overall ranking was calculated as the average of the two.

The estimated effects of NPIs from all studies reviewed are summarised in Table 3. In studies in which effects were estimated but could not be ranked [13, 14, 15, 16], all NPIs were assigned a value 2. In studies in which fewer than four NPIs were considered [13, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25], values were also assigned on the basis of descriptive ranking.

3 Results

Among the 34 studies selected in this review, there are 14 works that deal with cases incidence [13, 14, 16, 21, 24, 26, 27, 28, 29, 30, 31, 32, 33, 34], 11 works that deal with reproduction number [10, 11, 18, 20, 22, 34, 35, 36, 37, 38, 39], seven works that deal with infection growth rate [9, 12, 17, 19, 25, 40, 41], and nine works that deal with mortality [15, 16, 21, 23, 28, 29, 31, 40, 42]. Note that some works deal with more than one outcome and are thus mentioned more than once. Most of the works analyse time intervals before the vaccination, however two studies [31, 34] analyse time intervals when vaccines are used. Eventhough some papers consider only a few selected countries, 24 of the works include either all US states or at least 50 countries worldwide.

Boxplots of the effectiveness values of the NPIs are shown in Figure 1. Each box extends from the lower to the upper quartile of the NPI data, with a line at the median. The whiskers extending from the box show the range of the data. The most effective NPIs overall are restrictions on gatherings (C4), workplace closing (C2), public information campaigns (H1), and school closing (C1) with mean effectiveness value of 1.91, 1.92, 2.0, and 2.08, respectively. The NPIs with moderate effectiveness are stay at home requirements (C6), cancel public events (C3), restrictions on internal movement (C7), facial coverings (H6), and international traven controls (C8) with mean effectiveness value of 2.25, 2.54, 2.58, 2.63, and 2.75, respectively. The least effective NPIs are close public transport (C5), contact tracing (H3), and testing policy (H2), with mean effectiveness value of 3.33, 3.33, and 3.75, respectively. At this point it is important to note that Herby et al. [5] determined that lockdowns, which we find to have a moderate effect, only reduced deaths by 0.2–2.9 %.

4 Limitations

This review has the following limitations. Because the studies included in the review are based on experimental data, the NPIs are always used simultaneously, whereas the final results of the NPI effects are reported individually. Because combinations of NPIs active at the same time were very similar in different regions and time intervals, it is sometimes difficult to justify treating the effects separately.

In some papers, NPIs were not ranked, so these NPIs receive the same value in our study. In addition, some effectiveness values were assigned based on descriptive ranking.

Results are reported here as steady-state rankings, even though the effects of NPIs will change as they are imple-

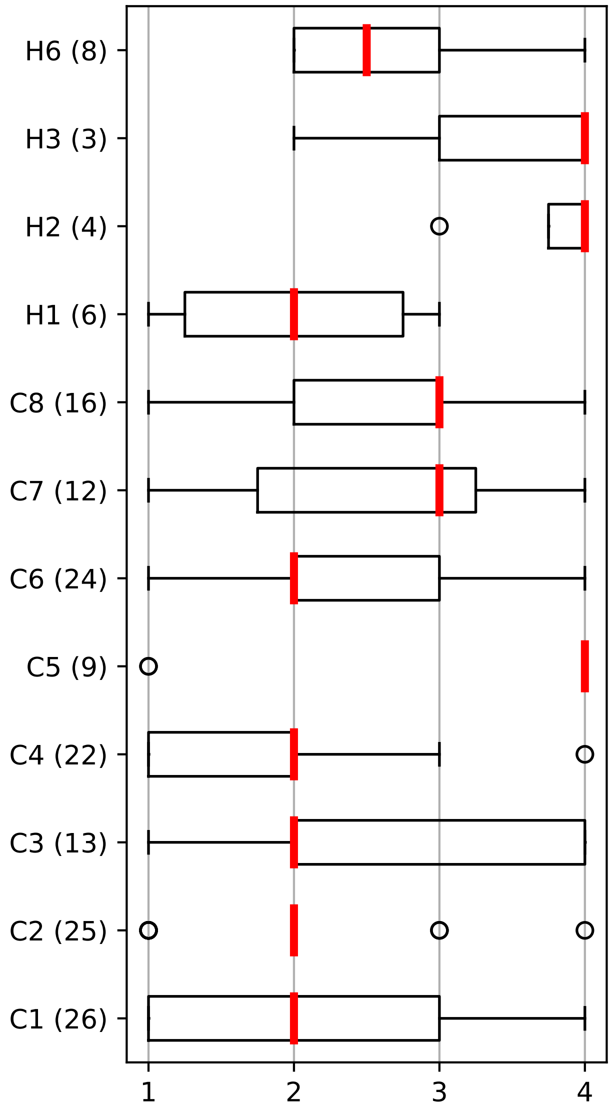

Figure 1: Boxplot of the NPIs' effectiveness. Value one corresponds to the maximum and four to the minimum effectiveness. The numbers in parentheses indicate the number of times the NPIs occurred in the studies examined.

mented (e.g., as people stop complying with restrictions on gatherings, as vaccines are developed, etc.). In addition, the time intervals studied vary in length, and the effects could differ between short and long intervals, as the effects of some NPIs diminish over time [43]. The NPIs are implemented with different stringency according to the Oxford database. This means that our results apply only to the average levels of stringency at which the NPIs can be implemented. Some NPIs may be much more effective (less effective) when implemented with higher (lower) stringency.

5 Conclusion

In this work, we reviewed 34 studies that assessed the effectiveness of 12 non-pharmaceutical interventions against COVID-19. The studies are all based on experimental data and cover up to 200 countries and regions worldwide with different time intervals covering time span between December, 2019 and August, 2021. We found that the overall most effective interventions are restrictions on gatherings, workplace closing, public information campaigns, and school closing. The interventions with moderate impact are stay at home requirements, cancel public events, restrictions on internal movement, facial coverings, and international travel controls. The interventions with the least amount of impact are close public transport, contact tracing, and testing policy.

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Table 1: Studies included in this review.

Authors	NPI data source	Countries covered	Time interval
Askitas et al. [26]	OxCGRT	175 countries	unclear
Banholzer et al. [27]	Collected by the authors	USA, Canada, Australia and 17 EU countries	Feb – May, 2020
Bendavid et al. [9]	COVID-19 policy data-bank	10 countries	Dec, 2019 – June, 2020
Bo et al. [35]	Collected by the authors	190 countries	Jan – Apr, 2020
Brauner et al. [36]	Collected by the authors	41 countries	Jan – May, 2020
Chan et al. [32]	WHO and John Hopkins University	50 countries	Dec, 2019 – June, 2020
Chaudhry et al. [28]	Collected by the authors	50 countries	Dec, 2019 – May, 2020
Chernozhukov et al. [17]	COVID Tracking Project	USA	Mar – June, 2020
Deb et al. [29]	OxCGRT	129 countries	Dec, 2019 – May, 2020
Dreher et al. [18]	unclear	USA	Dec, 2019 – Apr, 2020
Ebrahim et al. [19]	Hikma Health	1320 US counties	Mar – July, 2020
Esra et al. [37]	WHO-PHSM	26 countries and 34 US states	Dec, 2019 – May, 2020
Flaxman et al. [20]	unclear	11 EU countries	Feb – May, 2020
Gokmen et al. [33]	Our World in Data	4 countries	Dec, 2019 – June, 2020
Haug et al. [38]	CCCSL	56 countries	Dec, 2019 – Aug, 2020
Hunter et al. [21]	IHME	30 European countries	Dec, 2019 – Apr, 2020
Islam et al. [30]	OxCGRT	149 countries	Dec, 2019 – May, 2020
Jalali et al. [14]	Collected by the authors	30 US states	Mar – May, 2020
Jüni et al. [13]	Collected by the authors	144 worldwide regions	Dec, 2019 – Mar, 2020
Koh et al. [39]	OxCGRT	170 countries	Jan – May, 2020
Leffler et al. [15]	OxCGRT	200 countries	Dec, 2019 – May, 2020
Li et al. (a) [10]	OxCGRT	131 countries	Jan – July, 2020
Li et al. (b) [40]	NSF spatiotemporal center	USA	Mar – July, 2020
Liu et al. [11]	OxCGRT	130 countries and territories	Jan – June, 2020
Olney et al. [22]	Collected by the authors	USA	Feb – Apr, 2020
Papadopoulos et al. [16]	OxCGRT	151 countries	Jan – Apr, 2020
Piovani et al. [23]	OxCGRT	37 members of OECF	Jan – June, 2020
Pozo-Martin et al. [41]	OxCGRT and WHO-PHSM	37 members of OECD	Oct – Dec, 2020
Sharma et al. [31]	Collected by the authors	7 EU countries	Aug, 2020 – Jan, 2021
Stokes et al. [42]	OxCGRT	USA and 7 countries	Dec, 2019 – June, 2020
Wang et al. [34]	OxCGRT	139 countries	Dec, 2019 – Aug, 2021
Wibbens et al. [12]	OxCGRT	40 countries and US states	unclear
Wong et al. [24]	OxCGRT	139 countries	Mar – Apr, 2020
Zhang et al. [25]	NY Times and CNN	USA	Feb – Aug, 2020

Table 2: Estimation of effectiveness of NPIs in reviewed studies.

Study	C1	C2	C3	C4	C5	C6	C7	C8	H1	H2	H3	H6
Askitas et al. [26]	1	1	1	1	4	2	4	3				
Banholzer et al. [27]	2	2		1		4		3				
Bendavid et al. [9]	3	4	3	2	1	1	4	3				
Bo et al. [35]	1		1	1		3	4	4				2
Brauner et al. [36]	1	2		1		3						
Chan et al. [32]			4	4			1	1			2	
Chaudhry et al. [28]		2		2		2		3				
Chernozhukov et al. [17]		2				2						3
Deb et al. [29]	1	2	2	2	1	1	2	1				
Dreher et al. [18]	2	2				1						
Ebrahim et al. [19]		2				3						
Esra et al. [37]		3	3			1						2
Flaxman et al. [20]	4		4			3						
Gokmen et al. [33]	4	1	4	2	4	2	3	3				
Haug et al. [38]	1			1	4	3	3	2	2	3		
Hunter et al. [21]	1	2		3								
Islam et al. [30]	2	2		1	4	3	3					
Jalali et al. [14]	2											2
Jüni et al. [13]	2	2		2								
Koh et al. [39]		1				2	2	3				
Leffler et al. [15]	2		2					2				2
Li et al. (a) [10]	1	2	1	3	4	2	3	4				
Li et al. (b) [40]		2	2			3			1			
Liu et al. [11]	1	1	2	2	4	3	1	4	3	4	4	
Olney et al. [22]	2			1		1						
Papadopoulos et al. [16]	2	2						2	2			
Piovani et al. [23]	3			2								
Pozo-Martin et al. [41]	3	2		1						4		4
Sharma et al. [31]	4	1		2		3						3
Stokes et al. [42]	1	2		3				3				
Wang et al. [34]	3	3		2		2						
Wibbens et al. [12]	2	1	4	3	4	2	1	3	3	4	4	
Wong et al. [24]	3	2							1			
Zhang et al. [25]						2						3