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Personal protective equipment for healthcare workers during COVID-19: Developing and applying a questionnaire and assessing associations between infection rates and shortages across 19 countries☆

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ABSTRACT

This study aimed to assess the preparedness of European countries regarding personal protective equipment (PPE) for health and care workers (HCWs), the COVID-19 infection rates of HCWs compared to the general working age population, and the association between these. We developed a PPE-preparedness scale based on responses to a questionnaire from experts in the Health Systems and Policy Monitor network, with a response rate of 19 out of 31 countries. COVID-19 infection data were retrieved form the European center for Disease Prevention and Control. Shortages of PPE were found in most countries, in particular in home care and long-term care. HCW infection rates, compared to the general population, varied strongly between countries, influenced by different testing regimes. We found no relationships between HCW infection rates, PPE preparedness and shortages of PPE. Improved surveillance in the population as well as for HCWS are needed to be able to better assess these relationships.

1. Introduction

At the onset of the COVID-19 pandemic in early 2020, health and care workers (HCWSs) were one of the most exposed professional groups. Evidence on whether HCWs had a higher risk of infection with the disease compared to the general population is, however, mixed. Some studies in Europe and the USA showed a higher risk [1-8], other studies not [9-12]. Studies nevertheless show less severe outcomes in HCWs compared to the general population [2,3,7,9,13-17]. Evidence on which groups of HCWs were affected most is mixed. While some studies reveal high rates of infection and death among GPs [15,18,19] and nurses outside the hospital setting [18], some studies found that physicians in general had higher risk of contracting COVID-19 compared to nurses [13,20], whereas others found the reverse [1,8]. In some countries, infections and mortality were especially found among older healthcare workers compared to younger counterparts [18,19,21-23].

Appropriate use of personal protective equipment (PPE) is efficacious in preventing the transmission of viral respiratory pandemic pathogens [24], and the use of PPE is effective in preventing HCWs from an infection while caring for patients [25]. However, during the first COVID-19 wave (February and July 2020), shortages in PPE were reported in many countries in Europe. According to the COVID-19 Health Systems Response Monitor that collected and organized information on how countries were responding to the crisis in 50 participating countries in the WHO European Region, 26 reported PPE shortages, especially during the early months of the pandemic, although information on PPE was not requested in a systematic manner [26].

Lack of a sufficient supply of appropriate PPE [1,4,5,11,18,21,22,27-31], alongside a lack of knowledge on how to properly use PPE and insufficient infection prevention measures [5,11,16,30] contributed to the risk of infection among HCWs. Moreover, general lack of knowledge on the transmission of the virus at the start of the pandemic, and a high

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workload were important factors for infections among HCWs [1,10,21,27,28]. Guidelines on the appropriate use of PPE were an important prevention measure [30]. The implementation of a training protocol for dealing with COVID-19 patients but also lessons learnt during the SARS epidemic have most likely contributed to low infection rates among HCWs in China [11]. The PPE preparedness of a country in particular in terms of availability and proper use of PPE seems to have an impact on infection rates of HCWs during a pandemic. However, little is known about the relationship and effect of PPE preparedness on HCW infections rates from a cross-country comparison.

Given the severe availability and management problems of PPE in health and care settings in Europe, we seek to analyze whether some countries have performed better than others in regard to preparedness of PPE during the first months of the pandemic and whether this had implications for the protection of the health and care workforce. This paper therefore investigates how prepared European countries were with regard to PPE and whether HCW infection rates are linked to countries' preparedness in regard to PPE. We aim to disentangle the relationships between the various dimensions of PPE preparedness, defined as pre-pandemic PPE stockpiling, HCW training, PPE guidelines and PPE governance, and shortages of PPE and the actual HCW infection rates, during the first COVID-19 wave in 19 European countries. We will answer the following research questions:

- how prepared were European countries regarding PPE across different health and care settings?
- how strongly were HCWs affected regarding the infection rate compared to the rate in the general population?
- Were PPE shortages and PPE preparedness related to the HCW infection rate compared to the general population?

We conducted a cross-country survey with experts on the countries' PPE preparedness to build a composite indicator on 'PPE Preparedness' and used data from the European Centre for Disease Prevention and Control (ECDC) to identify HCW infection rates compared to the general population.

2. Materials and methods

Data for this study were taken from two sources: 1) a PPE preparedness questionnaire prepared by the authors to capture information on preparedness; 2) the European Surveillance System (TESSy) database of the ECDC, for information on COVID-19 infections in the general population and among HCWs in European Union (EU) countries.

2.1. Development and analysis of the PPE preparedness questionnaire

2.1.1. PPE dimensions

PPE preparedness is operationalized along four dimensions: stockpiles of PPE, guidelines for the use of PPE, training materials and requirements, and governance. For each dimension questions were developed, resulting in a total of eight questions. In addition, we asked two questions about shortages of PPE (appendix 1).

For the stockpiling dimension, we asked whether countries had emergency stockpiles of PPE and whether these were adequate for protecting against COVID-19. For the guideline dimension we asked for each healthcare sector whether national or regional guidelines were in place and what type of PPE was recommended. We also asked whether standards on the type of PPE to be used and under what circumstances, were lowered because of shortages. For the training dimension we asked whether instruction materials were available and through which body they were provided and whether providers were required to train staff in the use of PPE. For the governance dimension we asked questions concerning to the perceived fairness of PPE distribution, whether there was a monitoring system in place and whether any sector was prioritized in receiving PPE. While not included as a dimension of preparedness, we asked questions on shortages for each sector. These included whether any shortages lead to healthcare workers that could not protect themselves adequately and whether health services were stopped due to PPE shortages. For each dimension, an open question was asked to provide the opportunity to nuance the answers or provide important information that would be missed when only answering the yes/no questions.

2.1.2. Health and care sectors

As in some countries some sectors appeared to be better served with PPE, we distinguished between the following sectors: primary care, hospital care, long-term care in institutions and home nursing. We added ambulances as a specific sector, because of the direct contact of personnel with patients with (suspected) COVID-19 that needed to be transported to or between hospitals.

2.1.3. Time frame

The questions related to the peak of the first wave, which is for almost all countries between February and July 2020.

2.1.4. Respondents

We asked the members of the Health Systems and Policy Monitor (HSPM) network (This was a hyperlink: https://eurohealthobservatory.who.int/monitors/health-systems-monitor/overview) to fill out the questionnaire (one expert or expert group per country) or to forward it to someone who was considered to be more knowledgeable on the topic. This was up to the discretion of the HSPM member who received the questionnaire. The HSPM network is an international network of high profile institutions with a prestigious reputation and academic standing in health systems and policy analysis. The HSPM network largely overlaps with the experts who contributed to the COVID-19 Health Systems Response Monitor.

2.1.5. Testing and validation

The questionnaire was discussed during the annual meeting of the HSPM network in October 2021. The questions were presented, and we assessed the feasibility of answering them and made adaptations were the HSPM members suggested improvements. The results of the PPE preparedness scale were presented at the annual meeting of the HSPM network in October 2022. As a validation of the results, the HSPM members were asked whether they could agree with the position of their country on the PPE preparedness scale. This did not lead to adaptions or objections. We did not validate the PPE questionnaire with external data.

2.1.6. Data collection

The questionnaire was sent out to the European part of the HSMP network, containing 31 countries, on 22nd July 2021. Reminders were sent to non-responders in August 2021 and April 2022.

2.1.7. Analysis

To answer the first research question, we will provide a narrative description of the answers to the PPE preparedness questionnaire. Answers to the open questions will be used as illustrations of the kind of problems encountered.

For the statistical analysis we have constructed a PPE preparedness scale, using hierarchical latent variable regression in MLwiN with the items of the questionnaire nested in countries. We have used a selection of questions, some recoded, to reach a set of items that, combined, resulted in a scale with sufficient reliability to be used in further analysis. The following items (the numbers refer to the questions, see appendix 1) have been used to construct the scale:

- The question about stockpiles (Q1b; coding: no stockpiles or stockpiles not suitable=0; Yes, some items suitable=1; Yes, all items suitable=2).

- The questions on guidelines (Q3), on training of staff (Q4b) and on prioritization of sectors (Q5c) were counted per sector. This resulted in five items relating to guidelines, training and prioritization for the sectors primary care, ambulances, hospitals, long-term care facilities, and home nursing.
- The question on availability of instruction materials for the appropriate use (Q4a) was used separately by adding the 'yes'-answers, divided by the number of valid responses.
- For the questions on procurement and distribution of PPE (Q5a) and monitoring of the available supply (Q5b) the 'yes'-answers were added and divided by the number of valid responses (the yes plus no answers).

2.2. Data on infection rates

To answer the second research question, data on COVID-19 infection rates for HCWs and the general population were collected by ECDC and made available through the TESSy database. An application for the use of these data was filed on 09th June 2021, with permission for access granted for individual level and aggregate data on 16th June 2021. TESSy data must be interpreted with caution due to differences in data quality and methods of data collection across EU members states.

We focused on whether HCWs, defined as "those who work in healthcare settings who may come into contact with patients (including clinical administration staff, and home care staff)" (https://www.ecdc.europa.eu/sites/default/files/documents/Variable_Dictionary_VaccineTracker-15–03–2022.pdf) were experiencing higher infection rates compared to the general population, by dividing the infection rates of HCWs with the infection rates in the general population in the same age group (working age), resulting in the infection rates of HCWs as percentage of cases in the general population, including HCWs. We could not calculate the percentage of infections among HCWs due to lack of data on the size of the health and care workforce per country. We validated the infection rates of the general population with the international data source Our World in Data (Our World in Data, 2022; https://ourworldindata.org/). Infection rates for all countries matched, apart from Estonia and Poland which might be due to the fact that national authorities reported data retrospectively after data retrieval from ECDC.

For Spain only aggregated data were available in the TESSy database at the level of the general population and of all healthcare workers. Hence, for the general population, the figures include both working and non-working age population and there is no information available on unknown HCW status.

For the UK and Germany data from the TESSy database was not available. Instead, we used secondary data from national and regional studies. For Germany, we used the share of infected HCWs out of the general population in the city Frankfurt/Main based on surveillance data from 1 March to 31 August 2020 [32]. For the UK, we found reliable information on the risks of COVID-19 by occupation in NHS workers during the first COVID-19 wave only for England [33].

The TESSy data were prepared as follows:

- We included all cases of COVID-19 in individuals aged 20–69 years (working age), reported to TESSy between February 2020 and 31 July 2020 from countries that had at least 80% internal completeness of HCW status. This led to the exclusion of Malta, Austria, Sweden, Norway and Romania (more than 20% missing values or unknown on HCW status). Fig. 1 shows all countries with incomplete information on HCW status (total number of cases with unknown HCW, cases with NULL values for HCW status over total cases).
- We summed all COVID-19 cases reported to ECDC and all health care workers infected with COVID-19 between age 20–69 and calculated the proportion of the infected health workers over the general population in working age (20–69 years).

2.3. Infection rates related to PPE preparedness

To answer the third research question, on the relationship between PPE and infections among HCWs, we have calculated Spearman rank correlations between the PPE preparedness scale, the reported shortages of PPE, and the HCW infection rate as compared to the infection rate in

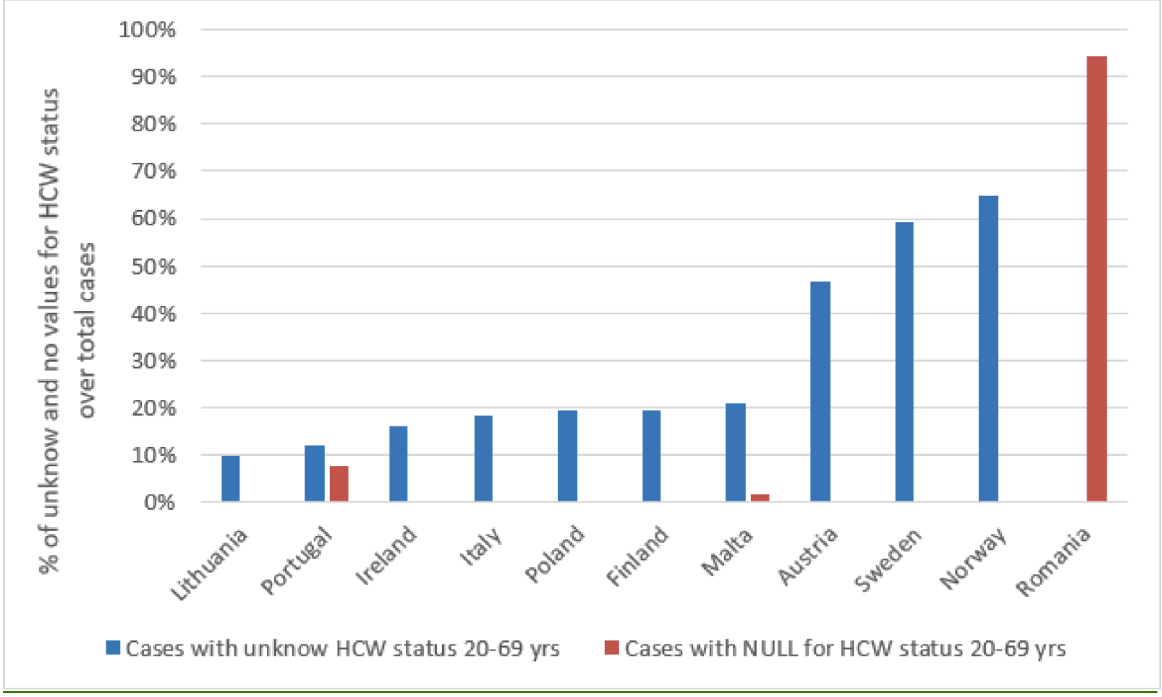

Fig. 1. Countries with incomplete information on HCW status.
Source: ECDC, HCW aged 20–69 years (working age), reported to TESSy between February 2020 and 31 July 2020 from countries that had at least 80% internal completeness of HCW status

the general population. Given the small number of countries with complete data on these variables, we have used a p-value of 0.10. As the data for three countries (Germany, Spain and UK) are based on a different source, we also performed a sensitivity analysis by re-calculating the correlations, leaving these countries out.

3. Results

Out of the 31 countries that were asked to participate, nineteen countries returned their questionnaire: Cyprus, Czechia, Denmark, England, Estonia, Finland, Germany, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Spain, and Switzerland.

3.1. Shortages

The questionnaire contains a section on shortages which is not part of preparedness but rather a consequence. This section shows that in nine countries, shortages existed in all sectors and there was no country without a shortage in at least one sector. Here Fig. 2 Shortages of PPE in the home care and long-term care sector were reported by most countries, while for the ambulance sector shortages were reported by the fewest countries. As an example, in the Netherlands, for all types of PPE there were shortages, with face masks especially scarce. In care outside hospitals, the use of PPE as a preventive measure by HCWs (i.e. with patients with no (suspected) COVID-19 infection) was deemed unnecessary and thus in view of shortages undesirable, according to the guideline update of the National Institute of Public Health of April 2020. the guideline update of August 2020 – that is by the end of the first wave – advised the preventive use of PPE. In long-term care, officially there was no scarcity according to the then existing guidelines, but with hindsight, protection appeared insufficient. Surgical masks were considered sufficient and only for when the contact lasted more than 15 min. However, workers in this sector felt differently and demanded better protection for their patients and themselves. The long-term care sector sought creative solutions, such as obtaining PPE from animal clinics and beauty salons[34]. Slovakia had a very mild first wave, and since most non-urgent care was put on hold, there was no strong demand for PPE. However, in primary care there were shortages and fear of COVID-19 which caused many providers to limit their services.

In nine countries health services were stopped due to shortages. Even if they were not stopped, the healthcare workforce was not properly equipped (as reported for Switzerland). In Italy, the need to optimize the use of PPE was one of the factors that contributed to the suspension of some non-urgent services and the shift to remote modes of care. The shortage also impacted the number of visitors allowed and required a revision of inpatient check-ups (for example, check-ups and distribution of food were joined to minimize entries in each room). Although there was a shortage on PPE in several countries, most of them reported that health services were not stopped due to this shortage. In some of them, there were postponed services, e.g. elective health care (Ireland, Malta, Poland, Finland, Germany), but in many the service providers coped with the emergency situation facing the unsolved shortage (Denmark in LTC, Hungary in home nursing, Netherlands, Spain, Switzerland, UK).

3.1.1. PPE preparedness

Table 1 contains the frequencies from the PPE-questionnaire.

3.2. Dimension one: stockpiles

Six out of nineteen countries did not have PPE in stock. From those countries that had PPE in stock, only three countries had PPE suitable for use; in the remaining countries only some of the PPE items in stock were suitable. Emergency stockpiles existed in Italy, but not at the volume as required by the National Pandemic Plan. Malta's available stockpile was linked to previous preparedness for Ebola and some items were missing. PPE was kept in stock in Switzerland, but some of the surgical/FFP masks were out of date, there was a general lack of material, and the repartition of PPE was inadequate. It was the responsibility of health institutions/regions to stock emergency material, which was not always respected nor controlled. In Finland the lack of common understanding on legal responsibility and the outsourcing of the storage services became major factors of PPE shortage in case of some providers. In Cyprus, with a mix of public and private health care, the stockpile was mostly for public providers. Luxemburg had stockpiles of PPE and a national supply of PPE was set up very early; individual providers

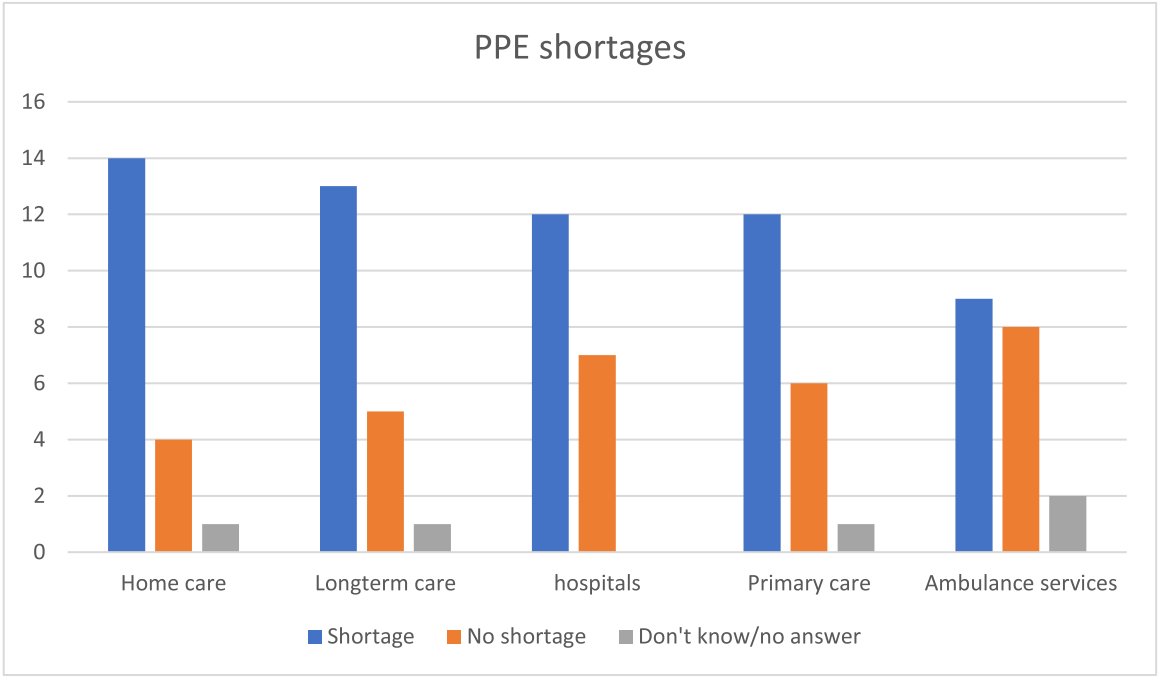

Fig. 2. Number of countries with shortages of PPE by sector (19 countries).

Table 1
Frequencies of the answers to the PPE-questionnaire (19 countries).

	Yes	No	Don't know/ no answer		
Prepandemic stockpile					
Stockpile present?	12	7	0	**Yes, all items**	**Yes, some items**
Suitable for COVID-19?	10	3	6	3	7
Guidelines					
For primary care	18	0	1		
For ambulance services	18	0	1		
For hospitals	19	0	0		
For longterm care	17	1	1		
For home care	15	2	2		
Training					
Instruction materials available from:					
National/regional healthauthorities	17	0	2		
Employers	10	0	9		
Professional bodies	7	0	12		
Were providers required to train staff?					
In primary care	11	1	7		
In ambulance services	13	1	5		
In hospitals	13	1	5		
In long-term care	12	1	6		
In home care	9	1	9		

Governance	Yes, all health and LTC	Yes, all health, but not LTC	Yes, hospitals only	Don't know/no answer
Coordination of procurement and distribution	18	1	0	0
Monitoring system in place?	12	1	3	3
Was there prioritization for:	**Yes**	**No**	**Don't know/no answer**	
Primary care	3	1	15	
Ambulance services	2	0	17	
Hospitals	7	0	12	
Long-term care	3	1	15	
Home care	2	1	16	

(mainly primary care) were supplemented with masks but there was no assessment undertaken to assess if this supply was adequate to cover their needs. The responsibilities for stockpiles of PPE in Germany are allocated at federal, regional and local level and are organised through various stakeholders, resulting in different approaches to stockpiling. Stockpiles were not sufficient and there was no large national stockpile. In Latvia, no national stockpiles existed; each health service provider was responsible for supplying PPE for their own needs. In Czechia the Supreme Audit Office [35] concluded that the state of emergency stocks of PPE, which the Administration of State Material Reserves had in its warehouses, has not changed since 2011. The total volume of PPE stocks was negligible, compared to the real need and could not solve the critical shortage in the first weeks after the declaration of the Emergency state (March 12).

3.3. Dimension two: guidelines

Guidelines for the use of PPE were available in all countries and with only two exceptions for all settings (one exception is no guidelines in LTC and home nursing; in the other country there were no guidelines in home nursing). In Portugal, the use of PPE by health professionals followed strict criteria. A decision algorithm for the use of PPE was created by the Portuguese Directorate General of Health, covering the different health contexts.

During the first wave of the pandemic guidelines evolved according to new evidence (Spain), and feedback from the field was taken into account (Luxemburg). Also, due to shortages mask and gowns were cleaned and reused (Germany, Spain, the Netherlands for nursing homes) and sometimes homemade equipment was used (Spain). In Germany, FFP2 and FFP3 masks could be reused under certain circumstances (e.g. no activities on infectious patients with pronounced exposure to aerosols) by medical personal in health care facilities and residential facilities through professional reprocessing, e.g. for the duration of an entire shift. Face masks could be reused if there was a temporary shortage of protective material. The reuse requires appropriate handling in regard to personalization, collection and decontamination. With a few exceptions, the standard on PPE use lowered over time due to evidence-based decisions or shortage or both. Reportedly, having "shortage-driven" guidelines was quite typical. In Estonia the use of PPEs that was over their shelf life was accepted, if no other PPE was available (based on the principle that it is better to use expired PPE than no PPE at all). Specific guidelines were available in Luxemburg for different settings and types of care (e.g. FFP2, head cover and apron for aerosol-producing procedures); three levels of PPE availability were distinguished: available, risk of limited supply, and shortage and guidelines were adapted accordingly. For Malta was reported that WHO and EU recommendations helped in adjusting very strict conditions for PPE without lowering quality standards (e.g. only FFP3 masks versus other filtered masks) making procurement more successful.

3.4. Dimension three: training

Appropriate use of PPE requires instruction materials and training. In seventeen countries instruction materials were publicly available from national/regional health care authorities; in ten countries these materials were (also) available from employers and in seven countries they were (also) available from professional bodies. For example, the Dutch College of General Practitioners provided ample instructions on infection prevention for GPs on their website (https://corona.nhg.org/infectiepreventie/; chapter 2 and 3). Also in the Netherlands, training materials, posters, instruction materials and protocols for correct use of PPE and hygiene measures in the long-term care sector were shared among institutes to learn from each other and to prevent that each institute had to re-invent the wheel.

Only two countries had no requirement for care providers to train staff in the use of PPE in any of the settings. In eight countries this was required and in thirteen in some of the settings. Experts in three countries did not know. A survey performed among Spanish nurses at the end of May 2020 showed that three out of four nurses felt they needed more training, whereas around 36% declared that they did not receive any training. (https://www.satse.es/comunicacion/sala-de-prensa/notas-de-prensa/5.500-enfermeras-y-enfermeros-graves-por-la-covid-19) Online education on the use of PPE was developed in Luxemburg and Italy and made publicly available; in-person training sessions for LTC facilities and home nursing were provided (Luxemburg). HCWs in Switzerland were already trained to use PPE before the pandemic, as part of their medical education. Continuous training was provided in most medical facilities. There was also PPE training in Cyprus for volunteer citizens, who did home visits (not nursing care). In Hungary, HCWs received training by using special materials and videos or by having group training.

3.5. Dimension four: governance

In all but one country there was organised coordination (either national or regional) of procurement and distribution of PPE during the first wave to ensure fair distribution and prevent competition between individual health and social care providers. In this one country, such coordination existed in all health care settings except for LTC. In the Netherlands, initially no national coordination of PPE supplies existed. This was installed only during the pandemic (end of March 2020) in the

form of a National Consortium for PPE and medical equipment, to monitor demand and distribute available PPE. Malta had national coordination through centralised procurement for the National Health System.

Monitoring of the available supply of PPE to determine when it would run out was in place in sixteen countries for at least some health care settings, and of these in twelve countries in all settings. Prioritization for receiving PPE (either based on official guidance or in practice if there was no official guidance) was reported from all but three countries for at least part of the settings. Hospitals were, according to the experts, prioritized (explicitly or implicitly) in most countries. Primary care, LTC and home nursing were only incidentally prioritized. There was no official prioritization in Denmark; however, in March 2020, the authorities decided that regions should be prioritized (over municipalities) in terms of protective equipment implying that hospitals and GPs had PPE, while nursing homes were lacking PPE. In Estonia, emergency care settings were prioritized (hospitals and ambulance care). In Latvia these were prioritized, based on infection risk. Also in Italy, prioritization was based on risk exposure. The Swiss federal government as well as some hospitals bought counterfeited masks from a Swiss company at a very high price which caused a national scandal. (https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-82620.html, DE/FR/IT). In Czechia, prioritization in general was according to the exposure to infected patients and not to the setting; however, the large number of single-handed primary care practices, even though primary care physicians were known to be at risk, prevented sufficient supply of PPE during the first wave.

3.5.1. PPE preparedness scale

The PPE preparedness scale, constructed on the basis of the responses to the questionnaire, has a reliability (comparable to Cronbach's alpha) of 0.71. This is satisfactory for use in further analyses. Fig. 3 gives the scale value for each country and the 95% confidence interval. The red line is the average over all countries (2.3). Czechia, the Netherlands, Slovakia and England have a significantly lower PPE preparedness scale than average, while Hungary, Ireland, Poland and Italy are significantly above average.

3.5.2. Infection rates of healthcare workers compared to the general population

Data on HCW infection rates was available for 21 countries. On average, nearly one in five persons infected with COVID-19 during the first wave was a HCW. However, there is large variation among the countries, with relatively high to very high infection rates in England, Ireland and the Netherlands and low rates in Luxembourg, Austria, Germany and many new EU member states (see Fig. 4 and Appendix table 1). The proportions of infected HCWs range from about 5% to nearly 50%. Inevitably reported infection rates among the population and HCWs is heavily influenced by testing regimes and laboratory capacity at the time of the first wave. For instance, England prioritised testing among HCWs whereas Luxembourg implemented wide-scale population testing quicker than many other countries in Europe. This should be taken into account when interpreting results.

3.5.3. Relationship between PPE preparedness scale, HCW infection rate and shortages of PPE

For seventeen countries data are available on both the PPE preparedness scale and the number of infections among HCWs relative to the number in the total population. The Spearman rank correlations between the PPE-scale and HCW infection rates, and between PPE-scale and HCW infection rates and shortages of PPE do not reach statistical significance (Appendix Table 2). The four countries with lowest preparedness scores have on average 27.0 HCW cases relative to the cases in the total population, the middle nine countries 13.3 HCW cases and the four countries with the highest preparedness scores have on average 27.1 HCW cases. All in all, there is no clear relationship between the PPE preparedness scale and the relative number of cases among HCWs. This lack of association between the two variables is illustrated in Fig. 4. The average percentages of cases among HCWs relative to the number in the total population is 14.2% in the countries without shortages of PPE and 22.8% in the countries with shortages. We found no significant relationships between reported shortages and the relative number of

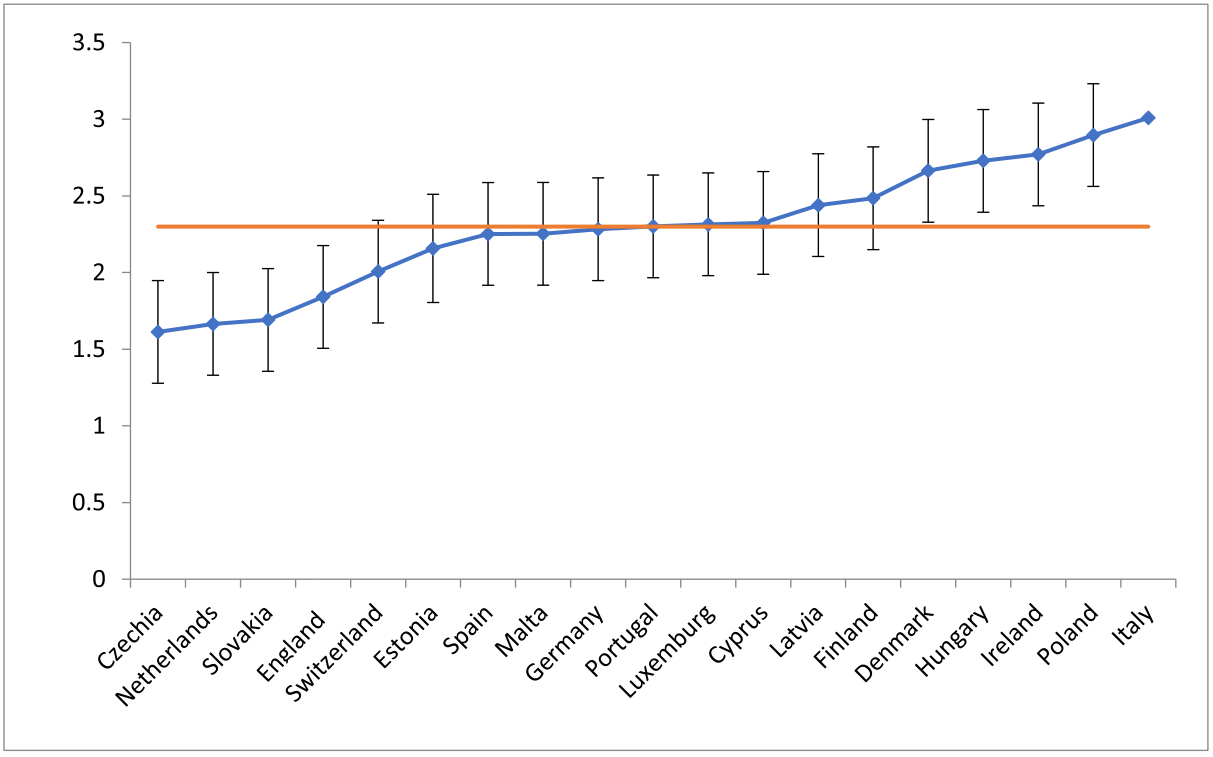

Fig. 3. PPE preparedness scale across 19 countries.

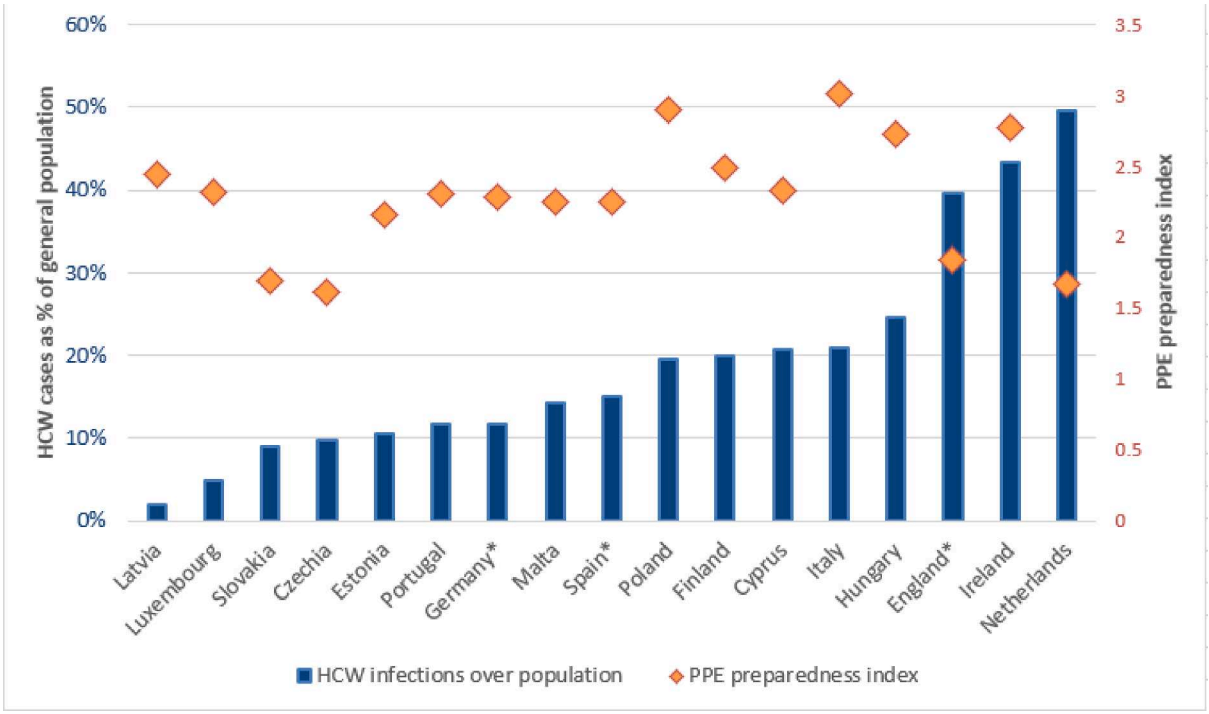

Fig. 4. PPE preparedness scale (right Y-axis) and HCW infections compared to the general population (left Y-axis), 17 countries.
Notes: * Spain: aggregate TESSy data; Germany and England: secondary data

infections among HCWs.

As a sensitivity analysis we have left out England, Germany and Spain. This only results in very minor differences, without consequences for our conclusions (not in table).

4. Discussion

4.1. Summary of the results

PPE preparedness (our first research question) in the 19 countries shows some common results worth further evaluation. Two characteristics are dominant in most countries. First, there was no country without any shortage in at least one sector, which contributed to the postponement or cancelation of various kinds of services. Second, the first wave was different in terms of the seriousness of its impact on system functionality, including PPE preparedness. Thus, timing could be a decisive factor in how a country was able to tackle any kind of shortage.

Regarding stockpiles, results from the questionnaire show that even if the majority of countries had PPE stockpiles prior to the pandemic, these were frequently either not suitable for the COVID-19 pandemic or not enough to meet the needs. The availability of stockpiles typically relied on estimation of needs reflecting previous flu epidemics and were not planned for a pandemic with the impact of COVID-19. This issue was in some cases exacerbated by uncertainties over which actor(s) had responsibility for storing and maintaining stockpiles.

Guidelines for the use of PPE were available in almost all countries. They were further developed and adapted over time according to actual needs and requirements of the pandemic, and in line with evolving evidence and international recommendations. In some cases, however, national guidelines were influenced by the shortage as well – e.g. altering guidelines to use FFP2 mask instead of FFP3 in some circumstances due to insufficient availability of high-grade masks.

In relation to training, results indicate that almost all countries provided adequate training materials and protocols to ensure proper usage of PPE. There were differences in relation to the form or the source of these educational materials, which could be online and/or face-to-face. Training materials were provided by different actors, including national or regional authorities, employers or professional bodies.

Concerning governance, all countries' experts reported that there was national or regional level coordination to ensure the timely and appropriate procurement and distribution of PPE and to prevent harmful competition among individual providers. To ensure effective distribution, almost all countries implemented or adapted existing systems for monitoring in real-time the available supply and demand of PPE. Almost all countries applied prioritization, especially in favor of hospitals. However, despite efforts to ensure adequate distribution, most countries experienced difficulties because of overall shortages of PPE, caused by competition among countries and rising global prices of PPE, among others.

Many factors contribute to the different infection rates among HCWs (our second research question). First and foremost epidemiological characteristics of the first wave differed between countries, such as the risk of exposure to SARS-CoV-2, determined by the number of infected patients in COVID-19 and non-COVID-19 settings/wards, and differences in transmission rates. Moreover, differences in reporting behavior of professionals, comprehensiveness of reporting [28] and in testing regimes may explain the variations. In many countries frontline HCWs were prioritized in testing together with people with severe symptoms, contacts of known cases and vulnerable groups [36] resulting in a low testing rate in the population but high rates of confirmed SARS-CoV-2 infections. In the Netherlands symptomatic HCWs were not tested routinely but required to self-isolate, although this changed over time, while in Ireland HCWs were only prioritized for testing when working on the frontline and with regular patient contact [26]. In contrast Luxembourg with a large-scale population wide testing strategy implemented in May 2020, had the highest testing rate in Europe at that time. The more targeted testing strategies inevitably led to higher rates of identified cases.

We found no significant associations between the PPE-preparedness scale, HCW infection rate compared to the general population, and shortages of PPE (our research question 3). This is perhaps due to the

low power of the analysis, with only 17 countries having data on PPE-preparedness, HCW infection rate and shortages of PPE. The rank correlation between the preparedness scale and HCW cases relative to cases in the population is positive (r_s =0.31, $p = 0.21$), but with this number of countries not significant. The same counts for the rank correlations between reported shortages and the relative number of cases among HCWs which is highest for shortages in ambulances (r_s=0.36, $p = 0.16$). The lack of a relationship between the PPE preparedness of countries and the HCW infection rate could also be the result of a performance paradox: better prepared countries also have better monitoring systems of COVID-19 infection rates.

4.2. Comparison with the literature

Emerging literature on the role of PPE for HCW protection during the pandemic confirms the dimensions of the PPE preparedness scale. Frontline HCWs experiences with PPE from the UK [37] and Australia [38] show that inappropriate provision of PPE, inadequate training, inconsistent guidance and reuse or extended use were the major barriers. In particular, absence of in-person PPE training was associated with lower confidence in PPE use [38]. A study from Belgium on the association between inadequate PPE during the first wave highlights that the share of HCWs in home care settings reporting insufficient PPE (56.6%) was substantially higher than those working in residential care (26.5%) and hospitals (14.4%). Moreover, no significant relationship between HCW infection and insufficient availability of PPE was identified. Both results are in line with findings in our study. Adequate training on the use of PPE was identified as important contributor to reducing the risk of HCW infection. Moreover, unavailability of appropriate guidelines in Belgium was identified as one reason for lack of knowledge on PPE use as guidelines were predominantly hospital oriented. Non-hospital health care settings were themselves responsible to set up practice guidelines and training [39]. A scoping review confirms that the main barriers for PPE implementation were shortages and supply problems, weakness in policies and communication procedures and lack of preparedness [40]. A national analysis on self-reported access to PPE of HCWs in the UK confirms the low PPE scale in England identified in our study. About only one third of HCWs in the UK reported access to appropriate PPE during the first lockdown and especially allied health professionals and dentists were less likely to report access to PPE while HCWs in intensive care units were more likely [41].

4.3. Strengths and limitations

A strength of our study is the interactive development of the PPE-questionnaire with experts from the HSPM network during network meetings. We also provided feedback of the results for validation by the experts. We relied on expert information on PPE-preparedness, but the experts were not asked to do extensive secondary research to back this information up. The questionnaire was answered by one respondent per country, often together with one or more colleagues. The judgments of the respondents are not merely personal opinions. The respondents have been invited to provide additional information in the open questions and many did so. In general the respondents were informed that the questionnaire may require some additional research for some questions. That the respondents have refrained from entering their personal opinions is underpinned by the fact that in particular with the subject of prioritization, which is often not an open, public process, they have used the 'don't know'-option most frequently. The use of the 'don't know'-option also illustrate that issues around PPE are complex, even for experts in the field.

Another strength is the combination of the PPE-survey with HCW infection rates. A major weakness is the difference in data collection across countries and reporting to ECDC. However, ECDC is the major source for data on infection rates among the working age population. Another weakness is the relatively low number of countries for which we have data on PPE-preparedness and HCW infection rates, partly explaining the insignificant correlations. A higher response would have given more opportunities for analysis of the data. The data on HWC infection rates had their limitations. Some countries had incomplete data on HCW infection rates and we excluded if over 20% of cases was missing. As noted, the validity of data on infection rates in the population and among HCWs was influenced by differences in testing regimes and laboratory capacity. For two countries we had to rely on alternative data sources; however, we did a sensitivity analysis for these countries. We don't know whether HCWs acquired the infection at work or in the community. Finally, the phase of the pandemic and waves were not the same for all countries. For some countries the first wave came later, and consequently, they had more time to acquire PPE.

We included four dimensions to cover key aspects of availability, guidelines and training to facilitate appropriate use, and governance of PPE. There are other aspects that we could have included (e.g. were masks mandated in different settings, were HCWs told to reuse masks? Etc.), but we wanted to keep the questionnaire focused and manageable for respondents. This means some aspects of preparedness are not captured, which may have influenced our results. However, this is a novel PPE-scale which highlights a number of important aspects of preparedness and that may contribute to the protection of HCWs. It can be taken as a starting point and refined and developed in future studies.

The PPE scale and its dimensions were discussed during the annual meeting of the HSPM network and the results were discussed in a subsequent meeting. This contributed to the face validity of the scale; however, other aspects of validity were not tested in this study.

Despite these limitations, we have added a useful contribution to the literature on PPE and HCWs' infections with COVID-19. The PPE-questionnaire will be useful in case of future outbreaks of infectious diseases that require wearing PPE to protect HCWs.

4.4. Policy implications

Apart from data limitations, varied testing regimes and overall differences in managing the pandemic which influenced infection rates during the first wave, make it challenging to draw any strong conclusions on the relationship between PPE availability and use, and HCW infections. There are nevertheless important policy implications that can be drawn from this paper. First, strengthening national surveillance systems to ensure data on infections in HCWs in the event of another pandemic is important to help protect frontline workers. Secondly, while many countries had PPE stockpiles prior to the pandemic, these were often not of sufficient quantity or did not contain appropriate PPE for managing an airborne pathogen. Moreover, in a few countries, stockpiles had not been maintained and some items were out of date. Ensuring PPE stockpiles are available, contain equipment for dealing with pandemics of different types to influenza and putting in place appropriate governance, monitoring and accountability structures for oversight are essential to improve preparedness.

Another major issue encountered in many countries was the critical lack of PPE for LTC providers, either as a result of prioritization of other providers (especially hospitals), a lack of monitoring and reporting systems in LTC and/or a lack of procurement mechanisms for the sector. These challenges are symptomatic of a general underfunding of LTC in many countries and lack of coordination between LTC and health care authorities. Including the specific needs of LTC providers and the people they care for in pandemic preparedness plans and ensuring their participation in joint procurement and monitoring systems could address some of these inequalities in the event of another pandemic.

Finally, many of the supply challenges in Europe in the first wave resulted from a reliance on other countries (notably China) producing the majority of PPE. PPE producing countries prioritised themselves in receiving PPE, while global competition drove up market prices forcing many countries to pay considerably more than usual to receive items. The use of an accelerated Joint Protection Agreement for PPE in May

2020 for EU Member States was successful in helping countries – especially small countries – with the procurement and distribution of PPE, even though such a mechanism was not designed to be used during a health emergency (https://www.medtecheurope.org/wp-content/uploads/2020/03/COVID-19-Procurement-Actions_20052025.pdf). The continuation of such joint procurement mechanisms at the EU-level, such as through the proposed Dynamic Purchasing System (https://health.ec.europa.eu/latest-updates/european-health-union-hera-sets-dynamic-purchasing-system-more-effective-joint-procurement-ppe-2022–10–04_en) to counter health threats, could prove crucial to improving preparedness in the future. Moreover, enhancing capacity to produce PPE within the EU would help reduce reliance on receiving PPE supplies from outside countries – something that could prove crucial in ensuring availability of PPE if external borders are closed in response to a future cross-border health threat.

5. Conclusion

PPE shortages were found in most countries, and in home care and long-term care most often. We developed a PPE-preparedness scale, based on a brief questionnaire that revealed cross-country differences in preparedness and revealed gaps in available evidence and focus areas for in-depth studies in the future. Shortages of PPE may have led to higher HCW infection rates, compared to the general population, but for various reasons we were unable to prove this. Better preparedness with monitoring and surveillance in place is needed, as is the participation of more countries in studies like this.

CRediT authorship contribution statement

Madelon Kroneman: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Gemma A. Williams:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Juliane Winkelmann:** Writing – review & editing, Writing – original draft, Validation, Data curation, Conceptualization. **Peter Spreeuwenberg:** Writing – review & editing, Methodology, Formal analysis. **Krisztina Davidovics:** Writing – review & editing, Writing – original draft. **Peter P. Groenewegen:** Writing – review & editing, Writing – original draft, Formal analysis.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.healthpol.2024.105097.

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