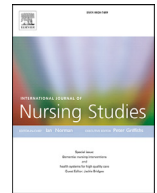ELSEVIER

Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Sufficient personal protective equipment training can reduce COVID-19 related symptoms in healthcare workers: A prospective cohort study

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ABSTRACT

Background: The association between inadequate personal protective equipment during the COVID-19 pandemic and an increased risk of SARS-CoV-2 infection in frontline healthcare workers has been proven. However, frontline healthcare workers with an adequate supply of personal protective equipment still showed an increased risk of contracting COVID-19. Research on the use of personal protective equipment could provide insight into handling present and future pandemics.

Objectives: This study aims to investigate the impact of the availability, training and correct selection of personal protective equipment on the incidence of SARS-CoV-2 infection or positive suspect cases in healthcare workers during the COVID-19 pandemic in Belgium.

Design: This was a prospective cohort study involving Belgian healthcare workers: nurses, nursing aides, and midwives working in hospitals, home care services, and residential care services.

Methods: Respondents were invited from May to July 2020 (period 1) followed by a second time in October 2020 (period 2) to complete a digital survey on personal protective equipment availability, training, personal protective equipment selection, screening ability, COVID-19 testing and status, and symptoms corresponding with the COVID-19 suspect case definition. The main outcome was a composite of COVID-19 status change (from negative to positive) during the study or a positive suspect case definition in period 2.

Results: Full data were available for 617 participants. The majority of respondents were nurses (93%) employed in a hospital (83%). In total, 379 respondents provided frontline care for COVID-19 patients (61%) and were questioned on personal protective equipment availability and personal protective equipment selection. Nurses were more likely to select the correct personal protective equipment compared with nursing aides and midwives. Respondents working in residential care settings were least likely to choose personal protective equipment correctly. Of all healthcare workers, 10% tested positive for COVID-19 during the course of the study and a composite outcome was reached in 54% of all respondents. Working experience and sufficient personal protective equipment training showed an inverse relation with the composite outcome. The relationship between personal protective equipment availability and the composite outcome was fully mediated by personal protective equipment training (-0.105 [95% confidence interval -0.211 − -0.020]).

Conclusions: Proper training in personal protective equipment usage is critical to reduce the risk of COVID infection in healthcare workers. During a pandemic, rapid dissemination of video guidelines could improve personal protective equipment knowledge in practitioners.

Tweetable abstract: Proper training in personal protective equipment usage is critical to reduce the risk of COVID infection in healthcare workers.

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What is already known

- The association between inadequate personal protective equipment and an increased risk of SARS-CoV-2 infection in healthcare workers has been demonstrated.
- Frontline healthcare workers with adequate access to personal protective equipment still had an increased risk to contract COVID-19 disease compared with the general community.

What this paper adds

- Nurses were more likely to select the correct personal protective equipment compared with nursing aides and midwives and respondents working in residential care settings were least likely to select the correct personal protective equipment.
- Proper training in personal protective equipment usage is critical to reduce the risk of COVID infection in healthcare workers.

1. Introduction

Since the start of the pandemic, frontline healthcare workers such as physicians, nurses, nurse assistants, and ancillary personnel were confronted with COVID-19 patients (European Centre for Disease Prevention and Control, 2021). Healthcare personnel received a great deal of societal support in return which is praiseworthy. However, treating COVID-19 patients is a dangerous, very serious and complex matter that requires close contact with patients which increases the risk of infection (Nguyen et al., 2020). Up to 10% of all confirmed COVID-19 cases in Italy, 20% in Spain, and 6% in The Netherlands were healthcare workers (Bandyopadhyay et al., 2020; European Centre for Disease Prevention and Control, 2020). In May 2020, 8.4% of all Belgian healthcare workers had SARS-CoV-2 antibodies which was almost twice the amount compared to the general population at that time (general population: 4.3%) (Desombere et al., 2020). Half of all infected healthcare workers in hospitals were nurses because they spend most time in direct patient care. Moreover, severe complications developed in 5% of COVID-19 positive healthcare workers, and 0.5% died (Gómez-Ochoa et al., 2021).

Staff should receive maximum protection to ensure safety, to avoid discontinuation of essential healthcare services, and to prevent cross-contamination of patients, colleagues, and relatives. However, at the start of the pandemic COVID-19 personal protective equipment guidelines were ambiguous, fluctuated over time, and differed across organizations and countries (MacIntyre and Chughtai, 2020). Generally, the choice of personal protective equipment depends on the type of care and of the nature of patient interactions and comprises droplet and contact protection for the general care and additional airborne protection for aerosol-generating procedures (Park, 2020). In February 2020, the Belgian authorities published hospital guidelines which included advice on COVID-19 patient cohorting (i.e., grouping infectious patients and nursing them separately), hand and face hygiene, droplet and contact measures (medical masks, gowns, gloves, eye protection) with additional protection (FFP2 masks and patient isolation) in case of aerosol-generating procedures (Sciensano, 2020a). However, no guidance was provided at the time on the duration of personal protective equipment usage, donning and doffing of personal protective equipment or waste management (World Health Organization, 2020b). Also, the training of healthcare workers in infection prevention and personal protective equipment usage was organized by each hospital, residential care facility or home care service which may have led to differences in practices. Additionally, severe global personal protective equipment shortages were leading to rationing of personal protective equipment, extended use, recycling, or even insufficient application (World Health Organization, 2020a). Nguyen and colleagues found that frontline workers in the USA and the UK reporting inadequate personal protective equipment or recycling had an increased risk of a positive COVID-19 test (Nguyen et al., 2020). This result was confirmed in a cross-sectional survey study in the UK (Kua et al., 2021). However, Nguyen et al. also discovered an increased risk of 1.78 versus 0.11 per 1000 person-days among those reporting adequate personal protective equipment compared with the general community respectively (Nguyen et al., 2020). Since the appropriate use and fitting of personal protective equipment are linked to adequate training, we hypothesize that (in)sufficient training could have increased the risk of infection in frontline workers (Houghton et al., 2020a). Insufficient training could lead to a decreased awareness of the importance of personal protective equipment or the lack of realization about the importance of the technique for safe removal of contaminated equipment (Gordon and Thompson, 2020). Other potential factors influencing infection risk are the sufficient availability and knowledge of personal protective equipment, whether COVID-19 patients are separated from non-covid patients (cohorting), and test availability. This study aimed to investigate the impact of personal protective equipment availability, training and use on the incidence of SARS-CoV-2 infection or suspect cases in healthcare workers during the COVID-19 pandemic in Belgium.

2. Methods

2.1. Study design and participants

This was a prospective cohort study recruiting Belgian nurses, nursing aides, and midwives working in hospitals, home care services, or residential care services from May to July 2020. Recruitment was done via social media (LinkedIn, Facebook, and Twitter) and professional associations affiliated with the General Union of Belgian Nurses who published a link to the survey on their websites (AUVB-UGIB-AKVB, 2021). Other healthcare workers (such as physicians) were automatically excluded at the beginning of the survey. After recruitment, a 20-minute digital survey was provided twice, at least once in May-July (Period 1 or P1) followed by a second survey in the same sample in October 2020 (Period 2 or P2). The survey included questions on demographics, personal protective equipment availability, training and use, cohorting, testing strategy, and COVID-19 infection status and symptoms (supplementary materials, survey in Dutch and translated into English). The research team, which included scholars and nurses and a medical doctor both working in the frontline, prepared the questionnaire and included questions that seemed relevant at the time. Questions about COVID-19 infection status and symptomatology were based on available guidelines and were reviewed by a medical doctor. The Qualtrics platform of the University of Antwerp was used to provide a publicly accessible link to the survey (Qualtrics, 2021). The survey was available in Dutch and French and was translated from Dutch to French by a professional translator using the forward-backward translation method (Lee et al., 2019). Respondents were asked to share their email-addresses to receive an invitation for the second period. Only healthcare workers participating at least two times in the survey were included.

2.2. Measures

2.2.1. Demographics

The survey included questions on the type of organization, occupation, age, working experience, and if respondents actively cared for suspected or confirmed COVID-19 patients (in the last seven days before survey participation).

2.2.2. Independent variables and confounders

Using a four-point Likert scale, the availability of personal protective equipment, if training in personal protective equipment use was perceived as sufficient, whether COVID-19 patients were separated from non-covid patients (cohorting), and screening ability (with Reverse Transcription Polymerase Chain Reaction tests) were surveyed with the option 'not-applicable' and ranging from strongly disagree (1) to strongly agree (4). The questions concerning availability and training were only shown to respondents caring for suspect or confirmed COVID-19 patients in the last seven days before the survey.

To measure if respondents correctly selected personal protective equipment, two clinical cases were presented (one including direct contact with a positive COVID-19 patient 'case A', and one including an aerosol-generating procedure in a positive COVID-19 patient 'case B'). Respondents were asked to select the proper personal protective equipment for each case. This test was used to estimate if current practice corresponded with the National guidelines (Sciensano, 2020a). Respondents were categorised into 'correct selection' of personal protective equipment if they selected gloves AND gown AND eye protection AND [medical mask OR FFP2/3 mask] without selecting other options in case A and if they selected gloves AND gown AND eye protection AND FFP2/3 mask without selecting other options in case B. Respondents selecting incompatible personal protective equipment (such as an FFP2/3 mask together with a medical mask), were considered missing data since the answer was not possible and could be due to a mistake. Respondents were considered to select incorrect personal protective equipment if they chose: 1) insufficient personal protective equipment in at least one of two clinical cases OR 2) 'I don't know' OR 3) 'I would use no PPE'. The test did not include questions about personal protective equipment wearing time, formal fitting or donning and doffing procedures.

2.2.3. Outcomes

Respondents were asked if they were tested at least once for COVID-19 using an RT-PCR test including its result. Symptoms of the COVID-19 suspect case definition were also surveyed. The COVID-19 suspect case definition used in this study was based on Belgian federal guidelines and concerned all respondents with new onset of dry cough OR shortness of breath OR chest pain OR anosmia OR dysgeusia OR at least two acute secondary clinical signs without known cause (i.e.: fever >38 °Celsius, myalgia, sore throat, headache, and diarrhea) (Sciensano, 2020b). The main outcome assessed in this study was a composite of COVID-19 status change during the study (status change from 'not even once a positive COVID-19 PCR test' to 'at least one positive COVID-19 PCR test') or a positive suspect case definition in the last month before the survey in period 2.

2.3. Statistical analysis

IBM's SPSS Statistics for Mac OS version 27 was used for statistical analysis (IBM, 2021). Four-point Likert scales of personal protective equipment availability, training, cohorting, and screening ability were recoded into binary outcomes to differentiate between disagreement and agreement (i.e., 'Strongly disagree' and 'Disagree' = 0 versus 'Agree' and 'Strongly agree' = 1). Respondents' characteristics that were lost-to-follow-up were compared with those completing follow-up using Chi-Squared tests for discontinuous data and independent t-tests for continuous data. Comparisons between periods 1 and 2 were done using paired t-tests for continuous data and McNemar tests for dichotomous data. To assess differences between insufficient versus sufficient personal protective equipment availability, personal protective equipment training, cohorting, and screening availability or incorrect

versus correct personal protective equipment selection, Pearson Chi-Squared tests were used. Logistic regression models were fitted using the backward conditional stepwise selection method (entry 0.05; removal 0.10) with as dependent variables correct personal protective equipment selection in period 2 and the main composite outcome in this study in period 2. Independent variables were included from period 1. Finally, to estimate the potential causal inference between personal protective equipment availability, training and healthcare worker confirmed or suspect COVID-19 infection, a mediation analysis was carried out using the PROCESS macro for SPSS which is an OLS and logistic regression path analysis modeling tool (Hayes, 2017). The indirect effect was calculated using bootstrapping procedures. Unstandardised indirect effects were computed for each of 5000 bootstrapped samples, and a 95% confidence interval was computed by determining the indirect effects at the 2.5th and 97.5th percentiles. During analysis a significance level of 0.05 was assumed.

2.4. Ethical approval and informed consent

All respondents agreed with the informed consent which was presented at the beginning of the survey. Respondents were asked if they would like to receive an email invitation for the following survey. Email addresses of healthcare workers were collected and only used to send invitation links to participants and to link datasets. The dataset was pseudonymised before data analysis. This study received ethical approval by the institutional review board of the University of Antwerp (Belgian registration number: 3002020000066). It was carried out in correspondence with the General Data Protection Regulation 2016/679 of the European Union (Krzysztofek, 2018).

3. Results

3.1. Included and missing respondents

A total of 1952 healthcare workers participated in the survey in period 1 (May, June, or July 2020), and 617 respondents participated a second time in period 2 (October 2020), resulting in a lost-to-follow-up of 68.4%. Respondents that were lost-to-follow-up ($n = 1335$ versus followed-up $n = 617$) were more likely to be employed in residential care (9.2% vs. 5.8% respectively, $p = 0.005$), were less likely to be a nurse (91.1% vs. 94.0% respectively, $p = 0.027$), showed a higher personal protective equipment training score (mean 2.59 vs. 2.48 respectively, $p = 0.010$), as well as a higher cohorting score (mean 2.92 vs. 2.68 respectively, $p<0.001$), and reported more screening ability (mean 2.99 vs. 2.85 respectively, $p = 0.002$). No differences were found between lost-to-follow-up and followed-up respondents in years of working experience ($p = 0.832$), personal protective equipment sufficient availability score ($p = 0.582$), and correct personal protective equipment selection ($p = 0.699$). Six hundred seventeen respondents completed follow-up and were included in the study for further analysis.

3.2. Demographics

Most respondents were nurses (93%) and were employed in a hospital (83%, Table 1). The mean age, mean working experience in the current job, and healthcare in general, were 43.3, 14.1, and 20.0 years. In the last seven days before survey participation, the proportion of healthcare workers actively caring for COVID-19 patients dropped from 90% to 72% ($p<0.001$). In total, 379 respondents cared actively for COVID-19 patients in both period 1 and period 2 (i.e., 61%). These 379 respondents were questioned on the

Table 1
Demographics and comparing personal protective equipment, cohorting, testing and outcome-related variables between periods 1 and 2.

demographics					
		P1 (n = 617)	P2 (n = 617)	Difference [S.E.]	Total (n = 617)
organization	hospital -% (n)				82.7 (510)
	home care service -% (n)				9.9 (61)
	residential care -% (n)				5.8 (36)
	other -% (n)				1.6 (10)
occupation	nurse -% (n)				93.4 (576)
	nursing aid or midwife -% (n)				6.6 (41)
	mean age - years (SD)				43.25 (11.49)
mean working experience in current job - years (SD)					14.05 (11.25)
mean working experience in healthcare - years (SD)					20.00 (12.06)
actively caring for COVID-patients -% (n) §		89.6 (553)	71.8 (443)	−17.8 [£] [2.2]	61.4 (379)
personal protective equipment$					
		P1	P2	difference [S.E.]	p-value
PPE sufficient availability -% [n = 376]		82.1	95.5	+13.4 [2.2]	<0.001 *
PPE availability score - mean (SD) [n = 376]		3.11 (0.74)	3.46 (0.61)	+0.35 [0.04]	<0.001 #
correct PPE selection -% (n) [n = 254]		63.8	67.7	+3.9 [4.2]	0.282 *
sufficient PPE training -% [n = 580]		48.6	65.0	+16.4 [2.9]	<0.001 *
PPE training score - mean (SD) [n = 580]		2.45 (0.81)	2.81 (0.89)	+0.36 [0.04]	<0.001 #
cohorting and screening availability					
		P1 (n = 617)	P2 (n = 604)	difference [S.E.]	p-value
COVID patients are separated from non-COVID patients (cohorting) -% (n)		60.6 (374)	66.9 (404)	+6.3 [2.8]	0.004 *
we can test (PCR) potentially infected patients (screening) -% (n)		73.4 (453)	85.7 (517)	+12.3 [2.3]	<0.001 *
outcomes					
		P1 (n = 617)	P2 (n = 617)	difference[S.E.]	p-value
	at least one test done for COVID (PCR) -% (n)	54.8 (338)	66.1 (408)	+11.3 [2.8]	<0.001 *
'a'	at least one positive COVID PCR test -% (n)	10.2 (63)	10.4 (64)	+0.2 [1.7]	1.000 *
'b'	positive COVID case definition -% (n)	60.8 (375)	53.5 (330)	−7.3 [2.8]	0.001 *
positive COVID case definition and never tested for COVID -% (n)		37.1 (229)	13.8 (85)	−23.3 [2.4]	<0.001 *
	'a' OR 'b' -% (n)	62.6 (386)	57.4 (354)	−5.2 [2.8]	0.018*
became COVID positive during study OR 'b' -% (n)			53.6 (331)		

P1 = period 1; P2 = period 2; S.E. = Standard Error; PPE = personal protective equipment; PCR = Polymerase Chain Reaction.
£ McNemar test p <0.001.
§ percentage of respondents who were actively caring for COVID patients in the week before responding to the survey in period 1 as well as period 2.
$ questions regarding personal protective equipment availability and selection were only shown to respondents actively caring for COVID patients in each period, respondents with a missing value in period 1 or 2 were excluded from this table.
% PPE sufficient availability = respondents who agreed that personal protective equipment was sufficiently available; % sufficient PPE training = respondents who agreed that they received sufficient personal protective equipment training; % cohorting = respondents who agreed that they could physically separate COVID from non-COVID patients; % screening = respondents who agreed that they could test potentially infected patients using a PCR test.
Differences are reported as proportional differences for proportions (with standard error) and mean difference for continuous variables (with standard error of the mean).
* McNemar Test; # Paired *t*-test.

availability and the correct selection of personal protective equipment in practice (i.e., the practice test including two clinical cases).

3.3. Availability, training, and the correct selection of personal protective equipment

We found no significant difference in personal protective equipment availability, personal protective equipment training, correct selection of personal protective equipment, cohorting, or screening availability between nurses and other healthcare workers in period 1 (Pearson Chi Squared test, $p \geq 0.05$). However, when comparing these variables between organization types in period 1 we found that only 43.4% of healthcare workers in the home care setting reported sufficiently available personal protective equipment (versus residential care: 73.5% and hospital: 85.6%, $p<0.001$ Pearson Chi Squared test). Correct personal protective equipment selection in period 1 was lowest in residential care facilities compared with home care and hospital settings (respectively: 17.6%, 52.2% and 65.4%, $p<0.001$ Pearson Chi Squared test). Additionally, patient screening availability was significantly lower in the home care setting than residential care facilities and hospitals (respectively: 10.3%, 75.6% and 81.1%, $p<0.001$ Pearson Chi Squared test). No differences were found in personal protective equipment train-

ing or cohorting between organization types in period 1 (Pearson Chi Squared test, $p \geq 0.05$).

In period 2, sufficient personal protective equipment availability rose significantly from 82% to 96%. Up to 64% of all respondents passed the personal protective equipment selection test indicating that appropriate personal protective equipment was chosen in two presented clinical cases (following the Belgian National guideline). However, there was no significant difference in personal protective equipment selection tests between periods 1 and 2. Training was perceived as insufficient in half of the healthcare workers in period 1 and 65% of respondents in period 2 indicated sufficient training ($+16\%$, $p <0.001$). The cohorting of COVID-patients was practiced in 61% of respondents in period 1 and rose to 67% in period 2. Suspect patients could be tested with a COVID-19 RT-PCR test in 73% and 86% of respondents in period 1 and period 2 respectively ($p<0.001$).

3.4. Outcomes

Half of all healthcare workers were tested at least once for COVID-19 using an RT-PCR test in period 1 and 66% of respondents were tested in period 2 ($p<0.001$). In total, 10% of all healthcare workers were tested positive for COVID-19 and respondents with

Table 2
The impact of independent variables measured in period 1 on SARS-CoV-2 infection or a positive COVID-19 case definition in period 2.

Period 1 variables	Period 2: outcome reached*% (n)	Difference [S.E.]	p-value
PPE insufficient availability - [n = 107]	61.7 (66)	−9.9 [5.3]	0.065
PPE sufficient availability - [n = 446]	51.8 (231)		
insufficient PPE training - [n = 310]	60.6 (188)	−14.2 [4.0]	<0.001
sufficient PPE training - [n = 304]	46.4 (141)		
incorrect PPE selection - [n = 134]	56.0 (75)	+1.8 [5.4]	0.737
correct PPE selection - [n = 218]	57.8 (126)		
insufficient cohorting - [n = 243]	61.7 (150)	−13.3 [4.0]	0.001
sufficient cohorting - [n = 374]	48.4 (181)		
insufficient screening availability - [n = 164]	50.6 (83)	+4.1 [4.6]	0.363
sufficient screening availability - [n = 453]	54.7 (248)		

* became COVID positive during study OR had a positive COVID case definition in period 2 difference = proportional difference, sufficient versus insufficient or correct versus incorrect
S.E. = Standard Error
PPE = personal protective equipment
p-values: Pearson Chi-Squared test.

Table 3
Multiple logistic regression analysis with as dependent variable 'correct personal protective equipment selection in period 2′.

Independent variables from period 1	OR 95% CI		
	B (S.E.)	OR	lower	upper
occupation (nurse)	1.328 (0.668)	3.77	1.02	13.98
PPE sufficient availability	1.448 (0.315)	4.26	2.29	7.90
organization (hospital)	0.796 (0.420)	2.22	0.97	5.05

multiple logistic regression model fitted using backward stepwise selection; Nagelkerke R^2: 0.137; p-model: <0.001; n = 332.
excluded variables: working experience in healthcare (decades); sufficient personal protective equipment training; sufficient cohorting; sufficient screening availability.
PPE = personal protective equipment.

a positive COVID-19 test or a positive case definition dropped significantly from 63% to 57% (p = 0.018). More importantly, 37% of all respondents in period 1 had a positive case definition without ever been tested for COVID-19 using an RT-PCR test. However, this number dropped to 14% in period 2 (p<0.001). The primary outcome in this study (i.e., a COVID-19 status change from no COVID-19 to COVID-19 positive during the study or a positive suspect case definition in period 2) was reached in 54% of all healthcare workers.

3.5. Factors influencing SARS-CoV-2 infection or a positive COVID-19 case definition in period 2

Respondents reporting insufficient personal protective equipment training or insufficient cohorting in period 1 were more likely to reach the composite outcome (Table 2). Insufficient availability of personal protective equipment was not significantly related to the main outcome but showed borderline non-significance (p = 0.065). We did not find significant differences in outcome status between respondents with incorrect or correct personal protective equipment selection and insufficient or sufficient screening availability. A binary multiple logistic regression model was fitted to investigate influencing factors predicting the correct selection of personal protective equipment (i.e., practice test including two clinical cases). Nurses and healthcare workers who reported sufficient personal protective equipment availability in period 1 showed increased odds of correctly selecting personal protective equipment in period 2 controlled for the type of organization (Table 3). A second binary multiple logistic regression model was fitted to investigate influencing factors predicting the composite outcome. For every 10 years working in healthcare, the risk of

becoming infected or to have a positive case definition dropped by 23% (Table 4). Additionally, we found a negative association between sufficient personal protective equipment training in period 1 and the primary outcome corrected for working experience.

Initially, no association was found in the multiple regression analysis between personal protective equipment availability and the composite outcome. A logistic mediation analysis was carried out further to investigate the mediating effect of personal protective equipment training. As Fig. 1 illustrates, the relationship between personal protective equipment availability and the composite outcome was fully mediated by personal protective equipment training (indirect path −0.105 [95% CI −0.211 and −0.020]; model p <0.001). Working experience in healthcare, COVID-19 patient cohorting and correct personal protective equipment selection were added as confounders to the mediation model which increased the total explained variance from 4.0% to 9.4% (Nagelkerke R^2 in final model, 0.094). Nevertheless, this did not change the nature of the relationship between the included variables.

4. Discussion

The link between personal protective equipment shortages and an increased risk of infection in healthcare workers was previously described in a large prospective study in the USA and the UK (Nguyen et al., 2020). However, it remained unclear why the authors found an increased susceptibility to infection even among those reporting adequate personal protective equipment. In this prospective cohort study, we confirmed the limited availability of personal protective equipment as a precursor for a change in COVID-19 status (i.e., from negative to positive status) or a positive suspect case in nurses, nursing aides, and midwives. This in-

Table 4
Multiple logistic regression analysis with as dependent variable 'change in COVID-19 status from negative to positive status or a positive suspect case in period 2'.

Independent variables from period 1	OR 95% CI			
	B (S.E.)	OR	Lower	Upper
working experience in healthcare (decades)	−0.268 (0.099)	0.77	0.63	0.93
sufficient PPE training	−0.844 (0.227)	0.43	0.28	0.67

multiple logistic regression model fitted using backward stepwise selection; Nagelkerke R^2: 0.092; p-model: <0.001; $n = 344$.
excluded variables: organization (hospital); occupation (nurse); personal protective equipment sufficient availability; correct personal protective equipment selection; sufficient cohorting; sufficient screening availability.
PPE = personal protective equipment.
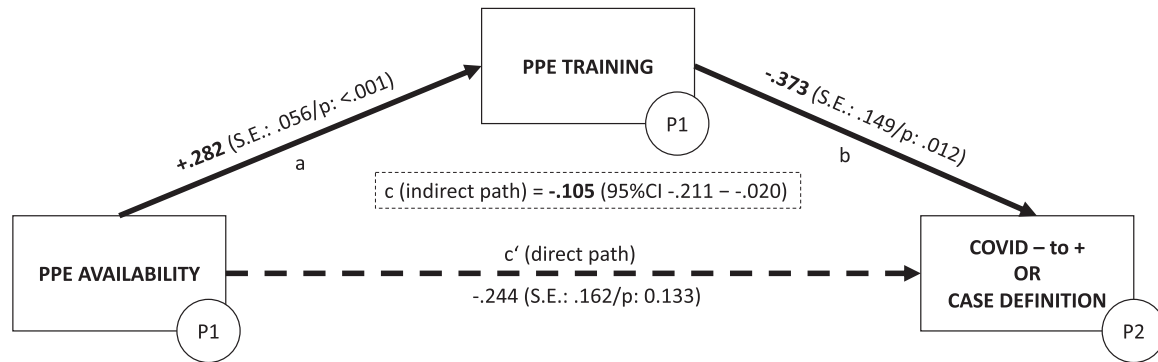
Fig. 1. Mediation analysis investigating the effect of personal protective equipment availability on the composite outcome in this study (i.e., change in COVID-19 status from negative to positive status or a positive suspect case).
P1 = Period 1; P2 = Period 2; S.E. = Standard Error; CI: Confidence Interval; PPE = personal protective equipment
p model <0.001; Nagelkerke $R^2 = 0.094$: $N = 350$
unstandardised coefficients reported.

verse relationship was fully mediated by the provided training in using personal protective equipment. Consequently, personal protective equipment training was perceived as more sufficient when availability was higher, and higher personal protective equipment training scores negatively influenced the chance of becoming ill in the future. We hypothesized that healthcare organizations with sufficient personal protective equipment stock, who invested in training their staff in using the available personal protective equipment, had lower infection amongst their personnel. It seems evident that healthcare workers without sufficient personal protective equipment showed a higher risk to become infected (MacIntyre and Chughtai, 2020; Kua et al., 2021; Suzuki et al., 2021). Because we did not find a direct significant effect between personal protective equipment availability and infection risk (assuming an alpha of 5%), we assume that sufficient personal protective equipment training is of importance in reducing infection risk in healthcare workers. Nguyen and colleagues described in their study including 99,795 frontline healthcare workers from the UK and the USA, that healthcare workers working in nursing homes and in home care services reported inadequate personal protective equipment most frequently (Nguyen et al., 2020). Our study confirmed these results and found that 14.4% of hospital caregivers, 26.5% of residential care caregivers, and 56.6% of home caregivers reported inadequate personal protective equipment availability. These numbers were all higher compared with the results from Nguyen and colleagues (i.e., hospital: 11.9%, residential care: 16.9%, and home care: 15.9%) (Nguyen et al., 2020).

Even if a stock of personal protective equipment is readily available and training is provided, it requires sufficient knowledge and practice to use it safely. Previous studies reported problems with correct adherence to personal protective equipment safety procedures including personal protective equipment wearing time, the correct selection and formal fitting of masks, and having a buddy when donning and doffing (Houghton et al., 2020b; Park, 2020;

Hoernke et al., 2021; Iheduru-Anderson, 2021; Ippolito et al., 2021). We found that in our cohort only 68% of all respondents correctly applied personal protective equipment in correspondence with the Belgian guideline (Sciensano, 2020a). This shows that 32% of all healthcare workers included in this study were not prepared to use select personal protective equipment in practice safely and were at risk of becoming infected and cross-contaminate. However, when compared with other caregivers, nurses were almost four times more likely to correctly choose personal protective equipment, while no difference in training sufficiency was detected between professions. This result contradicts previous results where no difference was found in personal protective equipment use between different types of healthcare workers (Tabah et al., 2020). Moreover, we found that healthcare workers in hospitals were twice more likely to correctly select personal protective equipment than other settings (i.e., home care services and residential care). The correct selection of personal protective equipment was very low in residential care settings (17.6%) while personal protective equipment availability was relatively high (73.5%). Our results indicate that even if personal protective equipment was sufficiently available during the COVID-19 pandemic, it was not always used appropriately. Healthcare workers' knowledge of personal protective equipment use lacked since no clear and uniform practice guidelines were available for all caregivers deployed in various sectors. Guidelines were predominantly hospital-oriented and other settings were responsible themselves to provide practice guidelines and training. This could have led to the initial suboptimal knowledge of personal protective equipment selection and use, especially in residential settings. A national professional organization, responsible for care practice and overarching different healthcare professions could have made a difference if it could provide rapid best evidence practice guidelines for all professions working with COVID-19 patients. Furthermore, a written guideline may be less effective in reaching care professionals working in differ-

ent settings handling a global pandemic. Caregivers should receive training about when and how to correctly use personal protective equipment using short informative videos provided alongside the actual guideline (Christensen et al., 2020).

In a seroprevalence study in May 2020 at the end of a first wave of infections 8.4% of tested healthcare workers had antibodies (Desombere et al., 2020). In our study (May 2020 until October 2020), 10.4% of all healthcare workers had at least one positive COVID-19 PCR test and this number corresponded with previous findings (i.e., 11%; $n = 97$ studies) (Gómez-Ochoa et al., 2021). We discovered that between 14 and 37% of healthcare workers had a positive COVID-19 case definition without ever being tested. It is plausible that the COVID-19 prevalence in healthcare workers is underestimated since it only includes confirmed (PCR tested) COVID-19 cases and because of the limited test capacity at the time (Sciensano, 2020a). Patient screening availability was low in the home care setting (i.e., 10.3%). This means that only one in ten home caregivers were able to test suspect COVID-19 patients in practice. In Belgium, a SARS-COV-2 PCR test could only be ordered by a general practitioner and not by other professions such as nurses. This way of working could have slowed or limited efficient testing of patients in the home care setting.

The mean age of the frontline healthcare workers in this study was 43 years which corresponded with the mean age of the nursing population in Belgium (i.e., 43.5 years) (Braeckevelt et al., 2013; Vandenbroele, 2010). Per increase of the healthcare workers' working experience with 10 years, we discovered a reduction in the risk of a positive COVID-19 case definition or SARS-CoV-2 infection of 23% (OR 0.77) even if corrected for training sufficiency. Since working experience was not associated with the correct selection of personal protective equipment, we hypothesized that younger healthcare workers could have been more exposed to COVID-patients and were thus at higher risk to become infected than their older counterparts.

5. Limitations

We acknowledge several limitations in this study. The survey was self-reported and therefore the results could be biased. We did not perform prior testing of the instrument in potential participants to ensure reliability. Since the sample size was limited and not randomly selected, it is difficult to generalize our results to all different settings in the Belgian healthcare system. We did not perform an a-priori power analysis to calculate the minimal sample size needed. Nonetheless, we did find a significant effect between personal protective equipment availability and the composite outcome fully mediated by training. Selection bias could have influenced our results since we recruited healthcare workers through social media and professional organizations. Moreover, it is possible that healthcare workers who were experiencing problems in personal protective equipment availability were more likely to participate. We had a relatively high rate of lost-to-follow-up (68%). The missing respondents had higher personal protective equipment training and cohorting scores and reported more screening ability.

Our primary outcome was a composite of a change in status from no confirmed SARS-COV-2 PCR test to a confirmed test or a positive COVID-19 case definition in period 2. We acknowledge that this does not correspond to a confirmed COVID-19 case and should be interpreted accordingly. However, solely depending on PCR tests in determining COVID-19 infection status at that time was not possible since testing was scarce and not readily available for all healthcare workers. Additionally, we found that up to 37% of healthcare workers corresponded to the COVID-19 case definition without ever being tested confirming that respondents were not always tested when necessary.

We discovered a complete mediating effect of personal protective equipment training on the relationship between personal protective equipment availability and the composite outcome. The indirect effect size found between personal protective equipment availability and the outcome was small. Nonetheless, because our study design uses data from two periods, we hypothesize that a causal effect exists between personal protective equipment availability and our study outcome which was mediated by training. This result is however highly dependent on the precision of the outcome measure which is debatable as we mentioned before.

Healthcare workers who contracted COVID-19 during this study could have been infected outside the workplace. We did not measure where or when respondents became sick or had a positive RT-PCR test. We did, however, only include front-line healthcare workers actively caring for COVID-19 patients in the last seven days before survey participation in our analyses concerning personal protective equipment availability, training, and the composite outcome.

6. Conclusions

We found an indirect inverse relation between personal protective equipment availability and the potential risk of infection which was fully mediated through the sufficiency in personal protective equipment training. Only 68% of all healthcare workers correctly selected personal protective equipment corresponding with National guidelines. Nurses were four times more likely to correctly select personal protective equipment compared with other healthcare workers. Moreover, hospital personnel were two times more likely to correctly select personal protective equipment compared with caretakers in home care or residential care services. Residential care settings had the lowest proportion of healthcare workers correctly selecting personal protective equipment while the availability was relatively high. Even if personal protective equipment was sufficiently available during the COVID-19 pandemic, it was not always used appropriately. We believe that, during the outbreak of a global pandemic, rapid dissemination of national guidelines accompanied by short informative videos aimed at all caregivers could improve personal protective equipment knowledge in practitioners. During a global pandemic, front-line nurses are best positioned to take the lead in organizing safe care. Hospitals could function as expert hubs by sending out nurse specialists to assist neighbouring care organizations in adopting national emergency guidelines and training front-line staff in selecting and using personal protective equipment.

Declaration of Competing Interest

None.

CRediT authorship contribution statement

Filip Haegdorens: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Erik Franck:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Pierre Smith:** Methodology, Validation, Investigation, Project administration. **Arnaud Bruyneel:** Methodology, Validation, Investigation, Project administration. **Koenraad G. Monsieurs:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Peter Van Bogaert:** Conceptualization, Methodology, Writing – review & editing, Supervision.

pretation, or writing of the report (AUVB-UGIB-AKVB, 2021). The researchers assume final responsibility.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijnurstu.2021.104132.

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