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Research Submissions

Headaches Associated With Personal Protective Equipment – A Cross-Sectional Study Among Frontline Healthcare Workers During COVID-19

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Background.—Coronavirus disease 2019 (COVID-19) is an emerging infectious disease of pandemic proportions. Healthcare workers in Singapore working in high-risk areas were mandated to wear personal protective equipment (PPE) such as N95 face mask and protective eyewear while attending to patients.

Objectives.—We sought to determine the risk factors associated with the development of de novo PPE-associated headaches as well as the perceived impact of these headaches on their personal health and work performance. The impact of COVID-19 on pre-existing headache disorders was also investigated.

Methods.—This is a cross-sectional study among healthcare workers at our tertiary institution who were working in high-risk hospital areas during COVID-19. All respondents completed a self-administered questionnaire.

Results.—A total of 158 healthcare workers participated in the study. Majority [126/158 (77.8%)] were aged 21-35 years. Participants included nurses [102/158 (64.6%)], doctors [51/158 (32.3%)], and paramedical staff [5/158 (3.2%)]. Pre-existing primary headache diagnosis was present in about a third [46/158 (29.1%)] of respondents. Those based at the emergency department had higher average daily duration of combined PPE exposure compared to those working in isolation wards [7.0 (SD 2.2) vs 5.2 (SD 2.4) hours, $P < .0001$] or medical ICU [7.0 (SD 2.2) vs 2.2 (SD 0.41) hours, $P < .0001$]. Out of 158 respondents, 128 (81.0%) respondents developed de novo PPE-associated headaches. A pre-existing primary headache diagnosis (OR = 4.20, 95% CI 1.48-15.40; $P = .030$) and combined PPE usage for >4 hours per day (OR 3.91, 95% CI 1.35-11.31; $P = .012$) were independently associated with de novo PPE-associated headaches. Since COVID-19 outbreak, 42/46 (91.3%) of respondents with pre-existing headache diagnosis either "agreed" or "strongly agreed" that the increased PPE usage had affected the control of their background headaches, which affected their level of work performance.

Conclusion.—Most healthcare workers develop de novo PPE-associated headaches or exacerbation of their pre-existing headache disorders.

Key words: personal protection equipment (PPE), headache, healthcare workers, face mask, N95, eyewear, goggles, coronavirus disease, coronavirus disease 2019

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INTRODUCTION

In late December 2019, reports emerged from the city of Wuhan, in Hubei Province, China, of a cluster of severe acute respiratory illness.[1,2] By January 2020, the condition now known as coronavirus disease 2019 (COVID-19), attributed to the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), had rapidly spread from Wuhan to other regions.[3] As of March 11, 2020, China has reported a total of 80,955 COVID-19 confirmed cases.[4] Outside of China, more than 37,300 cases have been identified across 113 countries or territories.[4] The Ministry of Health (MOH), Singapore, shifted its public health response level to enhanced preparedness on January 23, 2020 when it detected the first imported case of COVID-19.[5] It was subsequently followed by new cases among other visitors and returnees as well as community transmission.[5,6] On January 7, 2020, the level of Disease Outbreak Response System Condition (DORSCON), a color-coded framework that assesses the severity of a pandemic in Singapore, was changed from yellow to orange, with an escalation of measures instituted to contain the disease.[4] As of March 11, 2020, Singapore has reported a total of 178 COVID-19 cases, with 11 cases seen at our institution thus far.[4] During the escalation of the COVID-19 outbreak in Singapore, frontline healthcare workers in all major hospitals were mandated to wear personal protective equipment (PPE), while caring for suspected or confirmed COVID-19 patients, which involved the donning of close-fitting N95 face masks, protective eyewear (mainly goggles), gowns, surgical gloves, and the use of powered air-purifying respirators (PAPR). In real world practice, donning of the PPE is often felt cumbersome and uncomfortable by the frontline healthcare workers,[5] especially if a long period of exposure to such equipment is necessary during the outbreaks of emerging infectious diseases.[7]

Headaches arising from the sustained compression of pericranial soft tissues by donning of objects with tight bands or straps around the head (eg, hat, helmet, googles worn during swimming or diving, or frontal lux devices) have been previously reported in the literature.[8-14] Apart from the mechanical effects, adverse effects such as difficulty breathing has also been reported.[15] However, the scientific literature related to the PPE-associated headaches, specifically the combined usage of the N95 face mask and protective eyewear (specifically googles) is scarce. A previous study among healthcare providers wearing the N95 face mask during the 2003 severe acute respiratory distress syndrome (SARS) epidemic in Singapore reported new onset face mask-associated headaches with a prevalence rate of 37.3%.[16] Another study among nurses working in a medical intensive care unit reported headache as one of the main factors accounting for sub-optimal N95 face mask compliance.[17] Previous reports highlighted that pain or discomfort (headache, facial pain, and/or ear lobe discomfort) arising from tight-fitting face masks as well as elastic head straps resulted in limited tolerability when the N95 face mask was used for a prolonged period.[18-20]

The current COVID-19 outbreak in Singapore provided us a unique opportunity to study the association of PPE exposure and headaches (HAPPE study) – either with the use of N95 face mask alone or in combination with protective eyewear (mainly goggles). We hypothesized that the increased duration of PPE exposure predisposed to the development of de novo PPE-related headaches as well as leading to the exacerbation of pre-existing primary headache diagnosis. We evaluated the prevalence and characteristics of de novo headaches associates with PPE exposure (specifically N95 face mask and/or protective eyewear) among healthcare workers in our institution. In addition, we evaluated the impact of PPE usage on pre-existing headache disorders, identified risk factors for the development of PPE-associated headaches and evaluated the overall impact of headaches during COVID-19 on the work performance of healthcare workers.

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METHODS

This study was performed at the National University Hospital (NUH), a tertiary referral center located in the western region of Singapore. During COVID-19, the usage of PPE was mandated in front-line healthcare workers based in high-risk hospital areas in our institution such as the isolation wards (designated as "pandemic wards"), emergency rooms (equipped with a fever facility), and the medical intensive care unit (MICU). This was a cross-sectional study, which was conducted from February 26 to March 8, 2020, shortly after the surge in COVID-19 cases in Singapore, with a level of uncertainty about the duration of this outbreak. Participants were included if they were aged 21 years or more, able to understand English, and were healthcare workers based primarily in the aforementioned high-risk hospital areas. Written informed consent was taken and the study was approved by the local institutional review board. As there were no previous studies in similar populations available before study initiation, no formal sample size calculation was performed. Taking into consideration institutional infection control policies, a target sample size of 150 participants was deemed reasonable for recruitment. The authors involved in this study were themselves rostered to these high-risk areas during the period of the study and recruited participants in their respective areas. The number of potential participants in each high-risk hospital area at any point of time was known to the authors, given that healthcare workers were segregated by wards without inter-ward movement, in accordance with the infection control policy that was enforced during COVID-19 outbreak. This facilitated the recruitment of participants in the respective high-risk hospital areas and ensured that the sample was representative of all individuals working in this setting.

All participants completed a self-administered questionnaire written in English. The questionnaire comprised of 6 main sections which acquired the following information: (1) demographics (gender, age, ethnicity, occupation, and department), (2) past medical history, (3) PPE usage patterns since the start of COVID-19 in Singapore (N95 face mask and protective eyewear type, primary location where PPE was worn, average number of hours of each equipment used in isolation and together per day and during previous 30 days period, personal views on the change in usage frequency since COVID-19 outbreak), (4) phenotype and characteristics of any pre-existing primary headache disorder (changes in headache frequency, attack duration and frequency of acute medication usage), (5) personal views regarding the changes in characteristics of any pre-existing primary headache disorder since COVID-19, and (6) the phenotype, characteristics and personal views on de novo PPE-associated headaches. In addition, we also assessed the perceived impact of PPE-associated headaches on overall work performance (Supporting Appendix S1).

At our institution, 2 types of National Institute for Occupational Safety and Health (NIOSH) certified 3M® N95 face masks are widely used, with the specification to filter out 95% of particles with a size greater than 0.3 microns. By definition, the donning of full PPE necessitates the use of a pre-fitted size-appropriate N95 face mask rather than a surgical mask.[7] All healthcare workers at our institution underwent mandatory annual fit tests to select the right size of the N95 face mask. When properly fitted, the N95 face mask forms a tight seal against the wearer's face to provide respiratory protection. Protective goggles that provide splash protection against biological materials are also widely available and are used by the vast majority of healthcare workers instead of face-shields/visors, while working in high-risk areas (Fig. 1).

Statistical Analyses.—Descriptive analyses were used to study baseline characteristics. Variables that were measured on the ordinal scale were compared using a Mann-Whitney U test and summarized using median (IQR). Interval level data were compared using a t test and described using mean (SD). Chi-square analyses were used to compare nominal demographic data and PPE usage patterns across 2 groups (respondents with and without de novo PPE-associated headaches). To maximize sensitivity, variables with a univariable association of $P < .2$ were included as candidates into a multivariable logistic regression model. Predictor variables that were significant at $P < .05$ were retained in the

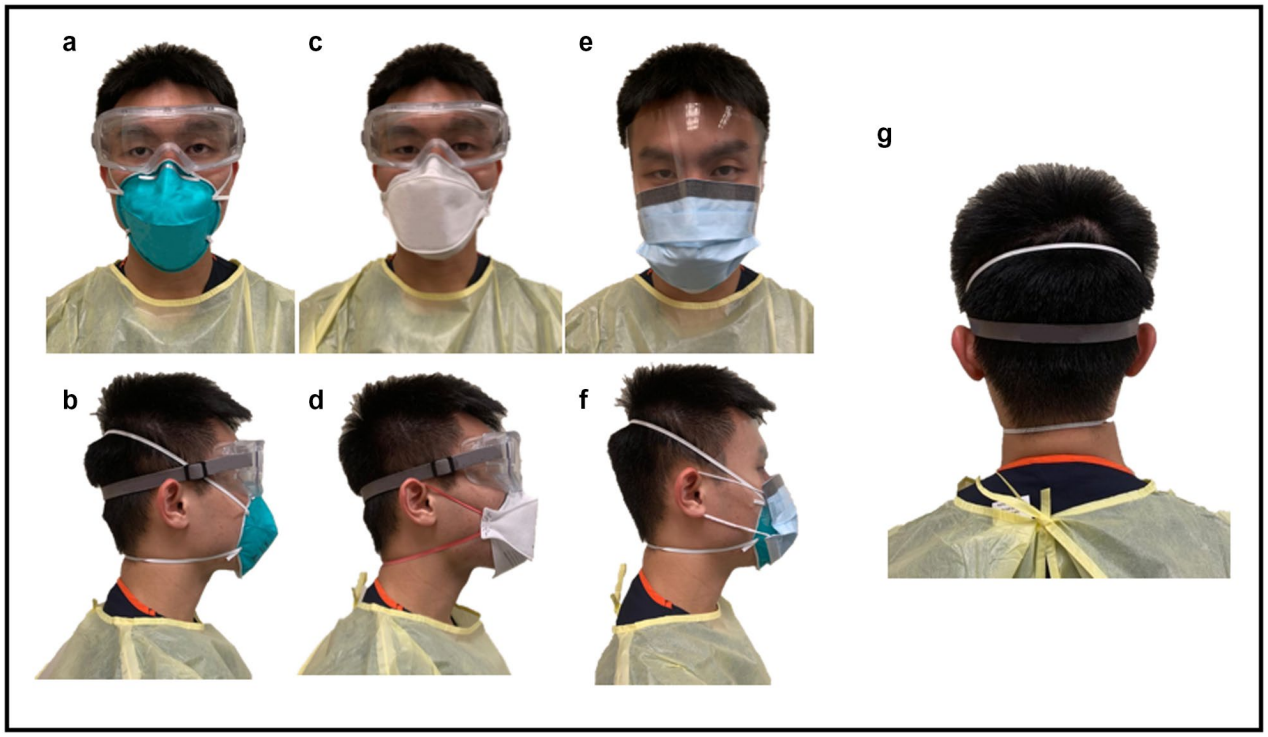

Fig. 1.—Frontal and side profiles of a healthcare working wearing N95 face mask and protective googles in combination (a-d). Alternatively, a face-shield or visor may be worn in combination with a N95 face mask (e,f). Posterior profile (g). Note where the edges of the N95 face mask and googles contact the head (including face). The figure also illustrates the positioning of the various elastic straps from the PPE upon the head (including face) and upper cervical region. [Color figure can be viewed at wileyonlinelibrary.com]

multivariable model. Multivariable logistic regression analyses were performed to identify the independent variables associated with the development of de novo PPE-associated headaches. A 2-way ANOVA test was conducted to test for differences in the mean hours per day of PPE exposure at various high-risk areas (isolation/pandemic wards, ED, and MICU) and further post hoc comparisons were performed using the Tukey test to adjust for multiple comparisons. When parametric tests were employed, assumptions of normality were verified using Q-Q plots and histograms. Statistical significance was set at $P < .05$. All analyses were 2-tailed. All statistical analyses were performed using the SPSS statistical package program version 25.0 for Windows (SPSS Inc, 2003, Chicago, IL, USA).

RESULTS

A total of 160 frontline workers were invited to participate in the study, with 158 agreeing, giving an overall response rate of 98.7%. The majority of study respondents were female [111/158 (70.3%)], aged 21-35 years [126/158 (77.8%)], and of Chinese ethnicity [92/158 (58.2%)]. Nurses contributed most [102/158 (64.6%)] followed by doctors [51/158 (32.3%)] and paramedical personnel [5/158 (3.2%)]. (Table 1). Out of 158 subjects, a pre-existing primary headache diagnosis was present in 46 respondents (29.1%). Other non-headache related concomitant co-morbidities were present in 27 (17.1%) participants (Table 2). There were no missing data.

PPE Usage Patterns.—All 158 healthcare workers reported that there was an increased frequency of PPE exposure since the COVID-19 outbreak in Singapore. On average, respondents donned the N95 face mask for 18.3 days over the 30-day period, with a mean of 5.9 hours per day. Goggles were used as protective eyewear in the majority [153/158 (96.8%)]. Protective eyewear was worn on an average of 18.2 days over the 30-day period, with a mean of 5.7 hours per day. The combined use of N95 face mask and protective eyewear was worn for an average of 18.0 days over 30 days, with

Table 1.—Baseline Characteristics of Healthcare Workers in High-Risk Areas Who Donned PPE During COVID-19 (n = 158)

Characteristics	Healthcare Workers N (%)
Female Gender	111 (70.3)
Age (years)	
21-40	138 (87.3)
>40	20 (12.7)
Ethnicity	
Chinese	92 (58.2)
Indian	18 (11.4)
Filipino	23 (14.6)
Malay	15 (9.5)
Others	10 (6.3)
Occupation	
Doctor	51 (32.3)
Nurse	102 (64.6)
Paramedical personnel	5 (3.2)
Department	
Internal medicine	33 (20.9)
Emergency department	56 (35.4)
Nursing	63 (39.9)
Medical intensive care unit	6 (3.8)

Table 2.—Pre-Existing Primary Headache Diagnosis and Other Co-Morbidities Among Healthcare Workers (n = 158)

Condition	Healthcare Workers N (%)
Pre-existing primary headache diagnosis	46 (29.1)
Migraine	30 (19.0)
Without aura	26 (16.5)
With aura	4 (2.5)
Tension-type headache	16 (10.1)
Cluster headache	0 (0.0)
Other background medical conditions	27 (17.1)
Asthma	8 (5.1%)
Ankylosis spondylitis	1 (0.6)
Cigarette smoking	2 (1.3)
Depression	1 (0.6)
Anxiety	1 (0.6)
Diabetes mellitus	1 (0.6)
Eczema	2 (1.3)
Fatty liver	1 (0.6)
Hypertension	2 (1.3)
Hypothyroidism	1 (0.6)
Hyperthyroidism	2 (1.3)
Hyperlipidemia	1 (0.6)
Ischemic heart disease	1 (0.6)
Stroke	1 (0.6)
Ventricular septal defect	2 (1.3)

Table 3.—PPE Usage Patterns Among Healthcare Workers During COVID-19 Outbreak (n = 158)

Characteristics	Healthcare Workers N (%)
N95 face mask	
Type 1 (3M® NIOSH 1860S)	144 (91.1)
Type 2 (3M® NIOSH 1870 + Aura)	14 (8.9)
Number of days worn over last 30 days (days) (mean ± SD)	18.3 ± 5.1
Number of hours worn per day (hours) (mean ± SD)	5.9 ± 2.4
Protective eyewear	
Goggles	154 (97.5)
Face shield/visor	4 (2.5)
Number of days worn over last 30 days (days) (mean ± SD)	18.2 ± 5.3
Number of hours worn per day (hours) (mean ± SD)	5.7 ± 2.5
Combination N95 face mask and eyewear usage	
Number of days worn in combination over last 30 days (days) (mean ± SD)	18.0 ± 5.2
Number of hours worn in combination per day (hours) (mean ± SD)	5.7 ± 2.5
Primary location where PPE was used by healthcare workers	
Isolation wards (designated "pandemic wards")	96 (60.8)
Emergency department	56 (35.4)
Medical intensive care unit	6 (3.8)
Change in the frequency of PPE usage since the COVID-19 outbreak	
Significant increase in frequency	137 (86.7)
Slight increase in frequency	21 (13.3)
No change in frequency	0 (0.0)

a mean of 5.7 hours per day (Table 3). Two-way ANOVA test with post hoc Tukey's test revealed that across departments, healthcare workers based at the ED had higher average daily duration of PPE exposure compared to those working in isolation wards [7.0 (SD 2.2) vs 5.2 (SD 2.4) hours, $P < .0001$)] or MICU [7.0 (SD 2.2) vs 2.2 (SD 0.41) hours, $P < .0001$)] (Fig. 2). However, there was no statistically significant difference when PPE exposure over a 30 days period was compared between high-risk areas (Fig. 2).

De Novo PPE-Associated Headaches.—Of the 158 respondents, 128 (81.0%) reported de novo PPE-associated headaches when they wore either the N95 face mask, with or without the protective eyewear. All respondents described the headaches as bilateral in location. Figure 3 illustrates the summated anatomical

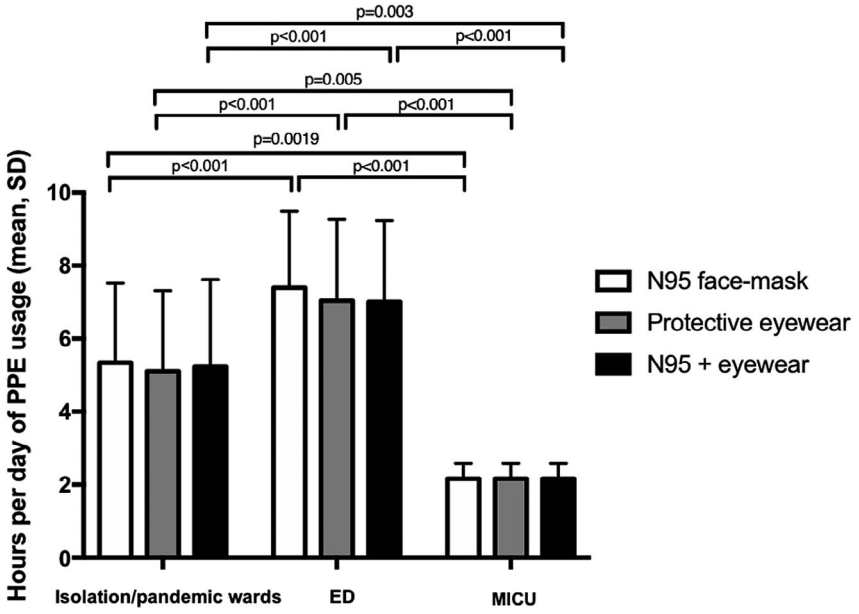

Fig. 2.—Two-way ANOVA analysis of PPE exposure per day (mean hours per day) across the various high-risk areas during COVID-19. ED: emergency department, MICU: medical intensive care unit.

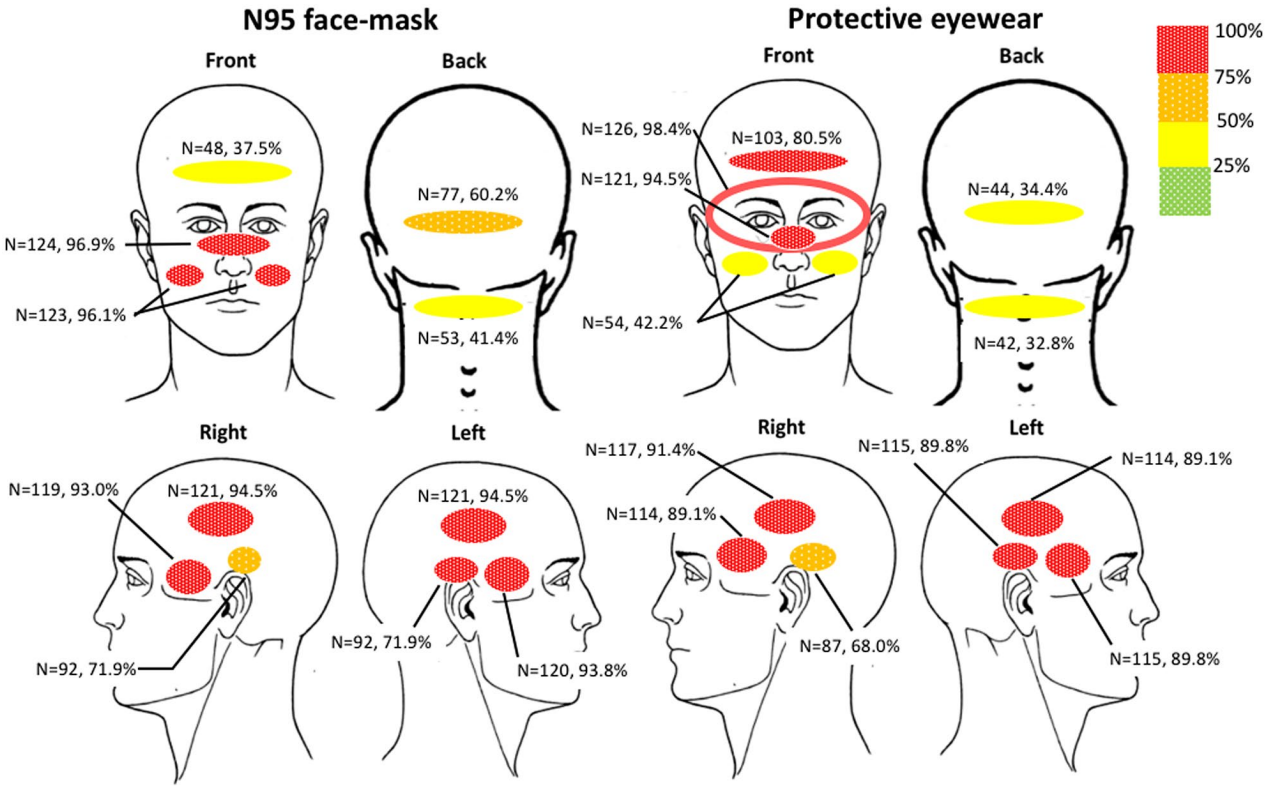

Fig. 3.—Anatomical localization and frequency distribution among 128 respondents who reported de novo PPE-related headaches. All respondents (n = 158) completing the questionnaire were asked to shade the areas where pain, pressure or compression from the respective PPE was experienced if this was present. [Color figure can be viewed at wileyonlinelibrary.com]

localization of headaches (marked by the study participants) and the corresponding frequencies of occurrence according to PPE subtype. Interestingly, the location of the discomfort experienced by the participants corresponded to the areas of contact from the face mask or goggles and their corresponding head straps. The majority [112/128 (87.5%)] reported a sensation of pressure or heaviness at the affected sites, with some [15/128 (11.7%)] characterizing it as a throbbing or pulling pain [1/128 (0.8%)].

The time interval between donning of N95 face mask or protective eyewear to the onset of headache was less than 60 minutes for the majority of respondents [104/128 (81.3%)] and [113/128 (88.3%)], respectively). After removal of PPE, the attributed headache resolved spontaneously within 30 minutes in the majority for both N95 face mask [113/128 (88.3%)] and protective eyewear [114/128 (89.1%)] (Table 4).

Majority of the respondents reported an attack frequency of 1-4 days [49/128 (38.3%)] over a 30-day period. Headache intensity was graded as mild by 92 out of 128 (71.9%) respondents. Associated symptoms were experienced by 30 out of 128 (23.4%) respondents, and comprised of nausea and/or vomiting, photophobia, phonophobia, neck discomfort, and movement sensitivity.

During an attack, the majority [88/128 (68.8%)] did not need acute analgesic treatment. Among the remaining participants, paracetamol was most frequently used drug, followed by non-steroidal anti-inflammatory drugs (NSAIDS). Triptans and opioids were used rarely.

Among those who took analgesics, the majority [38/40 (95.0%)] used them with a frequency of 1 to 9 days per month. Over a 30-day period, between 1 and 4 days of sick leave attributed to de novo PPE-associated headaches were taken only by 9 [9/128 (7.0%)] respondents.

Headaches were attributed as "likely" by 68 out of 128 (53.1%) respondents due to the N95 face mask, while protective eyewear was reported as the "likely" cause of headache in 66 out of 128 (51.6%) respondents. Donning of both the N95 face mask and protective eyewear was deemed the "likely" cause of the headache in 67 out of 128 (52.3%) participants. The majority [106/128 (82.8%)] opined that PPE-associated headaches resulted in a "slight decrease" in work performance.

Table 4.—Time Interval Between Wearing or Removal of PPE and the Onset or Resolution of De Novo PPE-Associated Headaches (n = 128)

Variable	Value
Time interval between wearing N95 face mask to onset of headache (minutes), N (%)	
≤10	27 (21.1)
11-20	28 (21.9)
21-30	19 (14.8)
31-40	19 (14.8)
41-50	11 (8.6)
51-60	0 (0.0)
61-120	24 (18.8)
Time interval between wearing protective eyewear to onset of headache (minutes), N (%)	
≤10	29 (22.7)
11-20	30 (23.4)
21-30	24 (18.8)
31-40	22 (17.2)
41-50	8 (6.3)
51-60	0 (0.0)
61-120	15 (11.7)
Time interval from removal of N95 face mask to resolution of headache (minutes), N (%)	
≤10	77 (60.2)
11-20	22 (17.2)
21-30	14 (10.9)
31-40	4 (3.1)
41-50	5 (3.9)
51-60	0 (0.0)
61-120	6 (4.7)
Time interval from removal of protective eyewear to resolution of headache (minutes), N (%)	
≤10	81 (63.3)
11-20	16 (12.5)
21-30	17 (13.3)
31-40	5 (3.9)
41-50	6 (4.7)
51-60	0 (0.0
61-120	3 (2.3)

Study participants with a pre-existing primary headache diagnosis (OR = 3.44, 95%; CI 1.14-10.32; $P = .013$) and those working in the emergency department (OR = 2.39, 95% CI 1.05-5.47; $P = .019$) were more likely to develop de novo PPE-associated headaches. None of the pre-existing headache subtype was found to predispose to de novo PPE-associated headaches. When PPE usage patterns were evaluated, N95 face mask (OR = 1.59, 95% CI 1.15-2.18; $P < .001$), protective eyewear (OR 1.60, CI 1.13-2.25; $P < .001$) or using them together (OR = 1.50, 95% CI 1.09-2.07; $P = .002$) for >4 hours per day had a higher chance of developing

such headaches. Similar patterns were observed with the headache frequency of >15 days per month with the use of N95 face mask (OR = 1.34, 95% CI 0.96-1.86; *P* = .043), protective eyewear (OR = 1.50, 95% CI 1.03-2.18; *P* = .013), or both together (OR = 1.47, 95% CI 1.01-2.13; *P* = .016) (Table 5).

Post hoc multivariable logistic regression analysis revealed that a pre-existing primary headache diagnosis (OR = 4.20, 95% CI 1.48-15.40; *P* = .030), as well as the combined use of N95 face mask and eyewear for >4 hours per day (OR 3.91, 95% CI 1.35-11.31; *P* = .012) was independently associated with developing de novo PPE-associated headaches. Due to multi-collinearity, the effect of only N95 face mask use and its use in combination with protective eyewear was analyzed in2 separate models for evaluating their role in the development of de novo PPE-related headaches (Table 6 and Supporting Appendix S2).

PPE-Associated Headaches Fulfilling ICHD-3 (2018) Diagnosis of 4.6.1 External Compression Headache.—The time interval between donning the N95 face mask to headache commencement was observed to be <60 minutes in majority [104/128 (81.3%)] of the respondents. Similar time interval of <60 minutes was reported by 122 out of 128 (95.3%) respondents for spontaneous headache resolution after removing the N95 face mask. High proportion of respondents developed headache within 60 minutes of donning the protective eyewear [113/128 (88.0%)] and had headache resolution within the same period after its removal [124/128 (97.7%)].

The ICHD-3 criteria for ECH were satisfied in majority of respondents who developed de novo PPE-associated headaches attributed to the N95 face mask [96/128 (75.0%)] and to protective eyewear usage [106/128 (82.8%)] (Table 7).

Pre-Existing Headache Diagnosis and Concomitant De Novo PPE-Related Headaches.—Of the 46 participants with pre-existing primary headache disorder (migraine with or without aura and tension-type headache), 43 (93.5%) experienced concomitant de novo PPE-associated headaches since the start of COVID-19. Majority of these respondents [37/43 (86.0%)] developed episodic headaches (<15 days per month). The mean duration of each attack was 3.5 ± 4.1 hours. None of these participants were on regular preventive treatment and acute analgesic treatment was used by 31 out of 43 (72.1%) respondents.

Course of Pre-Existing Headaches During COVID-19.—Majority of respondents [42/46 (91.3%)] with an underlying pre-existing headache diagnosis either "agreed" or "strongly agreed" that the increased PPE usage aggravated their background headaches in terms of frequency and attack duration (Figs. 4 and 5). Other important factors that could have potentially worsened their pre-existing headaches included sleep deprivation [28/46 (60.9%)], physical stress [13/46 (29.3%)], emotional stress [6/46 (13.0%)], irregular meal times [7/46 (15.2%)] and inadequate hydration [18/46 (39.1%)]. Nearly half of the respondents indicated that there was a "slight" or "significant increase" [25/46 (53.4%)] in acute medication usage and majority of them [41/46 (90.7%)] opined that their work performance was adversely affected "slightly" or "significantly."

DISCUSSION

Our study describes de novo PPE-associated headaches among frontline healthcare workers in Singapore during the current COVID-19 outbreak. Nearly 82% of respondents developed de novo PPE-associated headaches. The combined exposure to N95 face mask and protective eyewear use for >4 hours per day and those who had a pre-existing headache diagnosis had a greater likelihood of developing such headaches.

Our findings are in agreement with the report by Lim et al, albeit for N95 face mask exposure only.[16] Not surprisingly, doctors and nurses working in high-risk hospital areas, especially at the emergency department, had a greater risk for the development of such headaches. Nearly 70% of our cohort did not require any acute analgesic treatment for their de novo PPE-associated headaches, which is contrary to the previously reported use of up to 60%.[16] This could have occurred due to the infrequent episodic headaches in our cohort, which were mild in intensity. However, a large proportion of our participants experienced at least a "slight" decreased work performance, underscoring the potential impact on occupational health

Table 5.—Univariate Logistic Regression Analysis of Factors (Demographic Variables, Primary Location of PPE Usage, Pre-Existing Primary Headache Diagnosis, and PPE Usage) in Respondents With and Without De Novo PPE-Associated Headaches (n = 158)

Demographic Variables	With De Novo PPE-Related Headaches N = 128 (%)	Without De Novo PPE-Related Headaches N = 30 (%)	OR (95% CI)	*P*-Value†
Gender, female	92 (71.9)	19 (63.3)	1.14 (0.85-1.52)	.380
Age (years)				
21-40	111 (86.7)	27 (90.0)	0.96 (0.84-1.11)	.770
>40	17 (13.3)	3 (10.0)		
Ethnicity				
Chinese	72 (56.3)	20 (66.7)	0.84 (0.63-1.13)	.410
Non-Chinese	56 (43.8)	10 (33.3)		
Occupation				
Doctors and nurses	125 (97.7)	28 (93.3)	1.05 (0.95-1.16)	.241
Paramedical staff	3 (2.3)	2 (6.7)		
Underlying co-morbidities	23 (18.0)	3 (10.0)	1.80 (0.57-5.60)	.414
Originating department of healthcare workers				
Emergency department	51 (39.8)	5 (16.7)	2.39 (1.05-5.47)	.019*
Others: medicine, nursing, ICU	77 (60.2)	25 (83.3)		
Pre-existing primary headache diagnosis	43 (33.6)	3 (10.0)	3.44 (1.14-10.32)	.013*
Duration of N95 face mask wear per day				
>4 hours	115 (89.8)	17 (56.7)	1.59 (1.15-2.18)	<.001*
1-4 hours	13 (10.2)	13 (43.3)		
Frequency of N95 face mask wear per month				
>15 days	97 (75.8)	17 (56.7)	1.34 (0.96-1.86)	.043*
3-15 days	31 (24.2)	13 (43.3)		
Duration of protective eyewear use per day				
>4 hours	109 (85.2)	16 (53.3)	1.60 (1.13-2.25)	<.001*
1-4 hours	19 (14.8)	14 (46.7)		
Frequency of protective eyewear use per month				
>15 days	96 (75.0)	15 (50.0)	1.50 (1.03-2.18)	.013*
3-15 days	32 (25.0)	15 (50.0)		
Duration of combined N95 face mask and eyewear use per day				
>4 hours	109 (85.2)	17 (56.7)	1.50 (1.09-2.07)	.002*
1-4 hours	19 (14.8)	13 (43.3)		
Frequency of combined N95 face mask and eyewear use per month				
>15 days	94 (73.4)	15 (50.0)	1.47 (1.01-2.13)	.016*
3-15 days	34 (26.6)	15 (50.0)		

*Statistically significant results.
†Chi-square analyses (statistically significant if $P < .05$).

Table 6.—Multivariable Logistic Regression Analysis of Independent Factors and PPE Usage Patterns Associated With the Development of De Novo PPE-Associated Headaches (N = 158)†

Demographic Variables	Odds Ratio (95% Confidence Interval)	*P*-Value
Female gender	0.88 (0.33-2.34)	.790
Age (years)		
21-40	0.49 (0.11-2.12)	.337
>41		
Ethnicity		
Chinese	0.69 (0.27-1.79)	.454
Others: Indian, Malay, Filipino, Caucasian, etc		
Originating department of healthcare workers		
Emergency department	2.60 (0.84-8.03)	.087
Others: medicine, nursing, ICU		
Pre-existing primary headache diagnosis	4.20 (1.48-15.40)	.030*
Duration of combined N95 face mask and eyewear use per day		
>4 hours	3.91 (1.35-11.31)	.012*
1-4 hours		

*Statistically significant results.
†Due to multi-collinearity of variables ("duration of combined N95 face-mask & eyewear use per day" and "duration of N95 face-mask use per day), they were analyzed in 2 separate models, including only one of these variables in each model.

Table 7.—International Classification of Headache Disorders, 3rd Edition (ICHD-3) (2018) Criteria for External Compression Headache

1. At least 2 episodes of headache fulfilling criteria 2-4
2. Brought on by and occurring within 1 hour during sustained external compression of the forehead or scalp
3. Maximal at the site of external compression
4. Resolving within 1 hour after external compression is relieved
5. Not better accounted for by another ICHD-3 diagnosis

and productivity. We hypothesize that the headache frequency, severity, use of analgesics, and work performance may worsen if the current COVID-19 outbreak is sustained for a longer time. Perhaps, shorter duty shifts and the resultant shorter duration of PPE use might be a better strategy to avoid the adverse impacts of PPE usage.

The pathogenesis of de novo PPE-associated headaches could possibly have several etiological considerations, which include mechanical factors, hypoxemia,

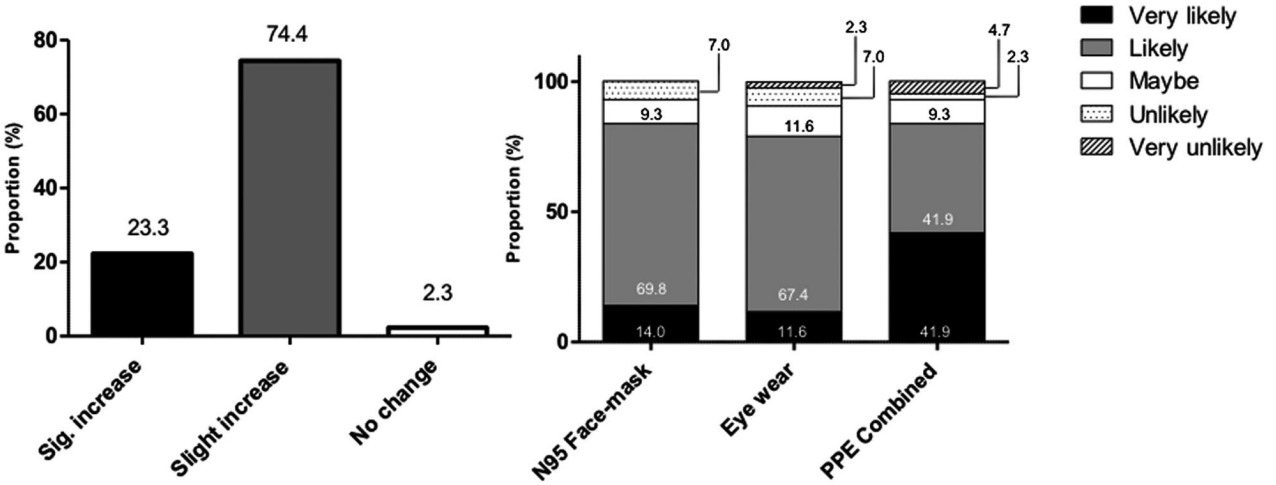

Fig. 4.—Extent of change in the average number of headache days per month in those with a pre-existing headache diagnosis (a), and the perceived relationship of this change attributable to PPE use (b).

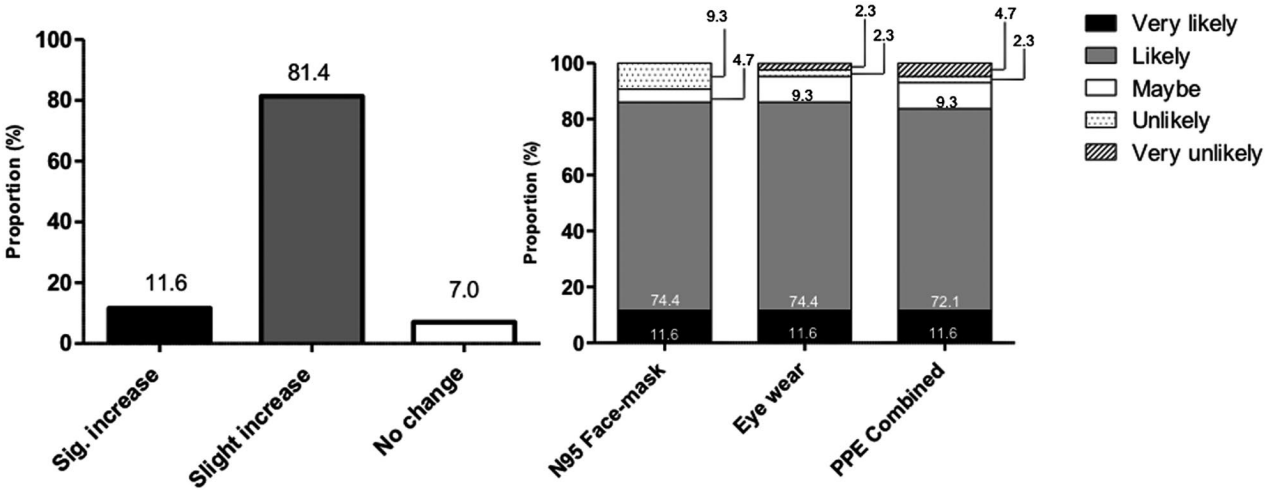

Fig. 5.—Extent of change in average attack duration in those with a pre-existing headache disorder (a), and the perceived relationship of this change attributable to PPE use (b).

hypercarbia, or the associated stress.[17-21] The phenotypic findings from our study suggest an anatomic basis for the headache or facial pain from PPE usage (Figs. 1 and 3). Pressure or tractional forces from the mask and/or goggles together with the accompanying straps may lead to local tissue damage and exert an irritative effect on the underlying superficial sensory nerves (in particular trigeminal or occipital nerve branches) innervating the face, head, and cervical region (Fig. 6).[9] The cervical neck strain from donning the equipment could have led to the development of cervicogenic headache or tension-type headache (TTH)[22-24] The peripheral sensitisation may activate the trigeminocervical complex through nociceptive information transmitted via different branches of the trigeminal nerve through the trigeminal ganglia and brainstem to the higher cortical areas thereby triggering the headache attacks coronavirus disease 2019[25,26] Alternatively, a neuralgia with transient effects on the underlying superficial sensory nerves could have occurred, although other reasons were more likely as most respondents did not report characteristics suggestive of a neuropathic process.[27] These etiological reasons could perhaps explain why a large proportion of those with pre-existing primary headache disorders and concomitant de novo PPE-associated headaches reported an increase in the average number of headache days over a 30 day period,

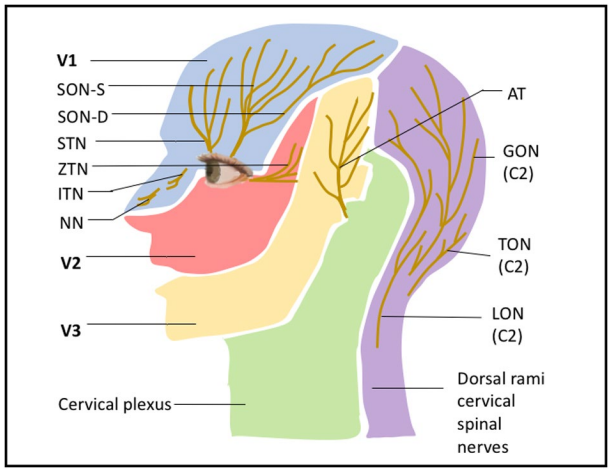

Fig. 6.—Sensory innervation of the head. Auriculotemporal nerve (AT); deep branch of the supraorbital nerve (SON-D); greater occipital nerve (GON); infratrochlear nerve (ITN); lesser occipital nerve (LON); mandibular branch of the trigeminal nerve (V3); maxillary branch of the trigeminal nerve (V2); nasal nerve (NN); ophthalmic branch of the trigeminal nerve (V1); superficial branch of the supraorbital nerve (SON-S); supratrochlear nerve (STN); third occipital nerve (TON); zygomaticotemporal nerve (ZTN). [Color figure can be viewed at wileyonlinelibrary.com]

with the perception that this change was probably attributable to the PPE.

Depending on the subtype of PPE exposure, the majority of respondents with de novo PPE-associated headaches fulfilled the ICHD-3 criteria for external compression headache (ECH) (Table 7) coronavirus

disease 2019 [8] A lower proportion of participants in our study had a pre-existing primary headache disorder, and thus the fulfillment of the ICHD-3 criteria for ECH was predictable in those who developed de novo PPE-associated headaches. We observed that in some participants the "on-gear-to-start-of-headache" and "off-gear-to-end-of-headache" intervals exceeded the 60-minutes limit as stipulated in the criteria. Our study found that responders with a combined exposure to N95 face mask and protective eyewear use for >4 hours per day were predisposed to the development of such de novo headaches. The increased duration of PPE exposure among frontline healthcare workers during COVID-19 is brought about by necessity as mandated by infectious diseases protocols, which is a clear departure from prior usage patterns before the start of the pandemic. Despite any discomfort, our subjects may have had to endure varying degrees of pain during their working hours, without the option of frequent adjustments or removal. In contrast, prior reports of ECH attributed to exposure to swimming googles or head gear were often short-lived, limited to approximately an hour, with the duration perhaps dictated by when the gear was removed due to any discomfort experienced by the wearer.[9,11,13] Additionally, up to a quarter of subjects had associated migrainous symptomatology such as nausea/vomiting, photophobia, phonophobia and movement sensitivity. We propose that in predisposed patients, if the stimulus is prolonged, external compression may lead to a more severe migraine headache or even a full-blown migraine attack.[28] From a purely anatomic standpoint, the report locations where pain is experienced may be consistent with migraine or TTH (Figure 3). Perhaps, larger field studies are necessary to clarify the phenotypic variance of ECH.

Since the start of COVID-19 in Singapore, most respondents with a pre-existing primary headache disorder experienced an increase in headache frequency, mostly attributed to PPE exposure. Other factors such as sleep deprivation, physical and emotional stress, irregular meal times and inadequate hydration contributed to this phenomenon. Our findings are in keeping with multiple studies demonstrating that the triggers in migraine or TTH were often related to a change in internal and external homeostasis, underscoring the importance of addressing these factors in optimizing headache control.[26,29-31]

We recognize that conventional N95 face mask and protective eyewear fit tests consider only the overall fit factor and do not take into account the level of comfort or tolerability especially when used for prolonged periods of time.[32,33] Pain or discomfort is often experienced from tight-fitting PPE, especially after prolonged use. The current mask and protective eyewear designs rely on elastic head straps to ensure a tight-fit, often causing headache, facial pain, and/or ear lobe discomfort due to tractional and tensional forces to the head. In addition, the PPE leads to thermal discomfort, causing a build-up of moist warm air inside the mask and googles.[34] These factors may cause de novo PPE-associated headache as well as affect compliance, with important ramifications for occupation health, workplace safety and productivity, and ultimately job satisfaction among healthcare workers. Through novel engineering solutions, we envisage that the next generation protective face mask and eyewear will have an improved design with an emphasis on tolerability, and consequently less propensity for headaches.[35]

We acknowledge some limitations of our study. First, the sample size may be considered small. However, the restrictions imposed by infection control protocols during COVID-19 outbreak and barriers in approaching healthcare personnel working in the high-risk areas made it difficult to recruit a larger number of participants. Second, since the study was performed among frontline healthcare providers based in high-risk hospital areas, we could have missed on more predisposed personnel who had avoided or been excused from working in such areas. Third, other predisposing factors such as psychological stress and sleep disturbances that could have contributed to the development of de novo PPE-associated headaches were not assessed in this study. Similarly, other non-PPE-related factors such as ambient room temperature and humidity were not assessed and may have influenced the appeal and use of PPE. For example, healthcare workers based at the outdoor ED fever facility tentages in a tropical country like Singapore are often subject to hot and humid conditions and these unaccustomed environmental changes may trigger new onset headaches or exacerbate pre-existing headaches. Fourth, we used

a self-administered questionnaire, which could have been affected by the recall bias. However, as this study was conducted during the zenith of the COVID-19 outbreak in Singapore, the ongoing exposure to PPE would have reduced the effect of this bias. Fifth, our study did not assess the efficacy of the analgesics used for the treatment of de novo PPE-associated headaches. Lastly, the anthropometric factors (such as body mass index (BMI), facial morphology, contours, presence of facial hair) and the head and neck muscle tension due to the weight of mask and eyewear were not assessed.

CONCLUSIONS

We present the prevalence and characteristics of de novo headaches and aggravated pre-existing headaches among frontline healthcare personnel working in high-risk areas of a tertiary institution during the current COVID-19 outbreak in Singapore. The magnitude of this condition is clinically significant and might worsen if the current outbreak spreads widely and stays for a longer time, affecting the work performance of healthcare workers. Perhaps, better strategies are needed for designing various personal protection equipment and reducing their exposure time by healthcare workers.

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REFERENCES

1. Huang C, Wang Y, Li X, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet*. 2020;395:497-506.
2. Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: Summary of a report of 72314 cases from the Chinese center for disease control and prevention. *JAMA*. 2020 [Epub ahead of print]. doi: 10.1001/jama.2020.2648.
3. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med*. 2020;382:727-733.
4. Ministry of Health Singapore. *Updates on COVID-19 (Coronovirus Disease 2019) Local Situation*; 2020. Available at: https://www.moh.gov.sg/covid-19. Accessed March 12, 2020.
5. Wong JEL, Leo YS, Tan CC. COVID-19 in Singapore-current experience: Critical global issues that require attention and action. *JAMA*. 2020. doi:10.1001/jama.2020.2467.
6. Young BE, Ong SWX, Kalimuddin S, et al. Epidemiologic features and clinical course of patients infected with SARS-CoV-2 in Singapore. *JAMA*. 2020. doi:10.1001/jama.2020.3204.
7. Rebmann TAS, Cain T, Citarella B, et al. *APIC Position Paper: Extending the Use and/or Reusing Respiratory Protection in Health Care Settings During Disasters*; 2009. Available at: http://www.apic.org/Resource_/TinyMceFileManager/Advocacy-PDFs/APIC_Position_Ext_the_Use_and_or_Reus_Resp_Prot_in_Hlthcare_Settings1209l.pdf. Accessed March 5, 2020.

8. Headache Classification Committee of the International Headache Society (IHS). The International Classification of Headache Disorders, 3rd edition. *Cephalalgia* 2018;38:1-211.
9. Krymchantowski AV. Headaches due to external compression. *Curr Pain Headache Rep*. 2010;14:321-324.
10. Rahmani Z, Kochanek A, Astrup JJ, et al. Helmet-induced headache among Danish military personnel. *Scand J Public Health*. 2017;45:818-823.
11. Jacobson RI. More "goggle headache": Supraorbital neuralgia. *N Engl J Med*. 1983;308:1363.
12. Pestronk A, Pestronk S. Goggle migraine. *N Engl J Med*. 1983;308:226-227.
13. O'Brien JC Jr. Swimmer's headache, or supraorbital neuralgia. *Proc (Bayl Univ Med Cent)*. 2004;17: 418-419.
14. Krymchantowski A, Barbosa JS, Cvaigman M, et al. Helmet-related, external compression headache among police officers in Rio de Janeiro. *MedGenMed*. 2004;6:45.
15. Khoo KL, Leng PH, Ibrahim IB, et al. The changing face of healthcare worker perceptions on powered air-purifying respirators during the SARS outbreak. *Respirology*. 2005;10:107-110.
16. Lim EC, Seet RC, Lee KH, et al. Headaches and the N95 face-mask amongst healthcare providers. *Acta Neurol Scand*. 2006;113:199-202.
17. Rebmann T, Carrico R, Wang J. Physiologic and other effects and compliance with long-term respirator use among medical intensive care unit nurses. *Am J Infect Control*. 2013;41:1218-1223.
18. Szeinuk J, Beckett WS, Clark N, Hailoo WL. Medical evaluation for respirator use. *Am J Ind Med*. 2000;37:142-157.
19. Radonovich LJ Jr, Cheng J, Shenal BV, et al. Respirator tolerance in health care workers. *JAMA*. 2009;301:36-38.
20. Shenal BV, Radonovich LJ Jr, Cheng J, et al. Discomfort and exertion associated with prolonged wear of respiratory protection in a health care setting. *J Occup Environ Hyg*. 2012;9:59-64.
21. Lance J, Goadsby PJ. Miscellaneous headaches unassociated with a structural lesion. In: Olesen J, Tfelt-Hansen P, Welch KM, eds. *The Headaches*. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2000:752-753.
22. Liang Z, Galea O, Thomas L, et al. Cervical musculoskeletal impairments in migraine and tension type headache: A systematic review and meta-analysis. *Musculoskelet Sci Pract*. 2019;42:67-83.
23. Fredriksen TA, Antonaci F, Sjaastad O. Cervicogenic headache: Too important to be left un-diagnosed. *J Headache Pain*. 2015;16:6.
24. Barmherzig R, Kingston W. Occipital neuralgia and cervicogenic headache: Diagnosis and management. *Curr Neurol Neurosci Rep*. 2019;19:20.
25. Goadsby PJ, Lipton RB, Ferrari MD. Migraine – Current understanding and treatment. *N Engl J Med*. 2002;346:257-270.
26. Goadsby PJ, Holland PR, Martins-Oliveira M, et al. Pathophysiology of migraine: A disorder of sensory processing. *Physiol Rev*. 2017;97:553-622.
27. Blake P, Burstein R. Emerging evidence of occipital nerve compression in unremitting head and neck pain. *J Headache Pain*. 2019;20:76.
28. Rasmussen BK, Olesen J. Symptomatic and nonsymptomatic headaches in a general population. *Neurology*. 1992;42:1225-1231.
29. Pellegrino ABW, Davis-Martin RE, Houle TT, et al. Perceived triggers of primary headache disorders: A meta-analysis. *Cephalalgia*. 2018;38:1188-1198.
30. Martin PR. Stress and primary headache: Review of the research and clinical management. *Curr Pain Headache Rep*. 2016;20:45.
31. Marmura MJ. Triggers, protectors, and predictors in episodic migraine. *Curr Pain Headache Rep*. 2018;22:81.
32. Or PP, Chung JW, Wong TK. A study of environmental factors affecting nurses' comfort and protection in wearing N95 respirators during bedside procedures. *J Clin Nurs*. 2018;27:e1477-e1484.
33. Li Y, Tokura H, Guo YP, et al. Effects of wearing N95 and surgical facemasks on heart rate, thermal stress and subjective sensations. *Int Arch Occup Environ Health*. 2005;78:501-509.
34. Locatelli SM, LaVela SL, Gosch M. Health care workers' reported discomfort while wearing filtering face-piece respirators. *Workplace Health Saf*. 2014;62:362-368.
35. Baig AS, Knapp C, Eagan AE, et al. Health care workers' views about respirator use and features that should be included in the next generation of respirators. *Am J Infect Control*. 2010;38:18-25.

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