

# Fatigue among health care workers during emergency interventions using biological personal protective equipment: an observational simulation study

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## Research

**Keywords:** Accident Prevention, Occupational Risks, Personal Protective Equipment, Safety, Simulation

**Posted Date:** April 10th, 2020

**DOI:** <https://doi.org/10.21203/rs.3.rs-20692/v1>

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# Abstract

**Background :** Biohazard incidents are ordinary situations usually managed by health systems with the mandatory priority of preventing the spread of the pathogen. Health care workers in charge of dealing with these situations must be equipped with personal protective equipment (PPE) for her/his own security. The main objective of this study was developing a risk model to predict whether health care workers will tolerate wearing PPE, III category, 4B / 5B / 6B type, against biological risks during a 30 minutes intervention.

**Methods :** A preliminary, prospective, simulation study, without intervention was conducted at the Advanced Simulation Center at the Medicine Faculty of Valladolid University (Spain) from April 3rd to 28th, 2017. Students and professional's health care were equipped with a PPE and performed a 30 minutes-long biohazard simulation. Anthropometric, physiological, analytical variables, and anxiety levels were measured pre- and post-simulation. A scoring model was constructed by using the estimate regression coefficients of the significant variables obtained from a multivariate model of the logistic regression for the outcome variable.

**Results :** 96 volunteers with median age of 26 years (25th-75th percentile: 22-41 years) of which 56 (58.3%) were women enter into the test. Half of the sample presented metabolic fatigue after 20 minutes of finishing the simulation. The predictive model included female sex, height, both muscle and bone mass and moderate level of physical activity. The validity of the main model using all the variables presented an area under the curve (AUC) of 0.86 (95%CI: 0.786-0.935), and the validity of the model presented an AUC of 0.725 (95%CI: 0.559-0.89).

**Conclusions :** Decision-making in biohazard incidents is a challenge for emergency team leaders. An a priori knowledge of physiological tolerance of wearing a PPE of the health care workers could improve their performance. The model presented here could help in the assessment of the worker response under biohazard conditions.

## Background

Previous epidemic incidents, such as the severe acute respiratory syndrome (SARS), the middle east respiratory syndrome coronavirus (MERS-CoV) or the Ebola virus epidemic, among others, represented a global wake-up call [1, 2]. Although biohazard incidents are part of the governments' agenda, they are still perceived by the general population as novel types of threats.

The coronavirus epidemic (COVID-19) emerged in China last November has seriously challenged the capacity of the country's health systems to deal with it, stressing the surmount importance that prevention and protection systems to control threats from biological risks[3] has. In these special circumstances, the personal protective equipment (PPE) is a fundamental pillar of the health system to allow health workers perform properly and safely their functions [4]. In every biohazard threat the primary objective is to prevent the spread and the confinement of the pathogen. In these situations, health

professionals should be adequately protected themselves against the risk of contamination. For instance, the Chinese Center for Disease Control and Prevention reported that 3.8% of healthcare personnel (1,716 cases) were infected by COVID-19, 14.8% (247 cases) of which were serious and 5 ended in deaths, as of February 11th, 2020 [5].

The use of PPE by health professionals guarantees performance with tolerable safety margins, but at the same time it generates both physiological and psychological stress due to reducing breathability, increasing temperature, decreasing visibility, etc. [6, 7], that certainly may affect the performance and security of the worker. Although some studies analyze the potential contamination of professionals during the removal of the PPE [8, 9], or how body temperature increases with the use of these equipments [10, 11], no study until now has focused on how wearing PPE affect the physiological status or what is the recommended time for wearing the PPE.

The main objective of this study was to develop a risk model, based on baseline demographic and physiological parameters, to predict whether a particular health care worker will tolerate wearing a PPE -III category, 4B/5B/6B type- against biological risks during 30 minutes of intervention.

## **Materials And Methods**

### **4.1. Study design and setting**

We conducted a preliminary, prospective, simulation study, without intervention, from April 3rd to 28th, 2017. The study was conducted at the Advanced Simulation Center on Medicine Faculty of Valladolid University (Spain). Ninety-six volunteers randomly chosen were stratified by sex, level of training, and professional category from an opportunity sample of 164 volunteers.

The Research Ethics Committee of Rio Hortega University Hospital approved the study protocol (PI-41/16). All participants signed informed consent. This study is reported in line with the STROBE statement. The present study was in accordance with Good Clinical Practice and the Declaration of Helsinki.

### **4.2. Participants**

Participants in the study were volunteers over 18 and under 65 years either undergraduate medical and nursing students' in the last years of degree and physicians and nurses (emergency department and emergency medical services). All participants have shown interest to participate in this study.

The exclusion criteria were age outside the range of the inclusion criteria, volunteers who have conducted similar studies or participants who do not sign the informed consent.

All volunteers admitted for eligibility underwent a health examination and those in any of the following cases were excluded from the study: arrhythmias; heart rate (HR) above 150 or below 40 bpm; systolic blood pressure (SBP) above 160 or below 80 mmHg; body mass index (BMI) greater than 40 Kg/m<sup>2</sup>;

functional disability or visual or hearing impairments that prevent from the maneuvers performed in the simulated case: oxygen saturation (OS) per 92% drop: capillary glycemia (CG) less than 65 mg / dl; fever: major surgery in the previous 30 days: acute skin diseases: systemic immune diseases or taking anticonvulsants or anticoagulants.

### **4.3. Study protocol**

Once the health assessment has been passed and the informed consent was signed, the volunteers were able to carry out the study.

An anthropometric study was performed firstly by measuring height, weight, body fat, muscle mass, bone mass, total water, and BMI. After that, the following vital signs were taken HR: SBP: diastolic blood pressure (DBP): respiratory rate (RR): temperature (T): capillary hemoglobin (HB): perfusion index (PI) OS: (CG): capillary lactate (CL).

Subsequently, the volunteer performed the Beck anxiety inventory (BAI), a self-report scale composed of 21 items (each item in the range 1–3), with high internal consistency (Cronbach's  $\alpha = 0.92$ ) [12, 13]. The sum of the items stratifies the volunteers into three levels, low anxiety (0–21 points), moderate anxiety (22–35 points), and potentially concerning levels of anxiety (score of 36 and above).

To complete the initial assessment, each volunteer completed the International Physical Activity Questionnaire (IPAQ), a self-report scale composed of 7 items, which evaluates the physical activity level (Cronbach's  $\alpha = 0.73$ ). The IPAQ determines three levels of activity, low, moderate or high [14, 15].

Then, each volunteer guided by an expert in biological risks, and following the protocol of the European Center for Disease Prevention and Control, was equipped with a PPE III category, 4B/5B/6B type [16]. The standard COVERSTAR® PLUS (ASATEX AG, Bergheim, Germany) equipment was composed of biological protection overall, hood, overboots, apron, fine dust mask FFP3, disposable gloves, nitrile non-powdered and panoramic glasses.

Once equipped, volunteers entered a 24 m<sup>2</sup> simulation laboratory with controlled temperature, humidity, noise and lighting. All groups performed the same simulated clinical case, using the patient simulator SimMan ALS (Laerdal, Stavanger, Norway). The simulated procedure was as follows: the medical emergency team (4 volunteers) must assist a patient with suspected biological disease while several events occur during the simulation. At minute 8 after the start of the simulation the patient begins to convulse and at minute 20 the patient suffers a non-defibrillable cardiac arrest. The simulation last 30 min and right after the end the volunteers take off the equipment. Finally, 20 minutes after the finalization of the simulation CL and HR were evaluated.

### **4.4. Outcomes and data collection**

The main outcome was CL values greater than 4 mmol/L or HR difference -between 20 minutes after the simulation's end and baseline values- above the 3rd quartile (equivalent to more than 31 bpm). This was

the main outcome after 30minutes of simulated work with a PPE -III category, 4B/5B/6B type- against biological risks. This outcome will be named “fatigue” from now on.

All members of the research staff were aware of the objectives of the study, the standardized way of obtaining the set of vital signs, the anthropometric examination, and the use of the electromedical equipment. A procedure for determining CL and CG was developed with specific training on the operation, cleaning, maintenance, and calibration of the equipment. The traceability of all test strips used in the study has been monitored, with control of expiration dates, serial numbers, and batch numbers.

Each volunteer was examined by a member of the research staff (physician or registered nurse) who collected: demographic variables -age, sex, and the corresponding group (student or professional); years of work experience and previous experience in biohazard incidents; set of vital signs: clinical observations: IPAQ: and BAI. After that they performed the analytical determinations.

The anthropometric study was performed with the MC-780U scale (Tanita Corporation, Arlington Heights, IL, USA). For the determination of the HR, SBP, and DBP, the BP-200 plus monitor (SCHILLER AG, Baar, Switzerland) was used. RR was calculated by counting for a minute the complete respiratory cycles. The temperature was obtained with the ThermoScan® PRO 6000 thermometer (WelchAllyn, Inc, Skaneateles Falls, USA). The Pronto 7 device (MASIMO, Irvine, Ca, USA) was used for the determination of HB, PI and OS. The FreeStyleOptium Neo device (Abbott Laboratories, Illinois, USA) was used to measure the GC and to obtain CL values we used an Accutrend Plus measuring device (Roche Diagnostics, Mannheim, Germany).

## 4.5. Missing data

All data were recorded electronically in a database created specifically for this purpose with the XLSTAT® BioMED software for Microsoft Excel® version 14.4.0. (Microsoft Inc., Redmond, USA).

By means of logical tests -of rank and consistency- a purification of the database was performed resulting in a total of 28 variables. Next, a complete analysis was carried out, variable by variable of unknown data, leaving for the analysis only complete data sets. The study variables did not present lost data. The case registration form was tested to eliminate ambiguous elements guaranteeing the robustness of the data collection instrument.

## 4.6. Data analysis

Categorical variables were represented by absolute value and percentage, and continuous variables were represented by median and interquartile range (IQR) because they did not follow a normal distribution. Additionally, a univariate model was performed to obtain the odd ratios for each variable considering fatigue the as outcome variable.

Firstly, A logistic regression with all the variables as precursors and the fatigue as the outcome was performed. A stepwise procedure with backward and forward searches based on the Akaike information

criteria was employed in the construction of the model. Significant variables were selected to build the main model.

Secondly, continuous variables were categorized based on the relationship they have with the outcome. To do that, we determined the range (base range) of values of each continuous variable that correspond to a higher incidence of lower fatigue. Then, the categorical variable was constructed with as many categories as ranges of the length of the base range existed.

Once the final variables to be introduced in the scoring system were selected and the continuous ones categorized, the sample was randomly split in training (2/3) and test (1/3) cohorts keeping in each case the same proportion of the outcome variable with rest as it is in the whole cohort sample.

The value of each variable in the model was derived from the regression coefficients of the regression model's significant variables in the following way: the rounded-integer coefficients of the logistic regression corresponding to the significant levels of the categorical variables (value of  $p < 0.05$ ) were selected to build the scoring system. The final value of the scale was obtained from the sum of each patient's score for each variable [17].

The discrimination validity of the score and the main value were assessed by the area under the curve (AUC) of the receiver operating characteristic (ROC) along with the 95% confidence interval (95%CI). For both cases the p value of the comparison against the null hypothesis (AUC = 0.5) was below 0.05.

All statistical analyses were performed using our own codes and base functions in R, version 3.5.1 (<http://www.R-project.org>).

## Results

One hundred and sixty-four volunteers were examined for eligibility. After applying the exclusion criteria and matching groups by random sampling stratified by sex, level of training and, professional category, 96 volunteers were finally selected to perform the study (Fig. 1). The median age was 26 years (25th-75th percentile: 22–41 years) and 56 (58.3%) were women. Global demographic characteristics are described in Fig. 1 as well as statistical differences between groups of medical and nursing students (49 volunteers, 51.0%) and health care workers (47 volunteers, 49.0%).

The environmental conditions of the simulation laboratory were: median temperature 30.9 °C (25th-75th percentile: 30.3–31.5 °C), lighting 641 lum (25th-75th percentile: 601–671 lum), humidity 51% (25th-75th percentile: 50–52%), and noise 71 dB (25th-75th percentile: 56–79 dB), in all cases  $p > 0.05$  between volunteers with fatigue and without fatigue.

Odd ratios are shown in Table 1, with: female (OR: 0.34, 95% CI: 0.15, 0.80), height (OR: 1.05, 95% CI: 1.00, 1.10), muscle mass (OR: 1.04, 95% CI: 1.00, 1.08), bone mass (OR: 2.18, 95% CI: 1.00, 4.74), and a moderate IPAQ (OR: 9.62, 95% CI: 2.41, 38.35) as the variables that showed a significant p value ( $p < 0.05$ ) for fatigue.

Table 1  
Characteristics of the study population

Variable	Total (N = 96)	No fatigue (n = 48)	Fatigue (n = 48)	Odds ratio (95%CI)	<i>p</i> - value
Age (years)	26 (22–41)	28 (23–40)	24 (22–41)	0.99 (0.95–1.03)	0.773
Sex					
Male	40 (41.7)	14 (29.2)	26 (54.2)		
Female	56 (58.3)	34 (70.8)	22 (45.8)	0.34 (0.15–0.80)	<b>0.014</b>
Experience Group					
Students	49 (51.0)	23 (47.9)	26 (54.2)		
Workers	47 (49.0)	25 (52.1)	22 (45.8)	0.78 (0.34–1.73)	0.540
Training in biological risk					
None	43 (44.8)	23 (47.9)	20 (41.7)		
Basic	20 (20.8)	8 (16.7)	12 (25.0)	0.92 (0.37–2.29)	0.864
Advanced	33 (34.3)	17 (35.4)	16 (33.3)	1.59 (0.51–4.91)	0.417
Anthropometric study					
Height (cm)	168 (162–173)	165 (161–172)	170 (164–178)	1.05 (1.00–1.10)	<b>0.037</b>
Weight (kg)	68 (58–79)	65 (57–74)	69 (61–81)	1.02 (0.99–1.05)	0.059
Fat (%)	21.7 (16.3–27.7)	22.2 (17.9–27.7)	20.7 (15.2–27.8)	0.98 (0.94–1.03)	0.656
Muscle mass (%)	47.0 (42.1–60.8)	44.9 (41.2–59.8)	52.6 (42.9–62.0)	1.04 (1.00–1.08)	<b>0.039</b>

\* Values expressed as total number (fraction) and medians [25 percentile-75 percentile] as appropriate.

CI: confidence interval; BMI: body mass index; IPAQ: International Physical Activity Questionnaire; BAI: Beck anxiety inventory; SBP: systolic blood pressure; DBP: diastolic blood pressure; RR: Respiratory rate; HB: capillary hemoglobin; CG: capillary glycemia; CL: capillary lactate

Variable	Total (N = 96)	No fatigue (n = 48)	Fatigue (n = 48)	Odds ratio (95%CI)	p- value
Bone mass (%)	2.5 (2.3–3.2)	2.4 (2.2–3.1)	2.7 (2.3–3.2)	2.18 (1.00–4.74)	<b>0.048</b>
Total water (%)	57.3 (53.3–61.1)	57.0 (53.4–60.7)	57.3 (53.2–61.6)	0.99 (0.93–1.06)	0.967
BMI (kg/m <sup>2</sup> )	23.9 (21.4–26.7)	23.2 (20.9–26.1)	23.9 (21.9–27.0)	1.05 (0.95–1.17)	0.260
IPAQ					
Low	49 (51.0)	16 (33.3)	33 (68.8)		
Moderate	30 (31.3)	18 (37.5)	12 (25.0)	9.62 (2.41–38.35)	<b>0.001</b>
High	17 (17.7)	14 (29.2)	3 (6.3)	3.11 (0.73–13.19)	0.124
BAI (points)	4 (2–7)	3 (2–7)	4 (2–8)	1.01 (0.91–1.11)	0.823
Basal vital sings					
Heart rate (bpm)	68 (62–75)	66 (60–71)	70 (64–76)	1.01 (0.97–1.06)	0.460
SBP (mmHg)	130 (120–138)	129 (121–136)	132 (119–139)	1.01 (0.98–1.04)	0.334
DBP (mmHg)	80 (73–87)	79 (73–86)	84 (74–90)	1.04 (0.99–1.08)	0.060
RR (bpm)	17 (15–18)	17 (15–18)	17 (15–18)	1.03 (0.80–1.33)	0.797
Temperature (°C)	36.7 (36.1–37.1)	36.7 (36.2–37.0)	36.7 (36.4–37.1)	1.20 (0.55–2.62)	0.635
HB (mg/dl)	13.7 (12.6–14.8)	13.5 (12.6–14.6)	14.2 (12.6–15.0)	1.15 (0.87–1.51)	0.319
Perfusion index (%)	2.0 (1.1–4.8)	1.9 (1.1–4.9)	2.2 (1.1–4.7)	1.01 (0.88–1.16)	0.849
Saturation (%)	98 (97–99)	98 (97–100)	98 (97–99)	1.09 (0.82–1.44)	0.524
* Values expressed as total number (fraction) and medians [25 percentile-75 percentile] as appropriate.					
CI: confidence interval; BMI: body mass index; IPAQ: International Physical Activity Questionnaire; BAI: Beck anxiety inventory; SBP: systolic blood pressure; DBP: diastolic blood pressure; RR: Respiratory rate; HB: capillary hemoglobin; CG: capillary glycemia; CL: capillary lactate					

Variable	Total (N = 96)	No fatigue (n = 48)	Fatigue (n = 48)	Odds ratio (95%CI)	p- value
CG (mg/dl)	106 (97–116)	107 (96–114)	106 (97–120)	1.01 (0.98–1.03)	0.361
CL (mmol/L)	2.1 (1.4–2.9)	2.0 (1.5–2.5)	2.2 (1.3–3.3)	1.18 (0.89–1.57)	0.236
Final vital sings					
Heart rate (bpm)	91 (83–101)	88 (81–94)	97 (85–108)	1.06 (1.02–1.11)	<b>0.001</b>
CL (mmol/L)	3.2 (2.3–4.5)	2.6 (1.7–3.1)	4.5 (3.4–5.3)	4.19 (2.30–7.64)	<b>&lt; 0.001</b>
* Values expressed as total number (fraction) and medians [25 percentile-75 percentile] as appropriate.					
CI: confidence interval; BMI: body mass index; IPAQ: International Physical Activity Questionnaire; BAI: Beck anxiety inventory; SBP: systolic blood pressure; DBP: diastolic blood pressure; RR: Respiratory rate; HB: capillary hemoglobin; CG: capillary glycemia; CL: capillary lactate					

The validity of the main model using all the variables presented an AUC of 0.86 (95%CI: 0.786–0.935) (Fig. 2).

Based on the stepwise selection procedure from the main model, the scoring model included the following: Experience group, sex, muscle mass, bone mass, SBP, DBP, Saturation, and IPAQ. The final variables from the logistic regression associated with their odd ratios are shown in Table 2, the value of both selected variables (sex and IPAQ) were obtained from the round value of the estimate which was divided by two maintaining their sign (negative and positive, respectively), since the sign indicates whether they are protective or negative, respectively. Figure 3 shows the relationship of the score value and the percentage of patients with fatigue for the training cohort, patients with negative values for the score presents a lower probability of fatigue than those with positive values. The validity of the model presented an AUC of 0.725 (95%CI: 0.559–0.89) (Fig. 4). Finally, further details about the model can be found in Table 3 and 4.

Table 2  
Variables of the scoring model

Variable	Estimate	Scale value	Std. Error	Z value	Odds ratio (95%CI)	p-value
Sex						
Female	-2.02	-2	0.92	-2.18	0.13 (0.01–0.71)	0.029
IPAQ						
High	3.2	3	1.12	2.85	24.5 (3.43–309.5)	0.004
Std: standard; CI: confidence interval; IPAQ: International Physical Activity Questionnaire						

Table 3. Measures of the scoring model for each value threshold

Threshold	Se	Sp	PPV	NPV	DA
-1	100	0	50	NA	50
0	91.6	45.8	62.8	84.6	68.7
1	31.2	91.6	78.9	57.1	61.4

Se: Sensitivity; Sp: Specificity; PPV: positive predictive value; NPV: negative predictive value; DA: diagnostic accuracy; CI: Confidence Interval.

Table 4  
Measures of the scoring model for each value threshold

Se (95%CI)	Sp (95%CI)	PPV (95%CI)	NPV (95%CI)	DA (95%CI)
74.3 (0-100)	45.3 (0-100)	63.9 (27.9–99.9)	70.8 (0-100)	68.06 (36.5–83.5)
Se: Sensitivity; Sp: Specificity; PPV: positive predictive value; NPV: negative predictive value; DA: diagnostic accuracy; CI: Confidence Interval.				

## Discussion

In this observational simulation study, we have obtained a model with the capability to predict which health care worker will develop metabolic fatigue wearing a PPE against biological risks, after 30 minutes of intervention. The model consists of 5 easy-to-obtain non-invasive parameters such as sex, height, muscle mass, bone mass, and IPAQ stratification.

Previous studies have analyzed the use of PPE and how these protective devices affect fine motor skills [18, 19], or how the use of PPE influences the performance of a quality resuscitation [20]. Other types of

studies addressed the issues of thermal perception and the perceived effort when working under these conditions [21, 22], or the increase in the HR above the recommended maximum levels [23]. However, we were unable to find equivalent studies to the one presented here..

In this work, CL and HR have been proposed as fatigue parameters. The lactate is a highly sensitive biomarker that provides accurate information about anaerobic metabolism [24, 25], easy to obtain, highly validated at the level of sports physiology [26], and others clinical contexts [27]. A subject with a CL level above 4 mmol/L -lacticaemia- after 20 minutes of rest implies that she/he continues with a high metabolic demand [28]. The other parameter considered critical to determine fatigue was a HR difference (between baseline values and 20 minutes after the end of the simulation) above the 3rd quartile (more than 31 bpm). During the progress of the simulation it is expected that the HR rises but returning to normal values when back in the rest situation. In subjects presenting fatigue however, a long-lasting HR recovery time has being observed [29, 30].

In our study, being female was as a protective factor against metabolic fatigue. In fact, males presented 8.4% more cases of fatigue than females. This difference can be explained by the higher percentage of muscle mass in males [31]. The lower muscle mass in females limits their thermogenic response capacity although this lower adaptation to thermal change does not generate a limitation, but rather makes females more thermally competent when using this type of PPE [32]. Likewise, those subjects with higher heights tolerate the proposed simulation scenario worse. Subjects with the highest height and greater muscle and bone masses not always are better adapted for certain type of physical works [33, 34]. The last variable included in the model is the IPAQ. Subjects with a moderate or high level of activity have a better physiological capacity to work with this type of PPE [35]. Physical activity improves aerobic capacity and improves resistance to metabolic stress [36, 37].

The results point out towards the existence of a pattern of subjects presenting better tolerance to fatigue while wearing the PPE: females of short stature with low muscle and bone mass and physically active. Variables that in principle could be of importance, such as experience (students or workers), training in biological risk, or the level of anxiety [38] did not influence the model.

The model can be useful to differentiate, based solely on baseline demographic and physiological parameters, which health care worker is best suited to work with PPE or, conversely, which subjects will require higher levels of training and care to work satisfactorily while wearing a PPE.

Health care workers must handle biohazard patients but must do so in the most appropriate safer conditions in each context. The use of PPE protects the professional, but also it generates an increase in temperature, tachycardia, higher levels of lactate, increased anxiety, difficulties in either vision or hearing (due to hood and panoramic glasses), etc. All these physiological responses must be taken into account at the time to adapt both the duration of its use and the workload with the objective to facilitate planning and execution of healthcare maneuvers in these complicated situations.

The strength of our study is in the diversity encompassed in the sample, which includes students and professionals, male and females, and nurses and physicians, representing a robust and illustrative sample of the healthcare system.

Our study has several limitations. The first one is the potential bias in the volunteer's selection which was based solely on the opportunity criteria. All the subjects were recruited in the Public Health System or in the Faculty of Health Sciences of the University of Valladolid, in line with similar studies [39, 40]. Second, although the sample size allows for preliminary results and for an internal validation, it is small enough for carrying out an external validation of the model, which would require a multicenter study to determine the physiological impact on workers wearing PPE under biological risks. Lastly, lactate has been selected as a biomarker because it is easy to obtain, has been previously validated, and with a low price of the test. However, other biomarkers such as cortisol, C-reactive protein, etc., cannot be ruled out and will be considered in future studies. With the above caveats in mind, this model should be interpreted with caution, since it is a preliminary study. In any case, professionals must continue following the operating procedures in force for each health service.

In conclusion, given that a high percentage of subjects suffer from fatigue using PPE in a simulated incident against biological risks, any model aimed to improve the correct selection of health personnel to work under critical and complex situation while wearing a PPE must be considered. Our proposed model is able to differentiate between subjects with good or bad tolerance to perform a simulation during 30 minutes with a PPE, III category, 4B / 5B / 6B type, shedding light on which baseline variables could potentially anticipate work fatigue.

## **Declarations**

-Ethical Approval and Consent to participate

The Research Ethics Committee of Rio Hortega University Hospital approved the study protocol (PI-41/16). All participants signed informed consent. This study is reported in line with the STROBE statement. The present study was in accordance with Good Clinical Practice and the Declaration of Helsinki.

-Consent for publication

This article is an original work, has not been published before, and is not being considered for publication elsewhere in its final form, in either printed or electronic media. It is not based on any previous communication to a society or meeting.

-Availability of supporting data

The data will be sent on demand and anonymized. The data refers to clinical parameters of the health evaluation of workers and, due to data protection criteria, are not provided online.

#### -Competing interests

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results. Sponsor's role: none.

#### -Funding

Not applicable

#### -Authors' contributions

CRediT authorship contribution statement:

Francisco Martín-Rodríguez conceptualised the project, managed and coordinated the project, assisted with design of methodology, analyzed data, prepared the initial and final drafts of the manuscript. Guillermo Ortega Rabbione and Ancor Sanz-García take responsibility for the data and their analysis. Guillermo Ortega Rabbione, Juan F. Delgado Benito, Raúl López Izquierdo, José Luis Martín Conty and Miguel A. Castro Villamor assisted with management and coordination for the project, assisted with the design of the methodology and contributed to reviewing the manuscript. Ancor Sanz García and Raúl López Izquierdo conceptualised the project, contributed to reviewing and commenting on the initial and final drafts of the manuscript. All authors performed a critical review and approval of the final manuscript for interpretation of the data and important intellectual input.

#### -Acknowledgements

Not applicable

#### -Authors' information

Francisco Martín-Rodríguez (principal investigator) on behalf of the other authors guarantee the accuracy, transparency and honesty of the data and information contained in the study, that no relevant information has been omitted and that all discrepancies between authors have been adequately resolved and described.

## References

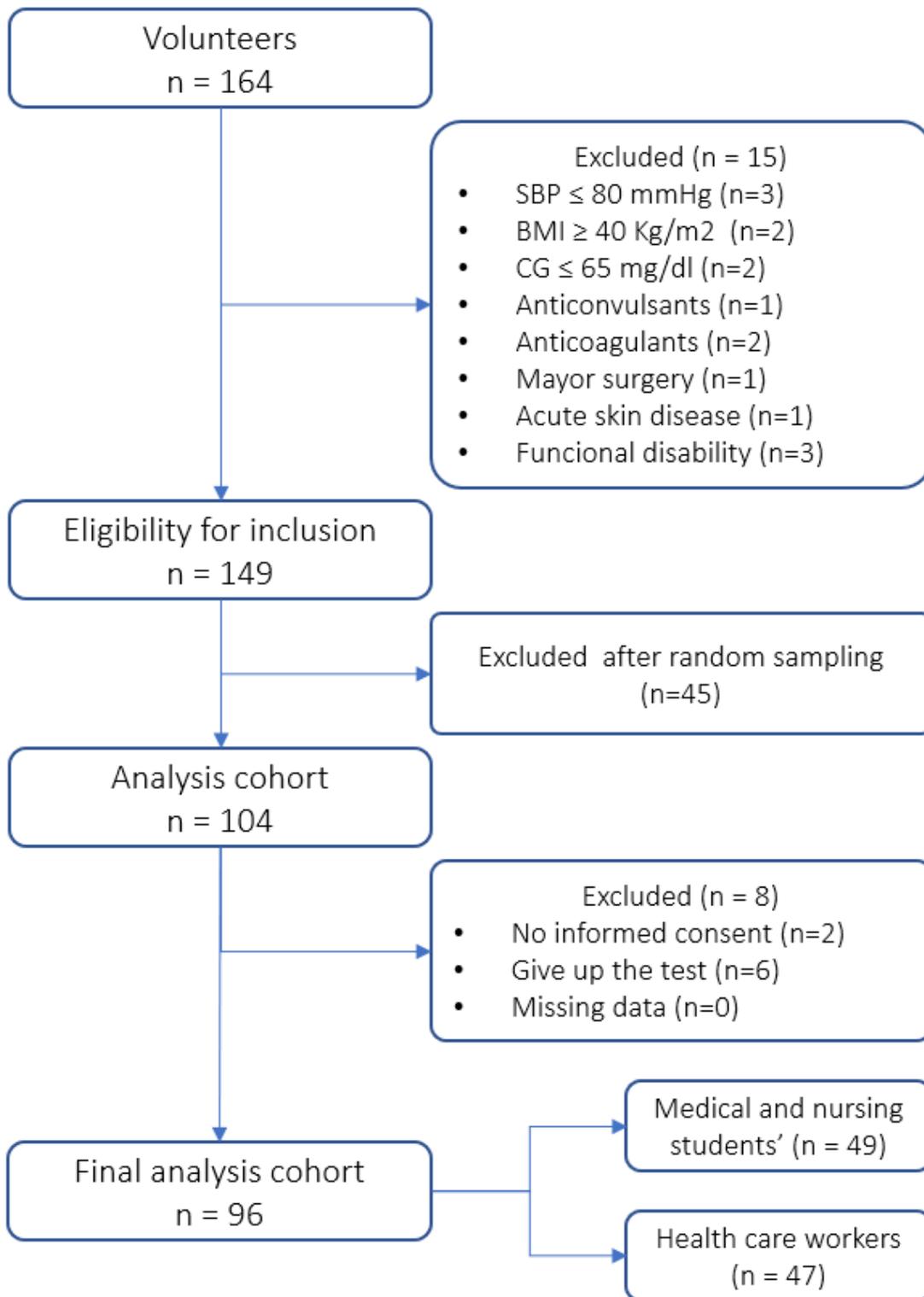
1. Coltart CEM, Lindsey B, Ghinai I, Johnson AM, Heymann DL. The Ebola outbreak, 2013–2016: old lessons for new epidemics. *Philos Trans R Soc Lond B Biol Sci.* 2017; 372(1721): p. DOI:.
2. Rajakaruna SJ, Liu WB, Ding YB, Cao GW. Strategy and technology to prevent hospital-acquired infections: Lessons from SARS, Ebola, and MERS in Asia and West Africa. *Mil Med Res.* 2017;4(1):32–2.

3. Peeri NC, Shrestha N, Rahman MS, Zaki R, Tan Z, Bibi S, et al. The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: what lessons have we learned? *Int J Epidemiol.* 2020. ). [Online ahead of print (DOI:.
4. Glancey M, Osei P, Patterson WA, Petney M, Scavo L, Ruparella C, et al. Design Improvements for Personal Protective Equipment Used in Ebola and Other Epidemic Outbreaks. *Glob Health Sci Pract.* 2017;5(2):325–8.
5. Wu Z, McGoogan JM. Characteristics of and Important Lessons From the Coronavirus Disease 2019 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases From the Chinese Center for Disease Control and Prevention. *JAMA.* 2020. ). [Online ahead of print (DOI:.
6. Maynard SL, Kao R, Craig DG. Impact of personal protective equipment on clinical output and perceived exertion. *J R Army Med Corps.* 2016;162(3):180–3.
7. Martín-Rodríguez F, Fernández Pérez C, Castro Villamor M, Martín Conty JL, Arnillas Gómez P, Casado Vicente V. Does level D personal protective equipment guard against hazardous biologic agents during cardiopulmonary resuscitation? *Emergencias.* 2018;30(2):119–22.
8. Kang J, O'Donnell JM, Colaianne B, Bircher N, Ren D, Smith KJ. Use of personal protective equipment among health care personnel: Results of clinical observations and simulations. *Am J Infect Control.* 2017;45(1):17–23.
9. Tomas ME, Kundrapu S, Thota P, Sunkesula VCK, Cadnum JL, Mana TSC, et al. Contamination of Health Care Personnel During Removal of Personal Protective Equipment. *JAMA Intern Med.* 2015;175(12):1904–10.
10. Borg DN, Costello JT, Bach AJ, Stewart IB. Perceived exertion is as effective as the perceptual strain index in predicting physiological strain when wearing personal protective clothing. *Physiol Behav.* 2017;169:216–23.
11. Buller MJ, Tharion WJ, Duhamel CM, Yokota M. Real-time core body temperature estimation from heart rate for first responders wearing different levels of personal protective equipment. *Ergonomics.* 2015;58(11):1830–41.
12. Vázquez Morejón A, Vázquez-Morejón Jiménez R, Bellido Zanin G. Beck Anxiety Inventory: Psychometric Characteristics in a Sample from the Clinical Spanish Population. *Span J Psychol.* 2014; 17(E76): p. DOI:.
13. de Oliveira IR, Seixas C, Osório FL, Crippa JAS, de Abreu JN, Menezes IG, et al. Evaluation of the Psychometric Properties of the Cognitive Distortions Questionnaire (CD-Quest) in a Sample of Undergraduate Students. *Innov Clin Neurosci.* 2015;12(7–8):20–7.
14. Macek P, Terek-Derszniak M, Zak M, Biskup M, Ciepiela P, Krol H, et al. WHO recommendations on physical activity versus compliance rate within a specific urban population as assessed through IPAQ survey: a cross-sectional cohort study. *BMJ Open.* 2019;9(6):e0283.
15. Reed JL, Prince SA, Pipe AL, Attallah S, Adamo KB, Tulloch HE, et al. Influence of the workplace on physical activity and cardiometabolic health: Results of the multi-centre cross-sectional Champlain Nurses' study. *Int J Nurs Stud.* 2018;81:49–60.

16. European Centre for Disease Prevention and Control. Safe use of personal protective equipment in the treatment of infectious diseases of high consequence. Stockholm: ECDC; 2014.
17. Zhang Z, Zhang H, Khanal MK. Development of scoring system for risk stratification in clinical medicine: a step-by-step tutorial. *Ann Transl Med.* 2017;5(21):436.
18. Merchan A, Clemente-Suárez VJ. Psychophysiological modifications in an assault infantry manoeuvre using a chemical, biological, radiological and nuclear personal protective equipment. *J R Army Med Corps.* 2019; Published Online First(doi: 10.1136/jramc-2019-001166).
19. Schumacher J, Arlidge J, Garnham F, Ahmad I. A randomised crossover simulation study comparing the impact of chemical, biological, radiological or nuclear substance personal protection equipment on the performance of advanced life support interventions. *Anaesthesia.* 2017;72(5):592–7.
20. Chen J, Lu KZ, Yi B, Chen Y. Chest Compression With Personal Protective Equipment During Cardiopulmonary Resuscitation: A Randomized Crossover Simulation Study. *Medicine.* 2016;95(14):e3262.
21. Borg DN, Costello JT, Bach AJ, Stewart IB. Perceived exertion is as effective as the perceptual strain index in predicting physiological strain when wearing personal protective clothing. *Physiol Behav.* 2017;169:216–23.
22. Borg DN, Stewart IB, Costello JT. Can perceptual indices estimate physiological strain across a range of environments and metabolic workloads when wearing explosive ordnance disposal and chemical protective clothing? *Physiol Behav.* 2015;147:71–7.
23. Martín Rodríguez F, Fernández Pérez C, Castro Villamor M, Martín Conty JL, Arnillas Gómez P, Casado Vicente V. Does level D personal protective equipment guard against hazardous biologic agents during cardiopulmonary resuscitation? *Emergencias.* 2018;30(2):119–22.
24. Brooks GA. The Science and Translation of Lactate Shuttle Theory. *Cell Metab.* 2018;27(4):757–85.
25. Hall MM. Lactate: Friend or Foe. *PM&R.* 2016;8(3S):S8–15.
26. Faghy MA, Lomax M, Brown PI. Active recovery strategy and lactate clearance in elite swimmers. *J Sports Med Phys Fitness.* 2019;59(9):1487–91.
27. Hermann R, Lay D, Wahl P, Roth WT, Petrowski K. Effects of psychosocial and physical stress on lactate and anxiety levels. *Stress.* 2019;22(6):664–9.
28. Proia P, Di Liegro CM, Schiera G, Fricano A, Di Liegro I. Lactate as a Metabolite and a Regulator in the Central Nervous System. *Int J Mol Sci* 2016; 17(9): p. DOI:.
29. Micklewright D, St Clair Gibson A, Gladwell V, Al Salman A. Development and Validity of the Rating-of-Fatigue Scale. *Sports Med.* 2017;47(11):2375–93.
30. Le Meur Y, Buchheit M, Aubry A, Coutts AJ, Hausswirth C. Assessing Overreaching With Heart-Rate Recovery: What Is the Minimal Exercise Intensity Required? *Int J Sports Physiol Perform.* 2017;12(4):569–73.
31. Castellani JW, Young AJ. Human physiological responses to cold exposure: Acute responses and acclimatization to prolonged exposure. *Auton Neurosci.* 2016;196:63–74.

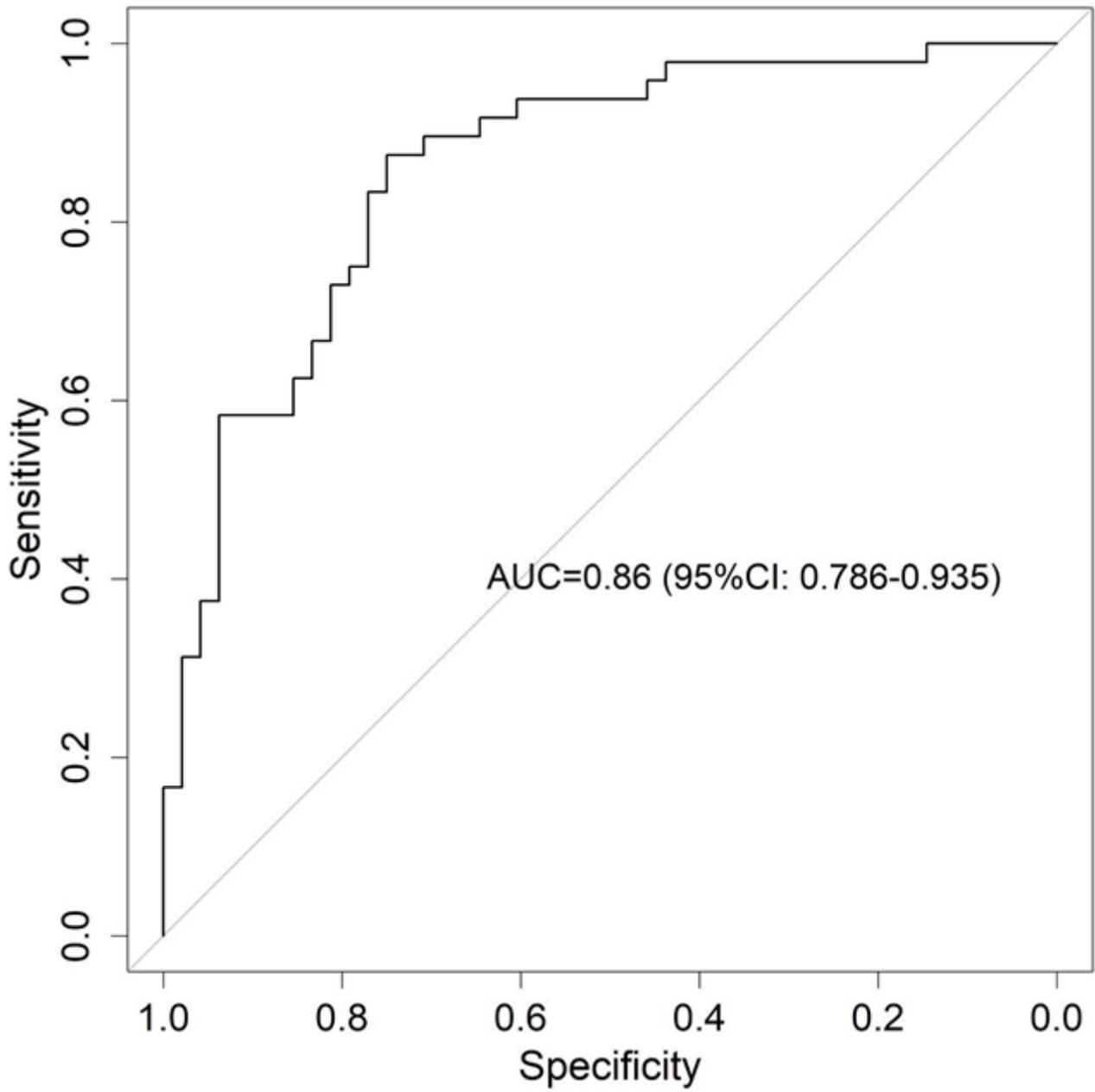
32. Mantooth WP, Mehta RK, Rhee J, Cavuoto LA. Task and sex differences in muscle oxygenation during handgrip fatigue development. *Ergonomics*. 2018;61(12):1646–56.
33. Cornell DJ, Gnacinski SL, Meyer BB, Ebersole KT. Changes in Health and Fitness in Firefighter Recruits: An Observational Cohort Study. *Med Sci Sports Exerc*. 2017;49(11):2223.
34. Giandolini M, Bartold S, Horvais N. Interaction between body composition and impact-related parameters in male and female heel-toe runners. *Gait Posture*. 2019;70:355–60.
35. Dorner TE, Wilfinger J, Hoffman K, Lackinger C. Association between physical activity and the utilization of general practitioners in different age groups. *Wien Klin Wochenschr*. 2019;131(11–12):278–87.
36. Reed JL, Prince SA, Pipe AL, Attallah S, Adamo KB, Tulloch HE, et al. Influence of the workplace on physical activity and cardiometabolic health: Results of the multi-centre cross-sectional Champlain Nurses' study. *Int J Nurs Stud*. 2018;81:49–60.
37. Loyen A, Van Hecke L, Verloigne M, Hendriksen I, Lakerveld J, Steene-Johannessen J, et al. Variation in population levels of physical activity in European adults according to cross-European studies: a systematic literature review within DEDIPAC. *Int J Behav Nutr Phys Act*. 2016;13:72.
38. Li Y, Wang H, Jin XR, Li X, Pender M, Song CP, et al. Experiences and challenges in the health protection of medical teams in the Chinese Ebola treatment center, Liberia: a qualitative study. *Infect Dis Poverty*. 2018;7(1):92.
39. John A, Tomas ME, Hari A, Wilson BM, Donskey CJ. Do medical students receive training in correct use of personal protective equipment? *Med Educ Online*. 2017;22(1):12641.
40. Alhmidi H, Koganti S, Tomas ME, Cadnum JL, Jencson A, Donskey CJ. A pilot study to assess use of fluorescent lotion in patient care simulations to illustrate pathogen dissemination and train personnel in correct use of personal protective equipment. *Antimicrob Resist Infect Control*. 2016;5:40.

## Figures



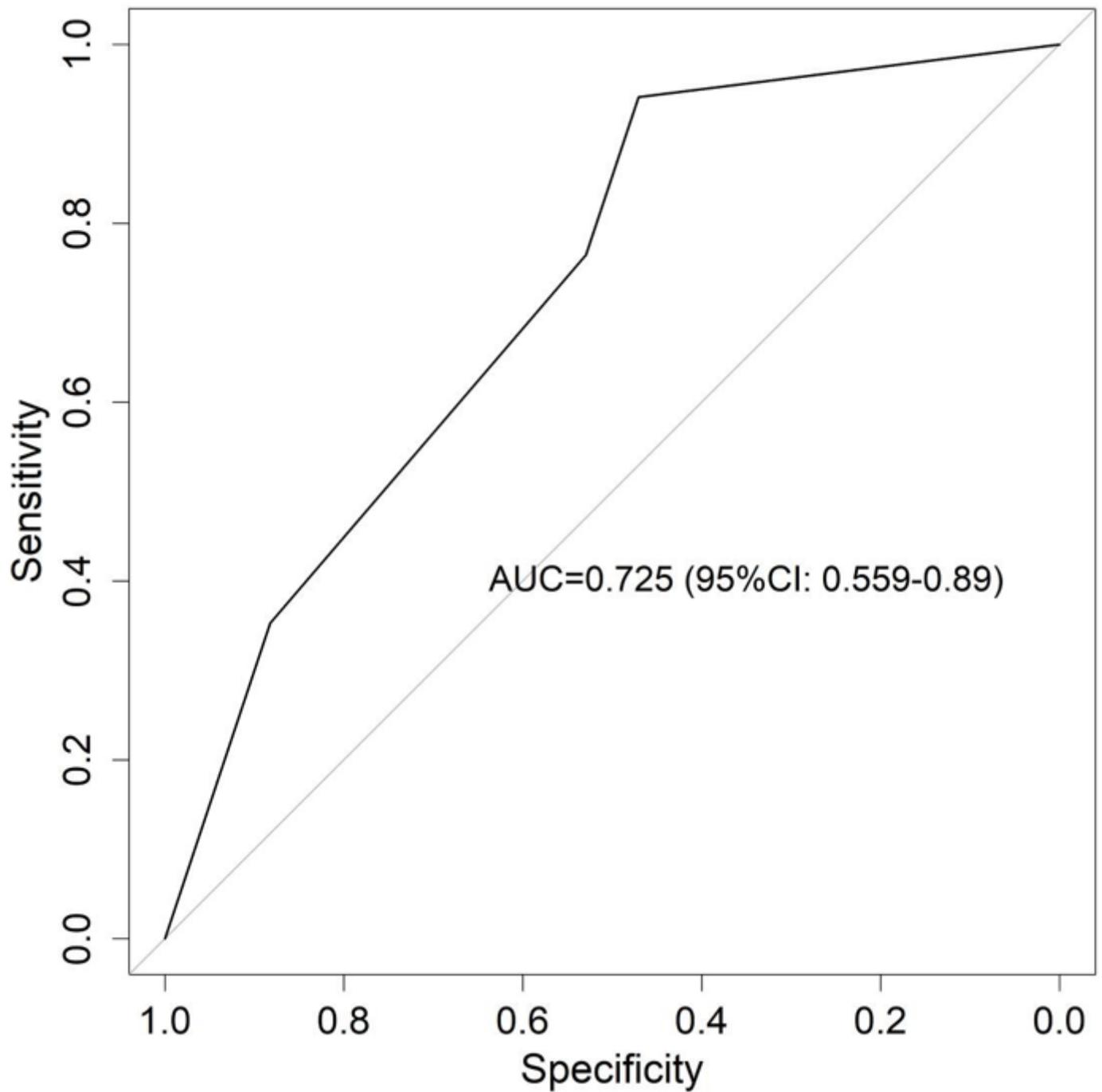
**Figure 1**

Flow chart of study population



**Figure 3**

Receiver operational characteristic (ROC) by fatigue for the main model. The bold line shows the value of the ROC curve. The values in the graph represent the area under the curve (AUC) and its 95% confidence interval.



**Figure 5**

Receiver operational characteristic (ROC) by fatigue for the scoring model. The bold line shows the value of the ROC curve. The values in the graph represent the area under the curve (AUC) and its 95% confidence interval.

## Scores versus probability of fatigue

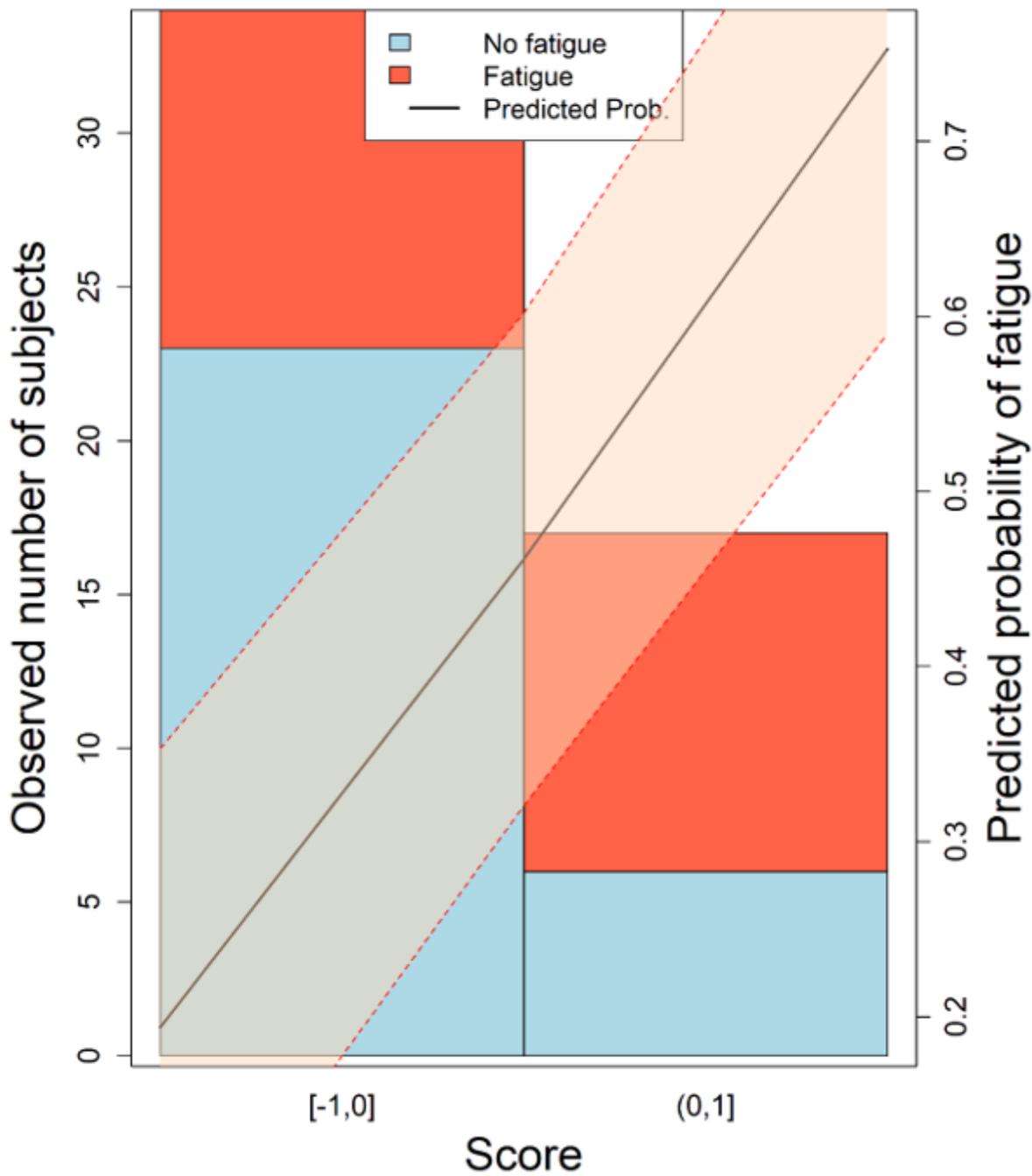


Figure 7

Probability of fatigue based on the value of score. The bar graph shows the number of patients in the training cohort for each scale value (presenting no fatigue in blue and fatigue in red). The trend line shows the estimated probability of fatigue.