USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

ESCOLA DE DOUTORAMENTO INTERNACIONAL DA USC

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Tese de doutoramento

# Quality of cardiopulmonary resuscitation and physiological impact on the rescuers in simulated special circumstances

Santiago de Compostela, 2022

Programa de Doutoramento en Investigación Clínica en Medicina

TESE DE DOUTORAMENTO

# QUALITY OF CARDIOPULMONARY RESUSCITATION AND PHYSIOLOGICAL IMPACT ON THE RESCUERS IN SIMULATED SPECIAL CIRCUMSTANCES

María José Fernández Méndez

**ESCOLA DE DOUTORAMENTO INTERNACIONAL**

**PROGRAMA DE DOUTORAMENTO EN INVESTIGACIÓN CLÍNICA EN MEDICINA**

SANTIAGO DE COMPOSTELA

2022

# DECLARACIÓN DA AUTORA DA TESE

## QUALITY OF CARDIOPULMONARY RESUSCITATION AND PHYSIOLOGICAL IMPACT ON THE RESCUERS IN SIMULATED SPECIAL CIRCUMSTANCES

Dona María José Fernández Méndez

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## QUALITY OF CARDIOPULMONARY RESUSCITATION AND PHYSIOLOGICAL IMPACT ON THE RESCUERS IN SIMULATED SPECIAL CIRCUMSTANCES

D. Antonio Rodríguez Núñez

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*En Santiago de Compostela, a 8 de xullo de 2022.*

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*A Áxel e Alan*

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Carballo-Fazanes A, Barcala-Furelos R, Eiroa-Bermúdez J, **Fernández-Méndez M**, Abelairas-Gómez C, Martínez-Isasi S, et al. **Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high. A pilot study. Am J Emerg Med**. 2020 Dec;38(12):2580-2585.doi: 10.1016/j.ajem.2019.12.048. Epub 2019 Dec 24. PMID: 31911060.

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# ABSTRACT

# ABSTRACT


**Background and purpose**

The circumstances in which cardiorespiratory arrest (CPR) may occur and cardiopulmonary resuscitation (CPR) be necessary are highly variable and in certain conditions, basic life support and advanced life support interventions may require modifications in relation to the general recommendations when CPR occurs in a special environment. As it is recognized that the scientific evidence to make recommendations on CPR in these special circumstances is very scarce, we have proposed this doctoral thesis project in the modality of thesis by compendium with the aim to obtain evidences related to different special circumstances (high altitude, high environmental temperature and in patients with infectious diseases) in which a person may have to perform CPR.

**Material and methods**

This doctoral thesis is composed of 3 articles that have followed a quasi-experimental methodology. These are quantitative, randomized and cross-sectional studies.

The participants who voluntarily collaborated in our investigations were health professionals and/or aquatic lifeguards. All of them consented and authorized their participation in the investigations. All the work has respected the ethical principles of the Declaration of Helsinki and has been authorized by the Ethics Committee of the Faculty of Education and Sports Sciences of the University of Vigo.

The study of variables was grouped into three blocks:

1) Physiological parameters

2) CPR quality metrics

3) Subjective perceptions

Data analysis was performed with SPSS statistical software (IBM Corp., Chicago, IL, USA).

**Results**

In the three research studies carried out, good CPR quality results were obtained in the simulated special extreme environments. Performing long duration CPR at a high altitude causes alterations in fine motor skills. There is an important physiological stress when performing CPR at a high ambient temperature (37ºC) that implies a significant increase in heart rate (HR) and body temperature. The use of personal protective equipment in performing prolonged CPR leads to higher HR, temperature, thermal sensation, thermal comfort and sweating compared to CPR performed with normal clothing. The subjective perception of effort and fatigue was higher in the three investigations compared to the control tests.

## Conclusions

Trained rescuers are able to perform good CPR under conditions of simulated hypoxia, in extreme heat (37ºC) and wearing PPE, although this task involves considerable physiological stress, such as higher cardiac output, more fatigue or loss of body fluid.

## Key words

Cardiopulmonary resuscitation, special circumstances, physiological stress, altitude, extreme heat, COVID-19.

# RESUMEN

# RESUMEN


### Antecedentes y propósito

Las circunstancias en las que puede ocurrir una parada cardiorrespiratoria (PCR) y ser necesaria una reanimación cardiopulmonar (RCP) son muy variables y en ciertas condiciones, las intervenciones de soporte vital básico (SVB) y soporte vital avanzado (SVA) pueden requerir modificaciones en relación a las recomendaciones generales cuando la PCR ocurre en un entorno especial. Como se reconoce que las pruebas científicas para hacer recomendaciones en RCP en dichos entornos especiales son muy escasas, nos hemos planteado este proyecto de tesis doctoral, en la modalidad de tesis por compendio, con el objetivo de obtener evidencias relacionadas con diferentes entornos especiales (altitud elevada, temperatura ambiental elevada y pacientes con enfermedades infectocontagiosas) en los que una persona puede tener que realizar una RCP.

### Material y método

Esta tesis doctoral está compuesta por 3 artículos que han seguido una metodología cuasiexperimental. Se trata de estudios cuantitativos, aleatorios y transversales.

Los participantes que colaboraron de manera voluntaria en nuestras investigaciones, fueron profesionales sanitarios y/o socorristas acuáticos. Todos ellos consintieron y autorizaron su participación en las investigaciones. Todo el trabajo ha respetado los principios éticos de la Declaración de Helsinki y ha sido autorizado por el Comité de Ética de la Facultad de Ciencias de la Educación y el Deporte de la Universidad de Vigo.

El estudio de variables se agrupó en tres bloques:

1) Parámetros fisiológicos

2) Métricas de la calidad de la RCP

3) Percepciones subjetivas

El análisis de los datos se realizó con el software estadístico SPSS (IBM Corp., Chicago, IL, EE.UU.).

**Resultados**

En los tres estudios de investigación realizados se obtuvieron buenos resultados de calidad de RCP en los ambientes especiales simulados. Realizar una RCP de larga duración a una altitud elevada provoca alteraciones en la motricidad fina. Existe un importe estrés fisiológico al realizar RCP a una temperatura ambiental elevada (37ºC) que supone un aumento significativo de la frecuencia cardíaca (FC) y de la temperatura corporal. El uso de un equipo de protección individual en la realización de una RCP prolongada conlleva mayor FC, temperatura, sensación térmica, confort térmico y sudoración en

comparación con la RCP realizada con la ropa habitual. La percepción subjetiva del esfuerzo y fatiga fue mayor en las tres investigaciones en comparación con los tests control.

**Conclusiones**

Los reanimadores entrenados son capaces de realizar una buena RCP en condiciones de hipoxia simulada, con calor extremo (37ºC) y portando un EPI, aunque esta tarea implica un considerable estrés fisiológico, como mayor gasto cardíaco, más fatiga o pérdida de líquido corporal.

**Palabras Clave**

Reanimación cardiopulmonar, circunstancias especiales, estrés fisiológico, altitud, calor extremo, COVID-19.

# RESUMO

# RESUMO


## Antecedentes e propósito

As circunstancias nas que se pode producir unha parada cardiorrespiratoria (PCR) e ser necesaria a reanimación cardiopulmonar (RCP) son moi variables e, en determinadas condicións, as intervencións de soporte vital básico (SVB) e de soporte vital avanzado (SVA) poden requirir modificacións en relación ás recomendacións xerais cando a PCR se produza nun ambiente especial. Dado que se recoñece que a evidencia científica para facer recomendacións sobre RCP nestes ambientes especiais é moi escasa, propuxemos este proxecto de tese doutoral, na modalidade de tese por compendio, co obxectivo de obter evidencias relacionadas cosdiferentes ambientes especiais (gran altitude, alta temperatura ambiental e pacientes con enfermidades infecciosas) nas que unha persoa pode ter que realizar RCP.

## Material e método

Esta tese de doutoramento está composta por 3 artigos que seguiron unha metodoloxía case-experimental. Trátase de estudos cuantitativos, aleatorios e transversais.

Os participantes que colaboraron voluntariamente nas nosas investigacións foron profesionais sanitarios e/ou socorristas acuáticos. Todas eles consentiron e autorizaron a súa participación nas investigacións. Todos os traballos respectaron os principios éticos da Declaración de Helsinki e foron autorizados pola Comisión de Ética da Facultade de Ciencias da Educación e do Deporte da Universidade de Vigo.

O estudo das variables agrupouse en tres bloques:

1) Parámetros fisiolóxicos

2) Métricas da calidade da RCP

3) Percepcións subxectivas

A análise dos datos realizouse co software estatístico SPSS (IBM Corp., Chicago, IL, EUA).

## Resultados

Nos tres estudos de investigación realizados obtivéronse resultados de boa calidade de RCP nos contornos especiais simulados. A realización de RCP de longa duración a gran altitude provoca alteracións na motricidade fina. Existe un estrés fisiolóxico importante cando se realiza a RCP a alta temperatura ambiente (37ºC) que implica un aumento significativo da frecuencia cardíaca (FC) e da temperatura corporal. O uso de equipos de protección individual na realización de RCP prolongada leva a unha FC, temperatura, sensación térmica, confort térmico e transpiración máis elevados en comparación coa

RCP realizada con roupa normal. A percepción subxectiva do esforzo e da fatiga foi maior nas tres investigacións en comparación coa proba de control.

**Conclusións**

Os reanimadores adestrados son capaces de realizar unha boa RCP en condicións de hipoxia simulada, con calor extrema (37ºC) e usando un EPI, aínda que esta tarefa implique un estrés fisiolóxico considerable, como un maior gasto cardíaco, máis fatiga ou perda de líquido corporal.

**Palabras chave**

Reanimación cardiopulmonar, circunstancias especiais, estrés fisiolóxico, altitude, calor extrema, COVID-19.

# SUMMARY IN SPANISH

# SUMARIO EN ESPAÑOL

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# SUMMARY IN SPANISH

*Nota. Este sumario es una versión reducida del documento principal en lengua inglesa. Las referencias bibliográficas han sido citadas en el manuscrito en inglés.*

CALIDAD DE LA REANIMACIÓN CARDIOPULMONAR E IMPACTO FISIOLÓGICO EN LOS RESCATADORES EN CIRCUNSTANCIAS ESPECIALES SIMULADAS

## INTRODUCCIÓN

En la parada cardiorrespiratoria (PCR) la atención a la víctima depende de la participación y la respuesta de la comunidad, que podrá actuar como primer interviniente, y del personal sanitario. Para obtener una mayor optimización de las acciones a realizar en el tratamiento inicial de una PCR, se diseñaron una serie de pasos compuestos por eslabones enlazados conocidos como la "Cadena de Supervivencia".

Con el fin de estandarizar las maniobras de reanimación cardiopulmonar (RCP), la Alianza Internacional de Consejos de Resucitación (ILCOR), el Consejo Europeo de Resucitación (ERC) y la Asociación Americana del Corazón (AHA) llevan a cabo procesos de búsqueda de evidencias y publican periódicamente recomendaciones, tanto para personal lego como para personal sanitario, en soporte vital básico (SVB) y avanzado (SVA).

El algoritmo de SVB publicado en las últimas guías publicadas en el año 2021 establece las instrucciones paso a paso que deben proporcionarse sobre cómo reconocer una parada cardíaca, alertar a los servicios de emergencia y proporcionar compresiones torácicas de alta calidad. Estas compresiones son el componente clave en una RCP como medio eficaz para proporcionar y/o mantener la perfusión de los órganos vitales en una parada cardíaca.

Las circunstacias en las que puede ocurrir una PCR y ser necesaria la RCP son muy variables. En ciertas condiciones, las intervenciones de SVB y SVA pueden requerir modificaciones en relación a las recomendaciones generales; por este motivo, el ERC y la AHA han incluido dentro de sus guías del año 2020/2021 apartados o secciones sobre la RCP en circunstancias especiales. Estas especificaciones podemos clasificarlas en tres secciones diferenciadas: causas especiales, entornos especiales y pacientes especiales. Se reconoce que las pruebas científicas para hacer recomendaciones en dichas circunstancias son muy escasas, por lo que los investigadores deberían realizar esfuerzos para aportar evidencias que permitan sustentar las guías de RCP en condiciones no habituales y circunstancias extremas.

Teniendo en cuenta este aspecto, nos hemos planteado llevar a cabo este proyecto de tesis doctoral, en la modalidad de tesis por compendio, en el que se investigaron diferentes entornos especiales en los que una persona puede tener que realizar una reanimación cardiopulmonar que se comentan a continuación:

**RCP a gran altitud**

El hecho de estar a gran altitud produce varios cambios fisiológicos que incluyen un aumento de la carga de trabajo cardíaco y respiratorio, especialmente durante el ejercicio. El rendimiento cardiopulmonar se ve afectado por encima de los 2500-3000 m de altitud, donde la presión arterial parcial de oxígeno (PaO2) es de 50-65 mmHg mientras que a nivel del mar es de 98 mmHg. Además, a partir de los 3000 m de altura, los cambios fisiológicos (aumento de la frecuencia cardíaca y de la presión arterial, arritmias, elevación de la presión intracraneal, …) se vuelven más relevantes porque los mecanismos compensatorios fisiológicos no son capaces de contrarrestar el efecto de la disminución de la saturación de oxígeno. Cabe señalar que, a pesar de todos los cambios fisiológicos que se producen en los reanimadores y víctimas, así como en la disminución de la calidad de la RCP realizada a una elevada altitud, y después de la publicación de una revisión sistemática de la literatura en la que se establecieron recomendaciones sobre la RCP a gran altura, hasta el momento las directrices del Consejo Europeo de Resucitación sobre reanimación a gran altitud no difieren de la RCP estándar.

**RCP en condiciones de altas temperaturas ambientales**

Las altas temperaturas elevadas, junto con una mayor cantidad de horas de luz y las vacaciones, provocan un incremento de afluencia de gente en espacios acuáticos durante la época estival, lo que conlleva un aumento en la tasa de ahogamientos. Realizar una RCP a altas temperaturas puede provocar una disminución en la calidad de las compresiones cardíacas, generar fatiga en el rescatador, que puede aumentar, ya sea por la duración o por las condiciones previas en las que se tenga que realizar dicha reanimación, como, por ejemplo, tras realizar un rescate acuático. Asimismo, este agotamiento generado por la realización de una RCP, que no deja de ser una actividad física intensa, puede verse incrementado por las variaciones termoambientales que provocan cambios a nivel fisiológico sobre las personas, como el aumento de las frecuencias cardíaca y respiratoria, la temperatura corporal, la tensión arterial o la deshidratación, y cambios a nivel psicológico, como la ansiedad.

**RCP en pacientes con enfermedades infectocontagiosas (COVID-19 y otras)**

Aunque muchas personas han estado en el foco de los contagios, los profesionales sanitarios son un colectivo con alto riesgo para contraer la enfermedad debido a las técnicas y procedimientos que deben realizar sobre pacientes con sospecha o confirmación de infección por COVID-19. En este aspecto, las guías publicadas por el Consejo Europeo de Resucitación (ERC) y la Asociación Americana del Corazón (AHA) sobre las recomendaciones de RCP y la enfermedad COVID-19, indican, sin lugar a dudas, que el profesional sanitario debe protegerse con un Equipo de Protección Individual (EPI) cuando vaya a realizar una RCP u otro procedimiento que suponga contacto con los pacientes. Para ello, las recomendaciones sobre qué dispositivos o materiales se deben utilizar,el ERC publicó cuál es el material mínimo a utilizar en caso de contagio por gotas o por aerosoles. Además, al tratarse esta situación de una circunstancia especial, el ERC sugirió realizar algunos cambios en relación al protocolo habitual de RCP.

## HIPÓTESIS

Este proyecto de tesis ha tenido las siguientes hipótesis de trabajo:

Hipótesis 1. La RCP en una simulación de ambiente hipóxico a gran altitud genera unas demandas fisiológicas incrementadas y una fatiga percibida superior a la reanimación a nivel del mar.

Hipótesis 2. La realización de una RCP simulada en condiciones de calor ambiental genera un estrés fisiológico con incremento de la fatiga y pérdida de líquidos corporales en el reanimador, así como una disminución de la calidad de las compresiones torácicas.

Hipótesis 3. La realización de una RCP prolongada con un equipo de protección individual generará una fatiga superior así como un confort térmico y calidad de RCP peores en comparación con la realizada sin el EPI.

## OBJETIVOS

Para tratar de confirmar o refutar las hipótesis previas, se plantearon los siguientes objetivos:

**Objetivo genérico 1**. Comparar el impacto fisiológico que tiene sobre los reanimadores realizar una RCP prolongada a 3250 m sobre el nivel del mar.

Objetivo específico 1.1. Determinar el efecto de la reducción de la fracción inspiratoria de oxígeno (O2 14%, equivalente a 3250 m) en la frecuencia cardíaca, la saturación de oxígeno y la fatiga percibida de los reanimadores en comparación con el nivel del mar.

Objetivo específico 1.2. Analizar la calidad de la RCP al realizarla en un entorno simulado de 3250 m de altitud frente a la realizada a nivel del mar.

**Objetivo genérico 2.** Estudiar el estrés fisiológico que genera en los reanimadores realizar una RCP prolongada a una temperatura ambiental de 37ºC.

Objetivo específico 2.1. Analizar la influencia del estrés térmico en el consumo metabólico, la fatiga percibida y la deshidratación de los reanimadores al realizar una RCP a temperatura ambiental muy elevada (37ºC).

Objetivo específico 2.2. Examinar la calidad de la RCP realizada a 37ºC frente a la realizada en un entorno neutro de 25ºC.

**Objetivo genérico 3.** Analizar el impacto del EPI en las demandas fisiológicas del reanimador y la calidad de la RCP durante la RCP prolongada simulada.

Objetivo específico 3.1. Analizar la frecuencia cardíaca, la temperatura, la pérdida de líquido corporal y el confort térmico portando un EPI al realizar una RCP simulada.

Objetivos específico 3.2. Evaluar la calidad de la RCP simulada realizada con un EPI compuesto de un mono de protección, pantalla facial, máscara KN95, mascarilla quirúrgica, guantes de nitrilo y calzas para los pies, frente a la realizada con la ropa habitual de los reanimadores.

## METODOLOGÍA

Esta tesis doctoral está compuesta por 3 artículos que han seguido una metodología cuasi-experimental. Se trata de estudios cuantitativos, aleatorios y transversales.

Los participantes, que colaboraron de manera voluntaria en nuestras investigaciones, fueron profesionales sanitarios y socorristas acuáticos. Todos ellos consintieron y autorizaron por escrito su participación en las investigaciones. Tenían 18 años o más, no tenían ninguna enfermedad ni discapacidad física y estaban al día en RCP según las Directrices de Reanimación del ERC vigentes en el momento de la investigación. Solamente un sujeto fue excluido de una de las investigaciones debido a fallos técnicos en el pulsioxímetro en el momento del test.

Todo el trabajo ha respetado los principios éticos de la Declaración de Helsinki y ha sido autorizado por el Comité de Ética de la Facultad de Ciencias de la Educación y el Deporte de la Universidad de Vigo. Los datos fueron seudonimizados y cumplieron con la legislación vigente en materia de protección de datos.

El estudio de variables se agrupó en tres bloques:

1) Parámetros fisiológicos

2) Métricas de la calidad de la RCP

3) Percepciones subjetivas

El análisis de los datos se realizó con el software estadístico SPSS (IBM Corp., Chicago, IL, EE.UU.). El test de Shapiro Wilk fue utilizado para el estudio de la normalidad. Los estudios presentan la media, la desviación típica, los intervalos de confianza (95%), las frecuencias y el tamaño del efecto. Las comparaciones por pares se realizaron con pruebas paramétricas (T-Student y Anova) y pruebas no paramétricas (Wilcoxon y Friedman). Además, se estableció un nivel de significación de $p < 0,05$ para todos los análisis.

## RESULTADOS (PUBLICACIONES)

### Artículo 1.

**Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high.**

[Exigencias fisiológicas de una reanimación cardiopulmonar de calidad realizada a una altura simulada de 3250 metros].

Carballo-Fazanes A, Barcala-Furelos R, Eiroa-Bermúdez J, **Fernández-Méndez M**, Abelairas-Gómez C, Martínez-Isasi S, et al. Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high. A pilot study. Am J Emerg Med. 2020 Dec;38(12):2580-2585. doi: 10.1016/j.ajem.2019.12.048. Epub 2019 Dec 24. PMID: 31911060.

**Objetivo**. Analizar el efecto de la reducción de la fracción de oxígeno (O2 14%, equivalente a 3250 m) en la calidad de la reanimación cardiopulmonar (Q-CPR) y en las demandas fisiológicas de los reanimadores.

**Método**. Se realizó un estudio cuasi-experimental en una muestra de 9 profesionales sanitarios expertos en reanimación cardiopulomar (RCP). Los participantes, en equipos de 2 personas, realizaron 10 minutos de RCP en un maniquí Laerdal ResusciAnne (relación 30:2 y alternando los papeles entre los reanimadores cada 2 minutos) en dos entornos simulados: T21-RCP a nivel del mar (FiO2 del 21%) y T14-RCP a 3250 m de altitud (FiO2 del 14%). La autopercepción del esfuerzo fue de 0 (sin esfuerzo) a 10 (máxima exigencia).

**Resultados**. La calidad de las compresiones torácicas fue buena y similar en ambas condiciones (T21 vs T14). Sin embargo, el porcentaje de ventilaciones con un volumen corriente adecuado fue menor en altitud que a nivel del mar (35,9 ± 25,2% frente a 54,7 ± 23,2%, p = 0,035). La percepción subjetiva del esfuerzo fue significativamente mayor en la altitud simulada (5 ± 2) que a nivel del mar (3 ± 2) (p = 0,038). La frecuencia cardíaca máxima durante las pruebas fue similar en ambas condiciones; sin embargo, la saturación media de oxígeno fue significativamente menor en las condiciones de altitud (90,5 ± 2,5% frente a 99,3 ± 0,5%; p < 0,001).

**Conclusión**. Aunque la realización de la RCP en condiciones de altitud hipóxica simulada aumenta significativamente las demandas fisiológicas y la sensación subjetiva de cansancio en comparación con la RCP a nivel del mar, los reanimadores entrenados son capaces de realizar una RCP de calidad en estas condiciones, al menos durante los primeros 10 minutos de reanimación

**Artículo 2.**

**Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study.**

[Medición del impacto fisiológico del calor extremo en los socorristas durante reanimación cardiopulmonar. Estudio aleatorio de simulación]

Barcala-Furelos R, **Fernández-Méndez M**, Cano-Noguera F, Otero-Agra M, Morán-Navarro R, Martínez-Isasi S. Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study. Am J Emerg Med. 2020 Oct;38(10):2019-2027. doi: 10.1016/j.ajem.2020.06.042. Epub 2020 Jun 26. PMID: 33142168.

**Objetivo**: Los equipos de socorristas realizan su trabajo en condiciones de calor extremo en muchas partes del mundo. El objetivo de este estudio fue analizar el impacto de las altas temperaturas en los parámetros fisiológicos durante la reanimación cardiopulmonar (RCP).

**Método**: Se utilizó un diseño aleatorio cuasi-experimental cruzado para analizar las demandas fisiológicas de los reanimadores (50 minutos de aclimatación + 10 minutos de RCP) en dos entornos térmicos diferentes: ambiente termo-neutral (25 °C) frente a un entorno hipertérmico (37 °C).

**Resultados**: Se incluyeron los datos obtenidos de 21 socorristas, esto abarca un total de 420 min de reanimación. El rendimiento de la RCP se mantuvo constante durante los 10 min. El consumo de oxígeno (VO2) osciló entre 17 y 18 ml/min/kg para las compresiones cardíacas (CC) y entre 13 y 14 ml/min/kg para las ventilaciones (V) tanto a 25 °C y 37 °C, sin diferencias significativas entre entornos ($p > 0,05$). El porcentaje de la frecuencia cardíaca (%FC max) aumentó entre un 7% y un 8% a 37 °C ($p < 0,001$), oscilando entre el 75% y el 82% de la FC máx. La pérdida de fluidos corporales (LBF) fue mayor en el entorno hipertérmico; LBF: (37 °C: 400 ± 187 g vs 25 °C: 148 ± 81 g; $p < 0,001$). La temperatura corporal fue 1 °C mayor al final de la prueba ($p < 0,001$). La fatiga percibida fatiga (RPE) aumentó en 37° una media de 2 puntos en una escala de 10 ($p = 0,001$).

**Conclusiones**: El calor extremo no es un factor limitante en el rendimiento de la RCP con dos socorristas. El consumo metabólico se mantiene con un aumento de la CC, por lo que la V puede servir de descanso activo. No obstante, la reanimación a 37 °C resulta en una mayor FC, es más agotadora y provoca una importante pérdida de líquidos debido a la sudoración.

**Artículo 3.**

**Analysis of physiological response during cardiopulmonary resuscitation with personal protective equipment: a randomized crossover study.**

[Análisis de la respuesta fisiológica durante la reanimación cardiopulmonar con equipo de protección personal: Un estudio aleatorio cruzado]

**Fernández-Méndez, M**; Otero-Agra, M; Fernández-Méndez, F; Martínez-Isasi, S; Santos Folgar, M; Barcala-Furelos, R; Rodríguez-Núñez, A. Analysis of Physiological Response during Cardiopulmonary Resuscitation with Personal Protective Equipment: A Randomized Crossover Study. Int. J. Environ. Res. Public Health . 2021 Jul 2;18(13):7093. doi: 10.3390/ijerph18137093. PMID: 34281042; PMCID: PMC8296930.

El uso de equipos de protección individual (EPI) es necesario para la autoprotección del personal sanitario durante la reanimación cardiopulmonar (RCP) en pacientes con riesgo de transmisión por aerosol de agentes infecciosos. El objetivo de este estudio fue analizar el impacto del equipo de protección personal en los parámetros fisiológicos durante la RCP. Se utilizó un diseño aleatorio, cuasi-experimental y cruzado. El estudio se llevó a cabo en un box de emergencias de entrenamiento y simulación y la muestra total fue de 20 profesionales sanitarios. Se compararon dos pruebas de RCP con la secuencia recomendada de 30 compresiones torácicas y 2 ventilaciones. La duración de cada prueba fue de 20 minutos. Una de las pruebas de RCP se realizó sin utilizar ningún EPI (RCP_control), es decir, con la ropa habitual de cada reanimador. La otra prueba se llevó a cabo realizando RCP con EPI (es decir, RCP_EPI). Las principales variables de interés fueron: calidad de la RCP, compresiones, ventilaciones, frecuencia cardíaca máxima, pérdida de líquido corporal, temperatura corporal, índice de esfuerzo percibido, confort y sensación térmica y sudoración. La calidad de la RCP fue similar en ambas pruebas. La frecuencia cardíaca máxima fue mayor en los intervalos activos intervalos (compresiones + ventilación con balón autoinflable) de la prueba con EPI. La RCP_EPI supuso un aumento del esfuerzo percibido, de la temperatura al inicio de la prueba, de la sensación térmica, del confort térmico y de la sudoración, en comparación con la RCP realizada con la ropa habitual. La realización de una reanimación prolongada con EPI no influyó en la calidad de la RCP, pero provocó importantes demandas fisiológicas. Los reanimadores estaban más fatigados, sudaban más y su confort térmico era peor. Estos resultados sugieren que la preparación física debe tenerse en cuenta al utilizar el EPI y también deben establecerse protocolos para la recuperación fisiológica después de su uso.

## DISCUSIÓN

Los principales objetivos de esta tesis fueron aportar nuevas evidencias acerca de la RCP en circunstancias especiais, y para ello se analizó el impacto fisiológico que tiene sobre los reanimadores realizar una RCP prolongada en distintos entornos especiales así como comparar la calidad de la RCP al realizarla en un ambiente estándar frente a la realizada en una circunstancia especial. Los estudios realizados suponen una innovación relevante en este campo de la investigación aplicada, ya que hasta el momento no se habían publicado resultados de estudios sobre esta temática que se hubieran planteado hipótesis y objetivos similares.

Los principales hallazgos de los estudios realizados fueron los siguientes:

a) Realizar RCP en circunstancias especiales tiene efectos sobre las habilidades motoras y afecta a nivel fisiológico con un aumento del gasto cardíaco, de la fatiga percibida y de una importante pérdida de líquido corporal.

b) La calidad de la RCP se mantiene estable en los tres entornos especiales cuando es realizada por sujetos bien entrenados y cuando la comparamos con un ambiente estándar.

1. Respuesta fisiológica en circunstancias especiales

Realizar RCP es una técnica exigente que genera una fatiga que aumenta con el tiempo y que, además, tiene una influencia negativa en la calidad de las compresiones torácicas y las ventilaciones. Teniendo en cuenta esta premisa, se estudió en qué medida los diferentes escenarios de simulación en los que se realizaba RCP influía en la fatiga de los intervinientes.

En la simulación a gran altitud los reanimadores tuvieron una mayor percepción de fatiga al realizar RCP que si se hubiera realizado en niveles normotóxicos, aun logrando con ello una buena calidad de reanimación en ambos escenarios.

Se sabe que existe una asociación entre la temperatura y el aumento de la FC, y a su vez entre el aumento de la FC y un mayor índice de esfuerzo percibido (perceived exertation rate - RPE), así como entre deshidratación y la fatiga temprana por calor. Esta respuesta fisiológica es coherente con el RPE más alto registrado por los socorristas a T37°C, coincidiendo con la fatiga percibida en un escenario a 3250 m. de altitud.

La declaración de la pandemia por COVID-19 y el aumento del uso del EPI, supusieron cambios y adaptaciones a nivel laboral por parte del personal sanitario, entre otros. En nuestro estudio, controlado y simulado, al realizar una RCP de larga duración con un EPI puesto, encontramos los mismos valores que realizar RCP en calor elevado (37ºC). El aumento del RPE está en concordancia con otros estudios, en los que la fatiga percibida muestra valores más elevados cuando se lleva un EPI que cuando no se lleva. Esto podría estar relacionado con el aumento de la temperatura corporal y el disconfort térmico producido en este ambiente

A nivel fisiológico, investigaciones anteriores han demostrado que la FC aumenta en la altitud, tanto en reposo como durante el ejercicio físico. En cambio, en nuestras pruebas, la FC apenas se incrementó en la simulación a 3250 m de altitud respecto a la línea de base obtenida en la simulación a nivel del mar.

Al cambiar de escenario, el efecto de la temperatura ambiental, en nuestro caso calor elevado, se registraron valores más altos de FC a T37°C. Existe una asociación entre la temperatura y el aumento de la FC por lo que nuestros resultados confirman esta teoría.

Los resultados de estos dos primeros estudios concuerdan con los resultados obtenidos en los ciclos de compresión cardíaca y ventilación cuando se realizó la tercera investigación y se utilizó un EPI ya que, la FC es mayor que en los ciclos de ventilación, y en el caso del EPI, se corresponde con la fase de fijación de la mascarilla sobre la cara de la víctima al haber sido modificado el protocolo de RCP en tiempos de COVID y ventilación con bolsa autoinflable.

Durante el ejercicio, numerosos mecanismos fisiológicos de pérdida de calor se activan para evitar un aumento excesivo de la temperatura central, pero en ambientes cálidos y húmedos esto puede suponer un reto en la termorregulación corporal. En entornos adversos por encima de los 35 °C, la actividad física puede provocar pérdidas de hasta 1,5 l por hora. Nuestros resultados mostraron una pérdida de 400 g en 1 h, tras un periodo de aclimatación de 50min y 10min de ejercicio, y aunque la RCP podría ser una actividad de bajo impacto para reanimadores entrenados, el ejercicio prolongado de baja intensidad provoca un aumento de la temperatura corporal y de la FC. Un mayor tiempo de reanimación, un mayor periodo de aclimatación, una deshidratación previa o una temperatura más elevada podrían ser factores limitantes para mantener el rendimiento de la reanimación cardiopulmonar.

Realizar RCP con un EPI puesto provoca un aumento de la temperatura corporal en los reanimadores que lo llevan. Los resultados obtenidos en nuestra investigación fueron similares a los obtenidos en un escenario a 37ºC de temperatura ambiente. Durante el ejercicio con calor, la producción de sudor suele superar la ingesta de agua, de ahí el déficit de agua corporal. El aumento de la fatiga ya comentado al realizar la RCP podría relacionarse con el aumento de la temperatura corporal y el confort térmico. La sensación térmica y el confort térmico pueden ser modificados por la temperatura de la piel, de tal manera que cuando el ejercicio se realiza en condiciones ambientales cálidas y moderadas, el malestar térmico es mayor en las primeras. Por lo tanto, sería aconsejable que los profesionales sanitarios y socorristas que tengan que realizar una RCP con un EPI se lo quitaran después de realizar la RCP y bebieran líquidos en una habitación a temperatura ambiente para rehidratarse y bajar su temperatura corporal para poder continuar con su trabajo en condiciones adecuadas.

2. Calidad de la RCP en circunstancias especiales

Una de las hipótesis de esta tesis por compendio era que al realizar RCP en estos entornos especiales disminuiría la calidad de la RCP, y tras las investigaciones realizadas, no se obtuvieron diferencias significativas en ninguno de los tres casos. La RCP se considera un ejercicio físico exigente que produce rápidamente fatiga en el reanimador. Esta fatiga aumenta con el tiempo y tiene influencia negativa en la calidad de las compresiones torácicas y las ventilaciones y, en consecuencia, se recomiendan los cambios de compresión/ventilación entre reanimadores cada 2 minutos, por ello nuestros tres estudios han sido realizados siguiendo estas indicaciones.

En nuestra primera investigación, el único cambio significativo en el rendimiento durante la RCP en condiciones de altitud fue una disminución del porcentaje de ventilaciones dentro del rango de volumen tidal recomendado (500 – 600 ml). Teniendo en cuenta que la ventilación con bolsa autoinflable es una tarea técnica y no física, podemos especular con que la hipoxemia podría afectar de alguna manera a las habilidades motoras finas de los reanimadores.

Nuestra segunda investigación, en la que se realizó una RCP de larga duración a 37ºC por socorristas, no mostró diferencias significativas al compararla con la realizada a 25ºC, aunque si obtuvo un porcentaje significativamente menor de ventilaciones efectivas en el test en condiciones de calor.

Cuando utilizamos un EPI al realizar RCP, nuestra investigación confirmó el mensaje de otros autores al aportar pruebas de reanimaciones de larga duración y, además, analizando las ventilaciones además de las compresiones. La ausencia de diferencias en la calidad de la RCP cuando se utiliza el EPI en comparación con la no utilización del mismo, refuerza el mensaje de que los profesionales sanitarios deben protegerse con un EPI en situaciones de riesgo ya que la calidad de la atención no se ve afectada negativamente.

***Implicaciones prácticas de los estudios***

Los resultados de los estudios incluidos en esta tesis doctoral podrán ayudar a los reanimadores a comprender qué efecto fisiológico les espera al realizar una RCP a una elevada altitud, ante una circunstancia de calor ambiental o si deben llevar un EPI puesto.

Las principales recomendaciones prácticas son las siguientes:

- Es necesario considerar programas de entrenamiento específico adaptativo para reanimadores que desempeñen o vayan a desempeñar sus labores en ambientes especiales.

- La hipoxia que se genera a una elevada altitud tiene efectos sobre las habilidades motoras, por lo que los reanimadores deberían entrenar las técnicas en esta circunstancia haciendo hincapié en el uso del balón resucitador.

- Realizar RCP en estos ambientes genera más fatiga que la realizada en un ambiente estándar, por lo que sería conveniente que el personal encargado de realizar las reanimaciones esté entrenado y que así se pueda gestionar el papel de cada reanimador según su capacidad física.

- El calor y el uso de equipo de protección individual genera deshidratación y aumento de la temperatura corporal, por lo que se recomienda, tras una RCP en estas circunstancias, que se realice una recuperación en una zona a temperatura ambiente y una rehidratación para así, continuar la jornada laboral en condiciones adecuadas.

***Limitaciones***

En general, las principales limitacines de estos tres estudios cuasi-experimentales es que son situaciones simuladas, con muestras de conveniencia y relativamente pequeñas. Son tres estudios piloto reproducibles que pueden generar mayor conocimiento si se estudian con otras poblaciones, con otros tiempos de reanimación y/o de aclimatación o si se aplicaran en casos reales.

## CONCLUSIONES

Los estudios incluidos en esta tesis doctoral llegaron a las siguientes conclusiones:

### Conclusiones en relación con la hipótesis 1

1.1. La hipoxia que se genera a una elevada altitud tiene efectos sobre las habilidades motoras, por lo que los reanimadores deberían entrenar las técnicas en esta circunstacia haciendo hincapié en el uso del balón resucitador.

1.2. Los reanimadores entrenados son capaces de realizar una buena RCP en condiciones de hipoxia simuladas (FiO2 del 14%), pero a costa de unas exigencias fisiológicas adicionales y una sensación subjetiva de cansancio

### Conclusiones en relación con la hipótesis 2

2.1. El consumo metabólico puede permanecer estable durante reanimación prolongada en calor extremo, sin embargo, mantener los estándares de calidad significa un mayor gasto cardíaco, más fatiga percibida y una importante pérdida de líquidos a través de la sudoración.

2.2. El calor extremo no es un factor limitante para la realización de la RCP por parte de los socorristas en comparación con un entorno a temperatura neutra.

**Conclusiones en relación con la hipótesis 3**

3.1. Existe un importante impacto fisiológico relacionado con el esfuerzo prolongado al llevar un EPI, por ello, es recomendable quitarse el EPI, rehidratarse y descansar en un entorno fresco para reducir la temperatura corporal y sentirse cómodo.

3.2. Cuando los profesionales sanitarios llevan un EPI son capaces de realizar una RCP prolongada de una calidad comparable a cuando la realiza con ropa normal, aunque esto implique un considerable estrés fisiológico. La formación en RCP con EPI es necesaria para que los reanimadores comprendan esta circunstancia especial y también puedan mejorar su condición física.

# SUMMARY IN GALICIAN

# SUMARIO EN GALEGO

# SUMMARY IN GALICIAN

*Nota. Este sumario é unha versión reducida do documento principal en lingua inglesa. As referencias bibliográficas foron citadas no manuscrito en inglés.*

CALIDADE DA REANIMACIÓN CARDIOPULMONAR E IMPACTO FISIOLÓXICO NOS RESCATADORES EN CIRCUNSTANCIAS ESPECIAIS SIMULADAS

## INTRODUCIÓN

Na parada cardiorrespiratoria (PCR) a atención á vítima depende da participación e da resposta da comunidade, que poderá actuar como primeiro interveniente, e do persoal sanitario. Para obter unha maior optimización das accións a realizar no tratamento inicial dunha PCR, deseñáronse unha serie de pasos compostos por eslavóns enlazados coñecidos como a "Cadea de Supervivencia".

Co fin de estandarizar as manobras de reanimación cardiopulmonar (RCP) , a Alianza Internacional de Consellos de Resucitación (ILCOR), o Consello Europeo de Resucitación (ERC) e a Asociación Americana do Corazón (AHA) levan a cabo procesos de busca de evidencias e publican periodicamente recomendacións, tanto para persoal lego como para persoal sanitario, en soporte vital básico (SVB) e avanzado (SVA).

O algoritmo de SVB publicado nas últimas guías no ano 2021 establece as instrucións paso a paso que deben proporcionarse sobre como recoñecer unha parada cardíaca, alertar ós servizos de emerxencia e proporcionar compresións torácicas de alta calidade. Estas compresións son a compoñente clave nunha RCP como medio eficaz para proporcionar e/ou manter a perfusión dos órganos vitais nunha parada cardíaca.

As circunstancias nas que poden ocorrer unha PCR e ser necesaria a RCP son moi variables. E en certas condicións, as intervencións de SVB e SVA poden requirir modificacións en relación ás recomendacións xerais, por este motivo o ERC e a AHA incluíron dentro das súas guías do ano 2020 apartados ou seccións sobre a RCP en circunstancias especiais. Estas especificacións podemos clasificalas en tres seccións diferenciadas: causas especiais, contornas especiais ou pacientes especiais. Recoñécese que as probas científicas para facer recomendacións nestas circunstancias son moi escasas, polo que os investigadores deberían realizar esforzos para aportar evidencias que permitan sustentar as guías de RCP en condicións non habituais e circunstancias extremas e especiais.

Tendo en conta este aspecto, propuxémonos levar a a cabo este proxecto de tese doutoral,na modalidade de tese por compendio, na que se investigaron diferentes contornas especiais nas que unha persoa pode ter que realizar unha reanimación cardiopulmonar e que se comentan a continuación:

## RCP a gran altitude

O feito de estar a gran altitude produce varios cambios fisiolóxicos que inclúen o aumento da carga de traballo cardíaco e respiratorio, especialmente durante o exercicio. O rendemento cardiopulmonar vese afectado por riba dos 2500-3000 m de altitude, onde a presión arterial parcial de oxíxeno (PaO2) é de 50-65 mmHg mentres que ao nivel do mar é de 98 mmHg. Ademais, a partires dos 3000 m de altura, os cambios fisiolóxicos (aumento da frecuencia cardíaca e da presión arterial, arritmias, elevación da presión intracranial, ...) vólvense máis relevantes porque os mecanismos compensatorios fisiolóxicos non son capaces de contrarrestar o efecto da diminución da saturación de oxíxeno.Cómpre sinalar que, a pesares de todos os cambios fisiolóxicos que se producen nos reanimadores e nas vítimas, así como na diminución da calidade da RCP realizada a unha elevada altitude,e despois da publicación dunha revisión sistemática da literatura na que se estableceron recomendación sobre RCP a gran altura, ata o momento as directrices do Consello Europeo de Resucitación sobre reanimación a gran altitude non difiren das RCP estándar.

## RCP en condición de  altas temperaturas ambientais

As temperaturaselevadas, , unha maior cantidade de horas de luz e as vacacións, provocan un incremento de afluencia de xente en espazos acuáticos durante a época estival, o que conleva un aumento na taxa de afogamentos. Realizar unha RCP a altas temperaturas pode provocar unha diminución na calidade das compresións cardíacas, xerar fatiga no rescatador,que pode aumentar, xa sexa pola duración ou polas condicións previas na que se teña que realizar dita reanimación, como, por exemplo, tras realizar un rescate acuático. Asemade, este cansazo xerado pola realización dunha RCP, que non deixa de ser unha actividade física intensa, pode verse incrementado polas variacións termoambientais que provocan cambios a nivel fisiolóxico sobre as persoas, como o aumento das frecuencias cardíaca e respiratoria, da temperatura corporal, da tensión arterial ou da deshidratación, e cambios a nivel psicolóxico, como a ansiedade.

**RCP en paciente con enfermidades infecto contaxiosas (COVID-19 e outras)**

Aínda que moitas persoas estiveron no foco dos contaxios, os profesionais sanitarios son un colectivo con alto risco de contraer a enfermidade debido ás técnicas e procedementos que deben realizar sobre pacientes con sospeita ou confirmación de infección por COVID-19. Neste aspecto, as guías publicadas polo ERC e a AHA sobre recomendacións de RCP e enfermidade COVID-19indican sen lugar a dúbidas, que o profesional sanitario debe protexerse cun Equipo de Protección Individual (EPI) cando vaia realizar unha RCP ou outro procedemento que supoña contacto cos pacientes. Para iso, as recomendacións sobre que dispositivos ou materiais se deben utilizar, o ERC publicou cal é o material mínimo que se debe utilizar no caso de contaxio por gotiñas ou aerosois. Ademais, ao tratarse dunha situación de circunstancia especial, o ERC suxeriu realizar algúns cambios en relación ao protocolo habitual de RCP.

## HIPÓTESES

Este proxecto de tese tivo as seguintes hipóteses de traballo:

<u>Hipótese 1.</u> A RCP nunha simulación de ambiente hipóxico a gran altitude produce unhas demandas fisiolóxicas incrementadas e unha fatiga percibida superior á reanimación ao nivel do mar.

Hipótese 2. A realización dunha RCP simulada en condicións de calor ambientas produce un estrés fisiolóxico cun aumento da fatiga e de perda de líquidos corporais no reanimador, así como na diminución da calidade das compresións torácicas.

Hipótese 3. A realización dunha RCP prolongada cun equipo de protección individual xerará unha fatiga superior , así como un confort térmico e calidade da RCP peores en comparación coa realizada sen EPI.

## OBXECTIVOS

Para tratar de confirmar ou refutar as hipóteses anteriores, propuxéronse os seguintes obxectivos:

**Obxectivo xenérico 1**. Comparar o impacto fisiolóxico que ten sobre os reanimadores realizar unha RCP prolongada a 3250 m sobre o nivel do mar.

Obxectivo específico 1.1. Determinar o efecto da redución da fracción inspiratoria de oxíxeno ($O2$ 14%, equivalente a 3250 m) na frecuencia cardíaca, na saturación de oxíxeno e na fatiga percibida nos reanimadores en comparación co nivel do mar.

Obxectivo específico 1.2. Analizar a calidade da RCP ao realizala nunha contorna simulada de 3250 m de altitude fronte a realizada ao nivel do mar.

**Obxectivo xenérico 2.** Estudar o estrés fisiolóxico que xera nos reanimadores realizar unha RCP a unha temperatura ambiental de 37ºC.

Obxectivo específico 2.1. Analizar a influencia do estrés térmico no consumo metabólico, na fatiga percibida e na deshidratación dos reanimadores ao realizar unha RCP temperatura ambiental moi elevada (37ºC).

Obxectivo específico 2.2. examinar a calidade da RCP realizada a 37ºC fronte a realizada nun ambiente neutro a 25ºC.

**Obxectivo xenérico 3.** Analizar o impacto do EPI nas demandas fisiolóxicas do reanimador e na calidade da RCP durante a RCP prolongada simulada.

Obxectivo específico 3.1. Analizar a frecuencia cardíaca, a temperatura, a perda de líquido corporal e o confort térmico portando un EPI ao realizar unha RCP simulada.

Obxectivo específico 3.2. Avaliar a calidade da RCP simulada realizada cun EPI composto de mono de protección, pantalla facial, máscara KN95, máscara cirúrxica, luvas de nitrilo e calzado para os pés, fronte a realizada coa roupa habitual dos reanimadores.

## METODOLOXÍA

Esta tese doutoral está composta por 3 artigos que seguiron unha metodoloxía cuasi-experimental. Trátase de estudos cuantitativos, aleatorios e transversais.

Os participantes,que colaboraron de maneira voluntaria nas nosas investigacións, foron profesionais sanitarios e socorristas acuáticos.

Todos eles consentiron e autorizaron por escrito a súa participación nas investigacións. Tiñan 18 anos ou máis, non tiñan ningunha enfermidade nin discapacidade física e estaban ao día en RCP segundo as directrices de reanimación do ERC vixentes no momento da investigación. Soamente un suxeito foi excluído dunha das investigacións debido a erros técnicos no oxímetro de pulso no momento do test.

Todo o traballo respectou os principios éticos da Declaración de Helsinki e foi autorizado polo Comité de Ética da Facultade de Ciencias de Educación e do Deporte da Universidade de Vigo. Os datos foron seudonimizados  e cumpriron coa lexislación vixente en materia de protección de datos.

O estudo de variables agrupouse en tres bloques:

1) Parámetros fisiolóxicos

2) Métricas da calidade da RCP

3) Percepcións subxectivas

A análise de datos realizouse co software estatístico SPSS (IBM Corp., Chicago, IL, EE.UU.). O test de Shapiro Wilk utilizouse para o estudo da normalidade. O estudos presentan a media, a desviación típica, os intervalos de confianza (95%), as frecuencias e o tamaño do efecto. As comparacións por pares realizáronse con probas paramétricas (T-Student e Anova) e as probas non paramétricas (Wilcoxon e Friedman). Ademais, estableceuse un nivel de significación de $p < 0,05$ para todas as análises.

## RESULTADOS (PUBLICACIÓNS)

### Artigo 1.

**Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high.**

[Requisitos fisiolóxicos dunha reanimación cardiopulmonar de calidade realizada a unha altura simulada de 3250 metros].

Carballo-Fazanes A, Barcala-Furelos R, Eiroa-Bermúdez J, **Fernández-Méndez M**, Abelairas-Gómez C, Martínez-Isasi S, et al. Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high. A pilot study. Am J Emerg Med. 2020 Dec;38(12):2580-2585. doi: 10.1016/j.ajem.2019.12.048. Epub 2019 Dec 24. PMID: 31911060.

Obxectivo: Analizar o efecto da redución da fracción de oxíxeno ($O_2$ 14%, equivalente a 3250 m) na calidade da reanimación cardiopulmonar (Q-CPR) e as demandas fisiolóxicas dos reanimadores.

Método: Realizouse un estudo cuasi-experimental nunha mostra de 9 profesionais sanitarios expertos en reanimación cardiopulmonar (RCP). Os participantes, en equipos de 2 persoas, realizaron 10 minutos de RCP nun maniquí Laerdal ResusciAnne (relación 30:2 e alternando os papeis entre os reanimadores cada 2 minutos) en dous ambientes simulados: T21-RCP a nivel do mar (FiO2 do 21%) e T14-RCP a 3250m de altitude (FiO2 do 14%). A auto percepción do esforzo foi de 0 (sen esforzo) a 10 (máxima esixencia).

Resultados: a calidade das compresións torácicas foi boa e similar en ambas condicións (T21 vs T14). Con todo, a porcentaxe de ventilacións cun volume corrente axeitado foi menor na altitude que ao nivel do mar ( 35,9 ± 25,2% fronte a 54,7 ± 23,2%, p = 0,035). A percepción subxectiva do esforzo foi significativamente maior na altitude simulada (5 ± 2) que a nivel do mar (3 ± 2) (p = 0,038). A frecuencia cardíaca máxima durante as probas foi similar en ambas condicións; Porén, a saturación media de oxíxeno foi significativamente menor nas condicións de altitude 90,5 ± 2,5% fronte a 99,3 ± 0,5%; p < 0,00).

Conclusión: Aínda que a realización da RCP en condicións de altitude hipóxica simulada aumenta significativamente as demandas fisiolóxicas e a sensación subxectiva de fatiga en comparación coa RCP ao nivel do mar, os reanimadores adestrados son capaces de realizar unha RCP de calidade nestas condicións, polo menos durante os primeiros 10 minutos de reanimación.

**Artigo 2.**

**Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study.**

[Medición do impacto fisiolóxico da calor extrema nos socorristas durante reanimación cardiopulmonar. Estudio aleatorio de simulación]

Barcala-Furelos R, **Fernández-Méndez M**, Cano-Noguera F, Otero-Agra M, Morán-Navarro R, Martínez-Isasi S. Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study. Am J Emerg Med. 2020 Oct;38(10):2019-2027. doi: 10.1016/j.ajem.2020.06.042. Epub 2020 Jun 26. PMID: 33142168.

Obxectivo: Os equipos de socorristas realizan o seu traballo en condicións de calor extrema en moitas partes do mundo. O obxectivo deste estudo foi analizar o impacto das altas temperaturas nos parámetros fisiolóxicos durante a reanimación cardiopulmonar (RCP).

Método: Utilizouse un deseño aleatorio cuasi-experimental cruzado para analizar as demandas fisiolóxicas dos reanimadores (50 minutos de aclimatación + 10 minutos de RCP) en dous ambientes térmicos diferentes: ambiente termo-neutral (25ºC) fronte a un ambiente hipertérmico (37ºC).

Resultados: Incluíronse os datos obtidos de 21 socorristas, o que engloba un total de 420 min de reanimación. O rendemento da RCP mantívose constantedurante os 10 min. O consumo de oxíxeno (VO2)

variou entre 17 e 18 ml/min/kg para as compresións cardíacas (CC) e entre 13 e 14 ml/min/kg para as ventilacións (V) tanto a 25ºC e 37 ºC, sen diferencias significativas entre os dous ambientes ( p > 0,05). A porcentaxe da frencuencia cardíaca (%FC max) aumentou entre un 7% e un 8% a 37ºC (p < 0,001), oscilando entre o 75% e o 82% da FC máx. A perda de fluídos corporais (LBF) foi maior no ambiente hipertérmico; LBF: (37 °C: 400 ± 187 g vs 25 °C: 148 ± 81 g; p <0,001 ). A temperatura corporal foi 1ºC maior ao final da proba (p < 0,001). A fatiga percibida (RPE) aumentou en 37º unha media de 2 puntos nunha escala de 10 (p = 0,001).

Conclusións: A calor extrema non é un factor limitante no rendemento da RCP con dous socorristas. O consumo metabólico mantensecun aumento da CC, polo que a V pode servir de descanso activo. Non obstante, a reanimación a 37ºC resulta nunha maior FC, é máis esgotadora e provoca unha importante perda de líquidos debido á transpiración.

**Artigo 3.**

**Analysis of physiological response during cardiopulmonary resuscitation with personal protective equipment: a randomized crossover study.**

[Análise da resposta fisiolóxica durante a reanimación cardiopulmonar con equipo de protección persoal: Un estudio aleatorio cruzado]

**Fernández-Méndez, M**; Otero-Agra, M; Fernández-Méndez, F; Martínez-Isasi, S; Santos Folgar, M; Barcala-Furelos, R; Rodríguez-Núñez, A. Analysis of Physiological Response during

Cardiopulmonary Resuscitation with Personal Protective Equipment: A Randomized Crossover Study. Int. J. Environ. Res. Public Health . 2021 Jul 2;18(13):7093. doi: 10.3390/ijerph18137093. PMID: 34281042; PMCID: PMC8296930

O uso de equipos de protección individual (EPI) é necesario para a autoprotección do persoal sanitario durante a reanimación cardiopulmonar (RCP) en pacientes con risco de transmisión por aerosol de axentes infecciosos. O obxectivo deste estudo foi analizar o impacto dos equipos de protección individual nos parámetros fisiolóxicos durante a RCP. Utilizouse un deseño aleatorizado, case experimental e cruzado. O estudo realizouse nunha sala de urxencias de formación e simulación e a mostra total foi de 20 profesionais sanitarios. Comparáronse dúas probas de RCP coa secuencia recomendada de 30 compresións torácicas e 2 respiracións. A duración de cada proba foi de 20 minutos. Unha das probas de RCP realizouse sen utilizar ningún EPI (CPR_control), é dicir, coa roupa habitual de cada socorrista. A outra proba realizouse realizando RCP con EPI (é dicir, EPI_CPR). As principais variables de interese foron: calidade da RCP, compresións, ventilacións, frecuencia cardíaca máxima, perda de líquidos corporais, temperatura corporal, valoración do esforzo percibido, confort e sensación térmica e transpiración. A calidade da RCP foi similar en ambas probas. A frecuencia cardíaca máxima foi maior nos intervalos activos (compresións + ventilación con balón autoinflable) da proba con EPI. A CPR_EPI implicou un aumento do esforzo percibido, da temperatura ao inicio da proba, da sensación térmica, do confort térmico e da transpiración, en comparación coa RCP realizada con roupa normal. A realización dunha reanimación prolongada con EPI non influíu na calidade da

RCP, pero provocou importantes demandas fisiolóxicas. Os socorristas estaban máis cansados, suaban máis e o seu confort térmico era peor. Estes resultados suxiren que se debe ter en conta a preparación física cando se use un EPI e tamén se deben establecer protocolos para a recuperación fisiolóxica despois do uso.

**DISCUSIÓN**

Os principais obxectivos desta tese foron achegar novas evidencias sobre a RCP en circunstancias especiais, e para este fin analizouse o impacto fisiolóxico que ten sobre os reanimadores realizar unha RCP prolongada en diferentes ambientes especiais, así como comparar a calidade da RCP cando se realiza nun ambiente estándar fronte ao realizado nunha circunstancia especial. Os estudos realizados supoñen unha innovación relevante neste campo da investigación aplicada, xa que ata o momento non se publicaron resultados de estudos sobre este tema nin se propuxeron hipóteses e obxectivos similares.

Os principais resultados dos estudos realizados foron os seguintes:

a) A realización da RCP en circunstancias especiais ten efectos sobre a motricidade e afecta o nivel fisiolóxico cun aumento do gasto cardíaco, da percepción de fatiga e dunha importante perda de líquido corporal.

b) A calidade da RCP mantense estable nos tres ambientes especiais cando é realizada por suxeitos ben formados e cando a comparamos cun ambiente estándar.

1. Resposta fisiolóxica en circunstancias especiais

A realización de RCP é unha técnica esixente que xera un cansanzo que aumenta co paso do tempo e que tamén inflúe negativamente na calidade das compresións torácicas e das ventilacións. Tendo en conta esta premisa, estudamos en que medida os diferentes escenarios de simulación nos que se realizou a RCP influíron na fatiga dos participantes.

Na simulación a gran altura, os socorristas tiveron unha maior percepción de fatiga á hora de realizar a RCP que se se realizara a niveis normotóxicos, a aínda así, conseguido unha boa calidade de reanimación en ambos escenarios.

Sábese que existe unha asociación entre a temperatura e o aumento da FC, e á súa vez entre o aumento da FC e unha maior taxa de esforzo percibido (perceived exertation rate - RPE), así como entre a deshidratación e a fatiga por calor temperá. Esta resposta fisiolóxica é consistente co RPE máis alto rexistrado polos socorristas a T37 °C, coincidindo coa fatiga percibida nun escenario de 3250 m. de altitude.

A declaración da pandemia de COVID-19 e o aumento do uso de EPI provocou cambios e adaptacións a nivel laboral por parte do persoal sanitario, entre outros. No noso estudo, controlado e simulado,ao realizar RCP de longa duración co EPI posto, atopamos os mesmos valores que a RCP a alta temperatura (37ºC). O aumento do RPE está de acordo con outros estudos, nos que a fatiga percibida mostra valores máis altos cando se usa o EPI que cando non. Isto podería estar relacionado co aumento da temperatura corporal e as molestias térmicas producidas neste ambiente.

A nivel fisiolóxico, investigacións anteriores demostraron que a FC aumenta en altitude, tanto en repouso como durante o exercicio físico. Pola contra, nas nosas probas, a FC apenas aumentou na simulación a 3250 m de altitude con respecto á liña base obtida na simulación a nivel do mar.

Ao cambiar de escenario, o efecto da temperatura ambiental, no noso caso da calor elevada, rexistráronse valores de FC máis altos a T37 °C. Hai unha asociación entre a temperatura e o aumento da FC, polo que os nosos resultados confirman esta teoría.

Os resultados destes dous primeiros estudos coinciden cos resultados obtidos nos ciclos de compresión cardíaca e ventilación cando se realizou a terceira investigación e se utilizou un EPI, xa que a FC é maior que nos ciclos de ventilación, e no caso dos EPI, corresponde á fase de fixación da máscara no rostro da vítima xa que se modificou o protocolo de RCP en tempos de COVID e máis a ventilación con bolsa autoinflable.

Durante o exercicio, actívanse numerosos mecanismos fisiolóxicos de perda de calor para evitar un aumento excesivo da temperatura central, pero en ambientes quentes e húmidos isto pode supoñer un desafío para a termorregulación corporal. En ambientes duros superiores a 35 °C, a actividade física pode provocar perdas de ata 1,5 l por hora. Os nosos resultados mostraron unha perda de 400 g en 1 h, despois dun período de aclimatación de 50 min e 10 min de exercicio, e aínda que a RCP podería ser unha actividade de baixo impacto para os socorristas adestrados, o exercicio prolongado de baixa intensidade provoca un aumento da temperatura coporal e da FC. Un tempo de reanimación máis longo, un período de aclimatación máis longo, unha deshidratación previa ou unha temperatura máis alta poderían ser factores que limiten manter a realización da reanimación cardiopulmonar.

A realización de RCP mentres se usa un EPI provoca un aumento da temperatura corporal nos socorristas que o levan. Os resultados obtidos na nosa investigación foron similares aos obtidos nun escenario a 37ºC de temperatura ambiente. Durante o exercicio en calor, a produción de suor adoita exceder á inxestión de auga, e así temos un déficit de auga corporal. O aumento da fatiga xa mencionado á hora de realizar a RCP podería estar relacionado co aumento da temperatura corporal e do confort térmico. A sensación térmica e o confort térmico poden ser modificados pola temperatura da pel, de tal xeito que cando o exercicio se realiza en condicións ambientais cálidas e moderadas, o malestar térmico é maior nas primeiras. Polo tanto, sería recomendable que os profesionais sanitarios e os primeiros respondedores que teñan que realizar RCP con EPI o quiten despois de realizar a RCP e beban líquidos nunha habitación a temperatura ambiente para volver a hidratarse de cara a baixar a súa temperatura corporal para poder continuar co seu traballo en condicións adecuadas.

## 2. Calidade da RCP en circunstancias especiais

Unha das hipóteses desta tese por compendio era que a realización da RCP nestes ambientes especiais diminuiría a calidade da RCP, e tras as investigacións realizadas non se obtiveron diferenzas significativas en ningún dos tres casos. A RCP considérase un exercicio físico esixente que fatiga rapidamente ao socorrista. Esta fatiga aumenta co paso do tempo e inflúe negativamente na calidade das compresións e ventilacións torácicas e, en consecuencia, recoméndanse cambios de compresión/ventilación entre os socorristas cada 2 minutos, polo que os nosos tres estudos foron realizados seguindo estas indicacións.

Na nosa primeira investigación, o único cambio significativo no rendemento durante a RCP de altitude foi unha diminución da porcentaxe de ventilacións dentro do intervalo de volume tidal recomendado (500-600 ml). Tendo en conta que a ventilación con bolsa autoinflable é unha tarefa técnica e non física, podemos especular que a hipoxemia podería afectar dalgún xeito á motricidade fina dos socorristas.

A nosa segunda investigación, na que os socorristas realizaron RCP de longa duración a 37ºC, non mostrou diferenzas significativas en comparación coa realizada a 25ºC, aínda que si obtivo unha porcentaxe significativamente menor de ventilacións efectivas na proba en condicións de calor.

Cando utilizamos EPI ao realizar a RCP, a nosa investigación confirmou a mensaxe doutros autores aportando evidencias de reanimacións de longa duración e, ademais, observando as ventilacións ademais das compresións. A ausencia de diferenzas na calidade da RCP ao utilizar os EPI en comparación con non usalo, reforza a mensaxe de que os profesionais sanitarios deben protexerse cos EPI en situacións de risco xa que a calidade asistencial non se ve comprometida.

***Implicacións prácticas dos estudos***

Os resultados dos estudos incluídos nesta tese doutoral poden axudar aos reanimadores a comprender que efecto fisiolóxico lles espera ao realizar a RCP a gran altitude, nun ambiente quente ou se deben levar EPI.

As principais recomendacións prácticas son as seguintes:

- É necesario contemplar programas específicos de adestramento adaptativo para os reanimadores que desenvolvan ou vaian realizar as súas funcións en contornas especiais.

- A hipoxia xerada a gran altitude ten efectos na motricidade, polo que os socorristas deben adestrar técnicas nesta circunstancia, facendo fincapé no uso do balón de reanimación.

- Realizar a RCP nestes ambientes xera máis fatiga que a que se realiza nun ambiente normalizado, polo que sería conveniente que o persoal encargado de realizar as reanimacións fose adestrado para que a función de cada reanimador poida ser xestionada en función da súa capacidade física.

- A calor e o uso de equipos de protección individual xera deshidratación e aumento da temperatura corporal, polo que se recomenda, tras a RCP nestas circunstancias, que a recuperación se realice nunha zona a temperatura ambiente e volver a hidratarse para así continuar a xornada laboral en condicións adecuadas.

***Limitacións***

En xeral, as principais limitacións destes tres estudos case experimentais é que se trata de situacións simuladas, con mostras de conveniencia relativamente pequenas. Trátase de tres estudos piloto reproducibles que poden xerar un maior coñecemento se se estudan con outras poboacións, con outros tempos de reanimación e/ou aclimatación, ou se se aplicaran en casos reais.

## CONCLUSIÓNS

A continuación preséntanse as conclusións desta tese de doutoramento.

### Conclusións da Hipótese 1

1.1. A hipoxia xerada a gran altitude ten efectos na motricidade, polo que os socorristas deben adestrar técnicas nesta circunstancia, facendo fincapé no uso do balón de reanimación.

1.2. Os socorristas adestrados son capaces de realizar unha boa RCP en condicións de hipoxia simuladas (14% $FiO_2$), pero a conta de demandas fisiolóxicas adicionais e unha sensación subxectiva de fatiga.

### Conclusións da Hipótese 2

2.1. O consumo metabólico pode permanecer estable durante a reanimación prolongada con calor extrema, non obstante, manter os estándares de calidade significa un maior gasto cardíaco, máis fatiga percibida e unha perda significativa de líquidos pola transpiración.

2.2. A calor extrema non é un factor restritivo para o rendemento da RCP dos socorristas en comparación cun ambiente de temperatura neutra.

**Conclusións da Hipótese 3**

3.1. Hai un impacto fisiolóxico significativo relacionado co esforzo prolongado cando se usa EPI, polo tanto, é recomendable quitar os EPI, volver a hidratarse e descansar nun ambiente fresco para reducir a temperatura corporal e sentirse cómodo.

3.2. Cando os profesionais sanitarios usan EPI son capaces de realizar unha RCP prolongada de calidade comparable a cando a realizan con roupa normal, aínda que isto impliqueun estrés fisiolóxico considerable. A formación en RCP cun EPI é necesaria para que os socorristas comprendan esta circunstancia especial e tamén para mellorar a súa condición física

# 1. INTRODUCTION

# 1. INTRODUCTION

Out-of-hospital cardiac arrest (OHCA) is a global health problem, both in Europe and the United States (1), and it has reached worrying figures which currently make it the third leading cause of death in Europe (2). However, the true incidence on this continent is not fully known and it may be underestimated in certain countries due to culture or beliefs, as many bystanders simply may not call the emergency services when they witness a cardiac arrest (CA) (3).

In order to establish what the most relevant indicators for the study and treatment of cardiopulmonary arrest (CPA) are, the first Utstein recommendations (4) were published, which helped researchers and professionals to unify criteria by using the same data and definitions. In addition to better understanding the epidemiology of cardiac arrest, this system facilitates comparisons between the information systems of each country, thus allowing an improvement in the overall quality of care and in clinical research (3).

Although there are registries on OHCA, only 70% of European countries use the registry system. OHCA has an annual incidence in Europe between 67% and 170% per 100,000 inhabitants. The rate of resuscitation attempts performed by emergency service personnel is around 50-60% (between 19% and 97% per 100,000 inhabitants) and the ratio of attempts by lay personnel is between 13% and 83%, with an average of 58% (3).

The European Cardiac Arrest Registry project (EuReCa ONE) (1) was the first attempt to study the epidemiology of CPA at a European level, but data collection was limited to just one month. As a continuation of this project, EuReCa TWO (2) emerged in which the study period was extended to three months and the participation of more countries in order to better understand the role of first responders in the treatment of out-of-hospital CPA.

In CPA, care for the victim depends on the participation and response of the community, as they may act as the first responder, as well as health personnel. In order to obtain a greater optimization of the actions to be carried out in the initial treatment of an arrest, a series of steps was designed. These are made up of interconnected links, known as the "Chain of Survival" (5). Over time, this has been updated (6), and in some cases, for instance the American Heart Association (AHA), the original chain of survival has been modified. In a number of instances, it incorporates a fifth (7) or sixth (8) link. In other scenarios, such as the recommendation by González-Salvado et al. (9), in which they suggest adding a new link, cardiac rehabilitation, the traditional linear sequence changes into an interdependent circular one.

Following the chain of the European Resuscitation Council (ERC) (10), these links are:

1. Early recognition and request for help.

Recognizing the cardiac origin of chest pain and calling emergency services before the victim passes out allows medical services to arrive before cardiac arrest occurs, thus significantly increasing survival (11-14).

2. Early initiation of cardiopulmonary resuscitation (CPR).

Immediate initiation of CPR can double or quadruple survival from cardiac arrest (11,15–19).

3. Early defibrillation.

Administering cardiac defibrillation within 3-5 minutes of cardiac arrest can produce survival rates of up to 50-70%. Hence, public access to defibrillators is promoted (20-23).

4. Early advanced life support and standardized care after advanced resuscitation, with advanced airway management, the use of drugs or the management of the causes that brought about the CA if it was not reversed (24,25).

In order to standardize CPR maneuvers, the International Alliance of Councils on Resuscitation (ILCOR), the ERC and the AHA carry out evidence-seeking processes and periodically publish recommendations on basic life support (BLS) (8,26) both for lay personnel and health personnel.

The BLS algorithm published in the latest guidelines sets out the step-by-step instructions that should be provided (26) on how to recognize cardiac arrest, how to alert the emergency services, and how to provide high-quality chest compressions (i.e. performing them on a smooth, firm surface, starting as soon as possible, compressing the lower half of the sternum to a depth of at least 5 cm but not more than 6 cm, at a rate of 100/120 compressions per minute, allowing the chest to fully re-expand after each compression and minimizing interruptions). These compressions are the key component in CPR as an effective means of providing and/or maintaining vital organ perfusion in cardiac arrest. The effectiveness of compressions depends on the correct position of the hands, the depth, rate of compression, and the degree of re-expansion or recoil of the chest wall after each compression. In addition to compressions, the administration of ventilations is still recommended in resuscitation, maintaining the ratio of 30 compressions and 2 ventilations, with a volume between 500 and 600 ml. (26).

The circumstances in which CA can occur and when CPR is necessary are highly variable, and under certain conditions, BLS and advanced life support (ALS) interventions may require modifications in relation to the general recommendations for cardiopulmonary resuscitation. For this reason, the ERC (27,28) and the AHA (29) have included sections on CPR in special circumstances in their guides.

These specifications can be classified into three different sections: special causes, special environments and special patients (27,28).

The first part covers the treatment of potentially reversible causes of cardiac arrest, for which there is a specific treatment, and which must be identified or excluded during ALS, such as hypoxia, hyperthermia or hypovolemia.

The second section covers cardiac arrest in special settings where universal guidelines need to be modified due to specific causes of cardiac arrest. Examples of special environments include drowning situations, places with a specific altitude, incidents in rough terrain or in remote areas, sports settings and multiple casualty incidents.

The third part focuses on patients with specific conditions and those with certain long-term comorbidities where a modified approach and different treatment decisions may be necessary (e.g. asthma, obesity, and pregnancy etc.).

It is widely recognized that the scientific evidence to make recommendations in such circumstances is very scarce, so researchers should make an effort to provide evidence to support CPR guidelines in unusual conditions and extreme circumstances.

For this reason we have considered this doctoral thesis project in the form of thesis by compendium in which different special environments were investigated, where a person may have to perform cardiopulmonary resuscitation. Those environments are discussed below:

**High altitude CPR**

In recent years there have been great developments in mountain tourism and high-altitude physical-sports activities such as hiking, mountaineering and skiing, which include elderly participants and those with a higher risk of suffering a cardiovascular event (30,31).

Being at high altitude produces several physiological changes (32) including increased cardiac and respiratory workload, especially during exercise (33). Cardiopulmonary performance is affected above altitudes of 2,500-3,000m where arterial partial pressure of oxygen ($PaO_2$) is 50-65 mmHg while at sea level it is 98 mmHg (34,35). Hypoxia is the direct consequence of breathing hypoxic air and is the main driver of the deleterious clinical effects that occur at altitude. Above a 3,000m altitude, resting oxygen saturation is around 90% and decreases with increasing altitude (36,37). Furthermore, from a 3000m altitude, physiological changes (32) (i.e. increased heart rate and blood pressure, arrhythmias, and increased intracranial pressure, etc.) become more relevant because the physiological compensatory mechanisms are not able to counteract the effect of decreased oxygen saturation (38). The degree to which the changes occur depends on several factors such as ascent rate, degree of hypoxia, previous medical history, intensity of exercise, or previous level of acclimatization (39).

However, despite all the physiological changes that occur in rescuers and victims, as well as the decline in the quality of CPR performed at high altitude (33,40,41), the European Resuscitation Council Guidelines (27,28) on high-altitude resuscitation do not differ from standard CPR recommendations. This is even true after the publication of a systematic review of literature (32) in which recommendations on high-altitude CPR were established.

Prolonged cardiopulmonary resuscitation at high altitude could pose a significant physiological challenge to rescuers. Preliminary studies have shown that performing CPR at altitude caused a decrease in arterial blood oxygen saturation (SpO2), an increase in heart rate

(HR), and self-reported exertion (based on the Borg scale score) (40-43). This fact could negatively affect the rate and depth of chest compressions (40,41) and also decrease the number of effective compressions (33,40). However, no studies have been found that analyze the quality of ventilation in high-altitude conditions, so in this compendium doctoral thesis it was decided to analyze the effects of reducing the oxygen fraction on the quality of CPR and the physiological demands on rescuers.

**CPR at high ambient temperatures**

It is known that exposure to excessive heat can be more lethal than other climate-related meteorological phenomena, aggravating chronic diseases and also causing diseases directly related to heat (44). High temperatures during the summer season, a greater number of daylight hours (45,46) and vacations (47), all cause a major increase in the influx of people in aquatic spaces, which consequently leads to an increase in the rate of drowning (47).

The response to OHCA in these environments is usually carried out by lifeguards (professionals in charge of preventing, reacting and mitigating incidents in aquatic environments) (48).

Performing CPR at high temperatures can cause a decrease in the quality of cardiac compressions (49), generate fatigue in the rescuer which can increase over time, either due to the duration or the previous conditions in which said resuscitation has to be performed, such as after performing a water rescue (50-53). Likewise, this exhaustion generated by performing CPR, which is still an intense physical activity, can be increased by temperature-environmental variations that cause physiological changes in people, such as increased heart and respiratory rates, body temperature, blood pressure or dehydration (54-56) and psychological changes, such as anxiety (56).

If we take into account that neither the ERC (27,28) nor the AHA (29) contemplates the environmental temperature of high heat as a special circumstance, this thesis by compendium decided to study what the effects of high environmental temperature on the quality of CPR can be and what physiological changes it causes in the rescuer.

**CPR in patients with infectious diseases and risk of contagion (COVID 19 and others)**

The appearance and rapid spread of the disease caused by severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2), known as COVID-19 (57), has created serious challenges, not only for medicine, but also for society in general, given the high degree of infectivity of the virus and the declaration of a pandemic in 2020.

Although many people have been exposed to infection, health professionals are a high risk group for contracting the disease due to the techniques and procedures they must perform on patients with suspected or confirmed COVID-19 infection (58). In just a few months (May 2020), more than 30,000 Spanish health professionals were reported infected (59).

Among the procedures that need to be performed, cardiopulmonary resuscitation entails an additional risk for such professionals. This is because the administration of chest compressions, positive pressure ventilation or the establishment of an advanced airway involve the inevitable generation of aerosols. This is a source of possible transmission of the virus, depending on how close the rescuers are to each other and to the patient when they have to perform compressions and ventilations (58).

In this regard, the guidelines published by the European Resuscitation Council (ERC) (60) and the American Heart Association (AHA) (58) on CPR recommendations and COVID-19 disease indicate, without a doubt, that the health professional must protect himself with PPE when performing CPR or other procedures that involve contact with patients. In order to achieve this, recommendations were made on what devices or materials should be used. The ERC (60) published the minimum of material that should be used in the case of droplet infection (i.e. gloves, a short-sleeved apron, a fluid-resistant surgical mask, and protection for the eyes and face) or by aerosols (gloves, a gown or long-sleeved suit, a FFP3 mask, a FFP2 mask if the former is not available, and eye or facial protection goggles).

Several strategies to minimize the risk of contagion, in addition to the use of personal protective equipment (PPE), include limiting the number of personnel involved in resuscitation, promoting the use of mechanical devices for performing compressions or using a high-efficiency particulate air (HEPA) filter when performing ventilations with a bag valve mask (BVM) (58).

A recent systematic review (61) suggests that the use of PPE may affect the rate and depth of cardiac compressions. However, other research (62-64) does not reveal significant differences in the quality of CPR depending on whether PPE is worn or not, thus reaffirming the message of various guidelines in which the use of PPE is recommended when performing CPR (58,56), since this equipment does not significantly reduce quality compared to when not wearing it.

As this situation is a special circumstance, the ERC suggested making some changes in relation to the usual CPR protocol (60):

- Do not open the airway to check if the victim is breathing.
- Placing a mask or cloth/towel over the mouth and nose before performing compressions, when resuscitation is performed by lay personnel.
- Performing CPR only via compressions.
- Washing hands as soon as possible with soap and water or an alcohol-based gel.
- Using PPE when performing cardiac compressions and ventilations.
- Sealing of the self-inflating bag mask by one of the rescuers while the other one performs chest compressions and ventilations.
- Use of a high-efficiency particulate air (HEPA) filter or a heat and moisture exchanging (HME) filter between the self-inflating bag and the mask to minimize the risk of spreading the virus.

Furthermore, the use of PPE has been shown to induce physiological (65) and psychological changes in rescuers (62,66,67) and changes in the performance of certain advanced procedures (66,68), such as orotracheal intubation (69) or cannulation of a venous access (70).

Given the diversity of published conclusions on the differences in the quality of CPR when using PPE (62,63,66,67,71,72), this thesis analyzes the physiological consequences of long-term resuscitation with PPE.

# 2. HYPOTHESIS & OBJETIVES

# 2. HYPOTHESIS & OBJETIVES

Our hypotheses and objectives are intended to expand the scientific evidence related to CPR performed in special environments as well as the physiological effects they cause in rescuers.

Performing high-quality resuscitation remains a fundamental premise in out-of-hospital cardiac arrest care, and performing CPR under particular conditions may differ from "ideal conditions" and from rescue performed in a controlled environment.

There is limited scientific evidence relating to CPR and the physiological changes produced in resuscitated patients in certain peculiar environments such as ones involving extreme heat or high altitude. Another factor to consider is the recent and ongoing COVID-19 pandemic and the thermal discomfort caused by wearing PPE. The following hypotheses and objectives have been formulated through the research studies presented in this doctoral thesis:

## 2.1. HYPOTHESIS

This thesis project has had the following working hypotheses:

**Hypothesis 1.** CPR in a simulated hypoxic environment at high altitude results in increased physiological demands and higher perceived fatigue than resuscitation at sea level.

**Hypothesis 2.** Performing simulated CPR in hot environmental conditions generates physiological stress with increased fatigue and loss of body fluids in the rescuer, as well as decreased quality of chest compressions.

**Hypothesis 3.** Performing prolonged CPR with personal protective equipment will lead to greater fatigue and worse thermal comfort and CPR quality compared to not wearing PPE.

## 2.2. OBJECTIVES

In order to try to confirm or refute the previous hypotheses, the studies included in this doctoral thesis had the following objectives:

**Generic Objective 1.** Compare the physiological impact on rescuers of performing prolonged CPR at 3250m above sea level.

Specific objective 1.1. To determine the effect of reduced inspiratory fraction of oxygen ($O_2$ 14%, equivalent to 3250 m) on heart rate, oxygen saturation, and perceived fatigue of rescuers compared to sea level.

Specific objective 1.2. To analyze CPR quality when performed in a simulated environment of a 3250m altitude compared to when performed at sea level.

**Generic objective 2.** To study the physiological stress generated in rescuers by performing prolonged CPR at an ambient temperature of 37ºC.

Specific objective 2.1. To analyze the influence of thermal stress on metabolic consumption, perceived fatigue and dehydration of rescuers when performing CPR at a very high ambient temperature (37ºC).

Specific objective 2.2. To examine CPR quality when performed at 37ºC versus in a neutral environment of 25ºC.

**Generic objective 3.** To analyze PPE impact on the physiological demands of the rescuer and quality of CPR during a prolonged and simulated CPR.

Specific objective 3.1. To analyze heart rate, temperature, body fluid loss, and thermal comfort when wearing PPE while performing simulated CPR.

Specific objective 3.2. To assess the quality of simulated CPR performed with personal protective equipment consisting of protective overalls, a face shield, a KN95 mask, a surgical mask, nitrile gloves, and footmuffs, compared to when performed using normal rescue clothing.

# 3. METHODOLOGY

# 3. METHODOLOGY

## 3.1. General Methodological Description

This doctoral thesis is composed of 3 articles, *Physiological demands of quality cardiopulmonary resuscitation performed at a simulated height of 3250 meters* (73), *Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation*, and *Randomized simulation study (74) and Analysis of Physiological Response during Cardiopulmonary Resuscitation with Personal Protective Equipment: A Randomized Crossover Study* (64), all of which have followed a quasi-experimental methodology. These are quantitative, randomized and cross-sectional studies. Data analysis was performed with SPSS statistical software (IBM Corp., Chicago, IL, USA). The Shapiro Wilk test was used to study normality. Studies present mean, standard deviation, confidence intervals (95%), frequencies, and effect size. Pairwise comparisons were performed with parametric tests (T-Student and Anova) and non-parametric tests (Wilcoxon and Friedman). In addition, a significance level of $p < 0.05$ was established for all analyses.

## 3.2. Samples

The participants who voluntarily collaborated in our investigations were health professionals and aquatic lifeguards. All of them gave written authorization for their participation in the investigations. They were 18 years of age or older, had no disease or physical disability, and were up to date on CPR according to the ERC Resuscitation Guidelines in effect at the time of the investigation. Only one subject was excluded from one of the investigations (73) due to technical failures in the pulse oximeter at the time of the test.

## 3.3. STUDY VARIABLES

The dependent variables are grouped, generically, in the following blocks:

1) CPR quality was recorded on the ResusciAnne manikin with SkillReporter QCPR software (Laerdal Medical, Stavanger, Norway). Partial variables of chest compressions (CC) were analyzed: Rhythm, Depth, Chest Reexpansion and hand position in addition to the total number of compressions.

   The CPR recording parameters were programmed under the 2015 European Resuscitation Council Guidelines (ERCG2015) (10).

   Ventilations (V) with effective air intake, adequate volume, insufficient volume, and total V were analyzed. They were administered with a bag valve mask (BVM) and a number 5 Ambu® Mark IV adult mask (Ballerup, Denmark).

2) Physiological parameters: Heart rate, measured with a Polar HR Bluetooth sensor H7 heart rate monitor (Kempele, Finland).

Saturation and oxygen consumption, recorded with a pulse oximeter (Oximeter DF8 W/USB 3018L XPOD, Ear clip SNRS 8000Q2; Nonin Medical, Plymouth, USA) and by indirect calorimetry (CortexMetalyzer 3B, Leipzig, Germany). Body fluid loss, recording weight before and after each test, which was recorded with high-precision multifrequency segmented scale (Tanita Corporation, Tokyo). Body temperature was measured with the Type FT-65 Beurer GmbH (Ulm, Germany) device.

3) Subjective perception: Rating of perceived exertion (RPE) according to the Borg scale (75,76). The measurement of thermal comfort, thermal sensation (77) and the sensation of sweating (78) were recorded with visual analogue scales.

## 3.4. Ethical Aspects

All the work has respected the ethical principles of the Declaration of Helsinki and has been authorized by the ethics committee of the Faculty of Education and Sports Sciences of the University of Vigo. The data was anonymized and complied with current legislation on data protection.

# 4. RESULTS (PUBLICATIONS)

# 4. RESULTS (PUBLICATIONS)

## 4.1. ARTICLE 1. PHYSIOLOGICAL DEMANDS OF QUALITY CARDIOPULMONARY RESUSCITATION PERFORMED AT SIMULATED 3250 METERS HIGH.

ELSEVIER

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Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high

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Figure 1. Screenshot of the article identification, available at https://www.sciencedirect.com/science/article/pii/S0735675719308551

### 4.1.1. Evidence of Quality

This article published in the journal *American Journal of Emergency Medicine* has an impact factor of **1.911** in the Journal citation Report (JCR - 2019).

- Category: Science Edition - EMERGENCY MEDICINE
- Indexed in JCR Quartile 2 (Q2)

Full citation of the manuscript

Carballo-Fazanes A, Barcala-Furelos R, Eiroa-Bermúdez J, **Fernández-Méndez M**, Abelairas-Gómez C, Martínez-Isasi S, et al. Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high. A pilot study. Am J Emerg Med. 2020 Dec;38(12):2580-2585. doi: 10.1016/j.ajem.2019.12.048. Epub 2019 Dec 24. PMID: 31911060.

Contributions to the publication:

Development of the idea. Data collection processing. Review of the manuscript.

Citations obtained until June 2022:

4.1.1.1. Barcala-Furelos R, **Fernández-Méndez M**, Cano-Noguera F, Otero-Agra M, Morán-Navarro R, Martínez-Isasi S. Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized

simulation study. Am J Emerg Med [Internet]. 2020;38(10):2019–27

4.1.1.2. Olejniczak R. Effectiveness of cardiopulmonary resuscitation depending on lifeguard's level of exhaustion. Cent Eur J Sport Sci Med [Internet]. 2020;30:57–70

4.1.1.3. **Fernández-Méndez M**, Otero-Agra M, Fernández-Méndez F, Martínez-Isasi S, Santos-Folgar M, Barcala-Furelos R, et al. Analysis of physiological response during cardiopulmonary resuscitation with personal protective equipment: A randomized crossover study. Int J Environ Res Public Health [Internet]. 2021;18(13):7093

4.1.1.4. Clebone A, Reis K, Tung A, OConnor M, Ruskin KJ. Chest compression duration may be improved when rescuers breathe supplemental oxygen. Aerosp Med Hum Perform [Internet]. 2020;91(12):918–22.

### 4.1.2. Article abstract

**Objective:** Lifeguard teams carry out theirwork in extremely hot conditions inmany parts of theworld. The aim of this studywas to analyze the impact of high temperatures on physiological parameters during cardiopulmonary resuscitation (CPR).

**Methods:** randomized quasi-experimental cross-over design was used to test physiological lifesaving demands (50 min acclimatization +10 min CPR) in two different thermal environments: Thermo-neutral environment (25 °C) vs Hyperthermic environment (37 °C).

**Results:** The data obtained from 21 lifeguards were included, this covers a total of 420 min of resuscitation. The CPR performance was constantly maintained during the 10 min. The Oxygen uptake (VO 2) ranged from 17 to 18 ml/min/kg for chest compressions (CC) and between 13 and 14 ml/min/kg for ventilations (V) at both 25 °C and 37 °C, with no significant difference between environments ($p > 0.05$). The percentage of maximum heart rate (%HR max) increased between 7% and 8% at 37 °C ($p < 0.001$), ranging between 75% and 82% of HR max. The loss of body fluids (LBF) was higher in the hyperthermic environment; LBF: (37 °C: 400 ± 187 g vs 25 °C: 148±81 g, $p < 0.001$). Body temperaturewas 1 °C higher at the end of the test ($p < 0.001$). The perceived fatigue (RPE) increased by 37° an average of 2 points on a scale of 10 ($p = 0.001$).

**Conclusion:** Extreme heat is not a limiting factor in CPR performance with two lifeguards. Metabolic consumption is sustained, with an increase in CC, so V can serve as active rest. Nevertheless, resuscitation at 37 °C results in a higher HR, is more exhausting and causes significant loss of fluids due to sweating.

## 4.2. Article 2. Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study

ELSEVIER

The American Journal of Emergency Medicine

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# Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study

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Figure 2. Screenshot of the article identification, available at https://www.sciencedirect.com/science/article/pii/S0735675720305301

### 4.2.1. Evidence of Quality

This article published in the journal *American Journal of Emergency Medicine* has an impact factor of **2.469** in the Journal citation Report (JCR - 2020).

- Category: Science Edition - EMERGENCY MEDICINE
- Indexed in JCR Quartile 2 (Q2)

Full citation of the manuscript

Barcala-Furelos R, **Fernández-Méndez M,** Cano-Noguera F, Otero-Agra M, Morán-Navarro R, Martínez-Isasi S. Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study. Am J Emerg Med. 2020 Oct;38(10):2019-2027. doi: 10.1016/j.ajem.2020.06.042. Epub 2020 Jun 26. PMID: 33142168.

Contributions to the publication:

Co-conception of the idea. Data collection processing. Methodology, Investigation, Writing - original draft, Supervision, Project administration.

Citations obtained until June 2022:

4.2.1.1. Martin-Conty JL, Polonio-López B, Maestre-Miquel C, Mohedano-Moriano A, Durantez-Fernández C, Mordillo-Mateos L, et al. Physiological response of quality cardiopulmonary resuscitation, crossover trial on mannequin in extreme temperature conditions. Int J Environ Res Public Health [Internet]. 2020;17(16):5835.

4.2.1.2. Abraldes JA, Fernandes RJ, Morán-Navarro R. Previous intensive running or swimming negatively affects CPR effectiveness. Int J Environ Res Public Health [Internet]. 2021;18(18):9843

4.2.1.3. **Fernández-Méndez M**, Otero-Agra M, Fernández-Méndez F, Martínez-Isasi S, Santos-Folgar M, Barcala-Furelos R, et al. Analysis of physiological response during cardiopulmonary resuscitation with personal protective equipment: A randomized crossover study. Int J Environ Res Public Health [Internet]. 2021;18(13):7093

4.2.1.4. Santos-Folgar M, Fernández-Méndez F, Otero-Agra M, Abelairas-Gómez C, Murciano M, Rodríguez-Núñez A, et al. Infant cardiopulmonary resuscitation quality while walking fast: A simulation study: A simulation study. Pediatr Emerg Care [Internet]. 2022;38(2):e973–7

4.2.1.5. Barcala Furelos RJ. Skills assessment in drowning incidents by rescuers. 2021.

### 4.2.2. Article abstract

**Objective:** Lifeguard teams carry out theirwork in extremely hot conditions inmany parts of theworld. The aimof this studywas to analyze the impact of high temperatures on physiological parameters during cardiopulmonary resuscitation (CPR).

**Methods:** A randomized quasi-experimental cross-over design was used to test physiological lifesaving demands (50 min acclimatization +10 min CPR) in two different thermal environments: Thermo-neutral environment (25 °C) vs Hyperthermic environment (37 °C).

**Results:** The data obtained from 21 lifeguards were included, this covers a total of 420 min of resuscitation. The CPR performance was constantly maintained during the 10 min. The Oxygen uptake (VO 2) ranged from 17 to 18 ml/min/kg for chest compressions (CC) and between 13 and 14 ml/min/kg for ventilations (V) at both 25 °C and 37 °C, with no significant difference between environments ($p > 0.05$). The percentage of maximum heart rate (%HR max) increased between 7% and 8% at 37 °C ($p < 0.001$), ranging between 75% and 82% of HR max. The loss of body fluids (LBF) was higher in the hyperthermic environment; LBF: (37 °C: 400 ± 187 g vs 25 °C: 148±81 g, $p < 0.001$). Body temperaturewas 1 °C higher at the end of the test ($p < 0.001$). The perceived fatigue (RPE) increased by 37° an average of 2 points on a scale of 10 ($p = 0.001$).

**Conclusions:** Extreme heat is not a limiting factor in CPR performance with two lifeguards. Metabolic consumption is sustained, with an increase in CC, so V can serve as active rest. Nevertheless, resuscitation at 37 °C results in a higher HR, is more exhausting and causes significant loss of fluids due to sweating.

## 4.3. Article 3. Analysis of Physiological Response during Cardiopulmonary Resuscitation with Personal Protective Equipment: A Randomized Crossover Study

Open Access | Article

### Analysis of Physiological Response during Cardiopulmonary Resuscitation with Personal Protective Equipment: A Randomized Crossover Study

by María Fernández-Méndez [1,2,3,4], Martín Otero-Agra [2,3], Felipe Fernández-Méndez [1,2,3,4,*], Santiago Martínez-Isasi [1,4,5], Myriam Santos-Folgar [2,3,6], Roberto Barcala-Furelos [1,2,4] and Antonio Rodríguez-Núñez [1,4,5,7]

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Figure 3. Screenshot of the article identification, available at https://www.mdpi.com/1660-4601/18/13/7093

### 4.3.1. Evidence of Quality

This article published in the journal *International Journal of Environmental Research and Public Health* has an impact factor of **3.390** in the Journal citation Report (JCR - 2021).

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<u>Full citation of the manuscript</u>

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<u>Contributions to the publication</u>

Leadership in writing the manuscript (first author). Development of the idea. Data collection processing. Preparation of tables. Project administration. Elaboration of the final version of the manuscript and the revised version.

<u>Citations obtained until June 2022:</u>

4.3.1.1. Rojo-Rojo A, Pujalte-Jesús MJ, Hernández-Sánchez E, Melendreras-Ruiz R, García-Méndez JA, Muñoz-Rubio GM,

et al. Risk of dehydration due to sweating while wearing personal 2 protective equipment in COVID-19 clinical care: A pilot study. Healthcare (Basel) [Internet]. 2022;10(2):267

### 4.3.2. Article abstract

The use of personal protective equipment (PPE) is required for the self-protection of healthcare workers during cardiopulmonary resuscitation (CPR) in patients at risk of aerosol transmission of infectious agents. The aim of this study was to analyze the impact of personal protective equipment on physiological parameters during CPR. A randomized, quasi-experimental, crossover design was used. The study was carried out in a training and simulation emergency box and the total sample consisted of 20 healthcare professionals. Two CPR tests were compared with the recommended sequence of 30 chest compressions and 2 ventilations. The duration of each test was 20 min. One of the CPR tests was carried out without using any PPE (CPR_control), i.e., performed with the usual clothing of each rescuer. The other test was carried out using a CPR test with PPE (i.e., CPR_PPE). The main variables of interest were: CPR quality, compressions, ventilations, maximum heart rate, body fluid loss, body temperature, perceived exertion index, comfort, thermal sensation and sweating. The quality of the CPR was similar in both tests. The maximum heart rate was higher in the active intervals (compressions + bag-valve-mask) of the test with PPE. CPR_PPE meant an increase in the perceived effort, temperature at the start of the test, thermal sensation, thermal comfort and sweating, as opposed to CPR performed with usual clothing. Performing prolonged resuscitation

with PPE did not influence CPR quality, but caused significant physiological demands. Rescuers were more fatigued, sweated more and their thermal comfort was worse. These results suggest that physical preparation should be taken into account when using PPE and protocols for physiological recovery after use should also be established.

# 5. DISCUSSION

# 5. DISCUSSION

The main objectives of this thesis were to provide new evidences about CPR in special circumstances and for this purpose, the physiological impact that performing prolonged CPR in different special and specials environments has on rescuers was analyzed and compared with the CPR quality when performed in a standard circumstance (versus a special circumstance). The studies carried out represent relevant innovation in this field of applied research because no study results on this subject had been published until now despite similar hypotheses and objectives being proposed in the past.

In brief, the main findings of the researchs were the following:

1. Performing CPR in special circumstances has effects on motor skills and affects physiological levels with an increase in cardiac output, perceived fatigue and a significant loss of body fluid.

2. CPR quality remains stable in all three special settings when performed by well-trained subjects and when compared to a standard setting.

## 5.1. PHYSIOLOGICAL RESPONSE IN SPECIAL CIRCUMSTANCES.

Physiological changes are relevant in any human activity, especially when physical activity is carried out and is mediated by unusual environmental alterations. Bearing in mind that performing CPR is a demanding technique and generates fatigue (79–83) which increases over time and also has a negative influence on the quality of chest compressions and ventilations, we studied to what extent the environment in which the CPR was performed influenced participant fatigue.

Similar results have been obtained in the three scenarios compared to resuscitation performed in the control situation. In the high-altitude simulation, although rescuers achieved good CPR quality, understanding CPR quality as being greater than 70% (84), they had a higher perception of fatigue at altitude (rated as hard) than at sea level conditions (rated as moderate) (76). Similar results were seen in similar studies (40,42,43,85). It was confirmed that the levels of hypoxia did not influence the rescuers when performing good-quality CPR, but they did report being more tired than if it had been performed at normoxic levels.

There is an association between temperature and increased HR (86), and in turn between increased HR and a higher rate of perceived exertion (RPE) (87) and finally between dehydration and early fatigue due to heat (86). This physiological response is consistent with the highest RPE recorded by rescuers at 37°C (74). Following the values of Foster et al. (76), in the hyper thermic environment, the rescuers perceived CPR as "hard", like in the altitude scenario, while in the thermoneutral environment, they perceived it as "somewhat hard". RPE using perceived stress scales is a widely used tool with high validity to quantify exercise intensity (87) and it is commonly used in resuscitation studies (55,72–74,88–90). The same values as performing CPR in high heat (37ºC) were those we obtained when performing 20 minutes of CPR with PPE on. The increase in RPE is in agreement with other studies, in which perceived fatigue shows higher values when PPE is worn than when it is not (62,66,67). This could be related to the increase in body temperature and the thermal discomfort produced in this environment (64).

Taking into account the previous premise about the relationship between increased HR and higher RPE (87), it could be inferred that there would be alterations in HR in the special environments designed for this study. Previous research has shown that HR increases at altitude, both at rest and during physical exercise (33,40,42). In contrast, in our tests, HR hardly increased in the simulation at a 3250 m altitude compared to the baseline obtained in the simulation at sea level. This may be related to the fact that the previous investigations were carried out in real ascent conditions and therefore the exposure time in high altitude conditions was longer. On the other hand, in a study in which a hypobaric chamber was used to create a hypoxic environment in which subjects spent 1 hour in high altitude conditions, Sato et al. (43) observed a higher HR inside the hypobaric chamber compared to outside it, just before and after CPR, but not during the period of chest compressions. It was observed that HR increased significantly during compression cycles compared to ventilation cycles, which could be considered as periods of active rest. But this fact occurs in a similar way in the scenarios of this thesis, altitude and sea level, so a longer test time in the high altitude simulation (e.g. an acclimatization period greater than 10 minutes) or a real ascent could produce changes in this variable. When changing environment, the effect of environmental temperature (high heat in our case), meant higher HR values were recorded at 37°C (74). There is an association between temperature and increased HR (86), and in turn between increased HR and higher RPE (87), so our results confirm this theory. In addition, as in high altitude environments (73), higher values have been obtained in the moments of compressions compared to the ventilation cycles in which the rescuer takes advantage in order to recover. The results of these first two studies (73,74) agree with the results obtained in the cardiac compression and ventilation cycles when PPE was used (64) since the HR is higher than in the ventilation cycles, and in the case of the PPE, it corresponds to the phase of fixing the mask on the victim's face, as the CPR protocol has been modified in times of COVID and ventilation is carried out with a self-inflating bag (91). Perhaps the application of protocols with more than one rescuer in which recovery periods can be carried out is the main key to guaranteeing quality resuscitation and the safety of healthcare personnel.

Along with HR, the levels of oxygen saturation (SpO2) reached by the rescuers in this research under hypoxic conditions has been studied. Participants experienced a significant and statistically significant decrease in SpO2, from 99% in sea level conditions to a mean value of 90% in a simulated altitude condition. However, SpO2 practically did not change during cycles of compression (intense effort) and ventilation (no effort). This is consistent with previous studies; Narahara et al. (42) found that SpO2 was significantly lower after an ascent to 2700m (mean SpO2 = 88 ± 4%) and 3700m (mean SpO2 = 80 ± 7%) compared to sea level (mean SpO2 = 98 ± 1%). Similar results were obtained by Wang et al. (40), who found that SpO2 dropped significantly from 98.6 ± 1% at sea level to 88.5 ± 3% after climbing to 3100 m. In both studies, these values were practically the same after performing CPR for 5 minutes under these conditions. High-altitude rescues should be considered physically demanding for rescuers. Therefore, when carrying out rescue activities, they have to take into account the factors involved, such as the reduction of the oxygen content in the air, the low temperature, the difficulties of access to hospitals and the lack of transport options for victims, as well as the limitations of rescue resources. In some conditions, rescuers should consider the use of oxygen delivery devices as well as mechanical compression devices in order to reduce strain and fatigue and maintain quality CPR over time (32,33,40,42). In addition, CPR with a protocol of chest compressions and ventilations would allow rest time during the ventilation cycles (43) so that the rescuer can recover.

When changing environments and considering a high ambient temperature, neither resuscitation duration nor thermovariability affected CPR performance in this investigation (74). An explanation for this phenomenon could be related to the maximum volume of oxygen that the body can process during individual exercise (VO2max) of each rescuer. Rescuers are physically trained professionals (92) and their VO2max can reach 53/55ml/min/kg (92–94), implying that the metabolic demand during CPR may be relatively low (95). The mean VO2 consumption during the test was 15 ml/min/kg (it was 17 for the cycles of cardiac compressions and 13 for the cycles of ventilations) with little variation in each cycle. These data coincide with the study by Sousa et al. (88) in which the rescuers in the basal physiological state reached values of around 16 ml/min/kg without great variations during a period of 4 min. Using these values as a reference, theoretically, rescuers can resuscitate at less than 30% of their VO2max, which is not the case with other rescuer profiles who, with less physically demanding protocols, require a higher percentage of VO2max to perform the same activity. Pierce et al. (95) found in a group of sedentary individuals that oxygen consumption was 26 mL/min/kg (54% of their VO2max) for 10 min. and in the study by Elvira et al. (50), the healthcare personnel's VO2 during a 16-minute CPR test was 14 mL/min/kg (45% of their VO2max).

Analysis of VO2 has been performed in several CPR studies (50,88,95–97), however, to our knowledge, this is the first study ever with rescuers performing team resuscitation that disaggregates the metabolic phases of compressions and ventilations. This is relevant because it has been suggested that compressions are the part with the greatest physiological demand during CPR (53,97,98), although the evidence related to this idea is limited (99).

VO2 was significantly higher during compressions and HR (%) was as well, with a higher rate at 37°C. Two ideas converge here: 1) Compressions are the part of CPR that produces the greatest muscle mobilization (100) and, therefore, the greatest associated muscle fatigue (95). The metabolic cost of compressions has metabolic equivalents with moderate-intensity physical activities such as recreational cycling or swimming (98). 2) The decrease in VO2 and HR (%) during ventilation may be due to the fact that this phase implies an active rest period (99), although Hong et al. (99) found a continuous increase and higher HR values during the ventilation phase for 10 min, possibly because their study was performed with a single rescuer while ours was performed by a team of two.

During exercise, numerous physiological heat loss mechanisms are activated to prevent an excessive rise in core temperature, but in hot and humid environments this can challenge body thermoregulation (101). When the air temperature exceeds 36°C, the human body gains heat by radiation and convection, so the thermoregulatory mechanism will consist of evaporation (102). In harsh environments above 35°C, physical activity can cause losses of up to 1.5 L per hour (86,103). Our results showed a weight loss of 400g in 1 hour, after a 50 min acclimatization period and 10 min of exercise (74). Although CPR could be a low-impact activity for trained rescuers, prolonged low-intensity exercise causes increased body temperature and HR (86). VO2 and HRmax suggest that CPR is an aerobic activity, and the literature shows that performance deficits in aerobic activities occur with 3% total body water dehydration or 2% body mass index loss (BMI) (104). Longer resuscitation time, higher temperature, or a state of dehydration may be limiting factors in maintaining CPR performance.

Performing CPR while wearing PPE causes a rise in body temperature in rescuers wearing it. The results obtained in our research (64) were similar to those obtained in a scenario at 37ºC ambient temperature (74). To control this temperature rise and with the activation of the thermoregulatory system, we obtained greater fluid loss when our rescuers performed PPE CPR (after 50 min of acclimatization and 20 min of CPR). In our study conducted in the hot environment, higher body fluid losses were also obtained in the extreme temperature scenario (with statistically significant losses), although, in their case, these values are 10 times higher than those obtained when using PPE (74). Taking into account that the performance deficit in aerobic activities occurs with the dehydration of 3% of body water or a loss of 2% of the body mass index (104), a longer resuscitation time, a longer period of acclimatization, previous dehydration or a higher temperature could all be limiting factors in maintaining the performance of cardiopulmonary resuscitation (74). During exercise in the heat, sweat production often exceeds water intake, hence the body water deficit (103). It would therefore be advisable for healthcare professionals and first responders who have to perform CPR while wearing PPE to remove the PPE after performing CPR and drink fluids in a room at room temperature so as to rehydrate and lower their body temperature in order to continue their work in proper conditions.

The aforementioned increase in fatigue when performing CPR could be related to the increase in body temperature (86) and thermal comfort (105). Thermal sensation and thermal comfort can be modified by skin temperature, in such a way that when exercise is performed in warm and moderate environmental conditions, thermal discomfort is greater in warm conditions (105). In addition, thermal comfort during exercise can be modulated by skin moisture, as in the case of exercising in the heat and profuse sweating, and it has been determined that skin temperature is not particularly relevant in determining thermal comfort due to the evaporative cooling of sweat. Sweating does not directly reduce thermal comfort, so its accumulation on the skin contributes to thermal discomfort (105).

Even so, when performing CPR with PPE (64), the participants in our research reported being "uncomfortable" and "wet or very wet" (78) when they finished the test wearing the PPE, which is related to the loss of body fluid that they suffered. This is because thermal comfort during exercise in hot environments is strongly influenced by clothing choice (106). Such a circumstance reinforces the idea of removing PPE after resuscitation and recovering until dry and comfortable in order to return to work safely.

## 5.2. CPR QUALITY IN SPECIAL CIRCUMSTANCES.

One of the hypotheses of this compendium thesis was that performing CPR in these environments would decrease CPR quality. However, after the investigations were carried out, no significant differences were obtained in any of the three cases. CPR is considered a physically demanding exercise which rapidly fatigues the rescuer. This fatigue increases over time and has a negative influence on the quality of chest compressions and ventilations (79–83). Consequently, compression or ventilation changes between rescuers every 2 minutes are recommended (107,108) and our three studies were carried out following these indications.

Improving resuscitation skills in special circumstances is both a goal and a challenge for CPR providers. One of these special environmental conditions is the high altitude scenario (27,28).

One of our studies (73) has looked at how reducing the oxygen fraction from 21% to 14% under laboratory altitude conditions might affect CPR quality and influence the physiological demands on competent rescuers. In this investigation, the only significant change in performance during higher altitude CPR was a decrease in the percentage of ventilations within the recommended tidal volume range (500–600 mL (27)). Considering that self-inflating bag ventilation is a technical and not a physical task, we can speculate that hypoxemia could somehow affect the fine motor skills of the rescuers. Previous research has reported that cognitive functions are impaired after exposure to hypoxic conditions at high altitude (31,109–113). In our tests, excessive volume ventilations (which would lead to hyperventilation in eventual real cases) were more frequent than insufficient ventilations (which would lead to hypoventilation). In any case, both situations would worsen resuscitation outcomes, as has been reported in previous experimental and clinical studies (114–117). On the other hand, when quality variables of chest compressions were analyzed, participants were able to perform the skills with similar quality while breathing hypoxic and normoxic air.

Continuing along the lines studied, we have incorporated a scenario that we consider to be a special circumstance but which is not currently included in the ERC or AHA guidelines (8,27,28), extreme environmental heat, and there is also a direct relationship between drowning and high ambient temperature (47). In 2015, a protocol for CPR in drowning cases was published for the first time in the ERCGR2015 European Resuscitation Council Guidelines (27). The inclusion of a specific protocol for drowning cases was justified by the high incidence of this circumstance (118) and the particularity of its pathophysiology and treatment (119–122).

Performing long-term CPR at 37ºC by rescuers did not show significant differences when compared to CPR performed at 25ºC (74), although it did obtain a significantly lower percentage of effective ventilations in the test in hot conditions. The results obtained in our study differ from the research by Martín-Conty et al. (49), where the quality of compressions worsens when performing CPR at 41ºC. This difference may be due to the fact that their study was carried out at a higher temperature than ours, or that it was carried out by nursing students or that the resuscitations were carried out individually.

Another special scenario was the one that emerged as a result of the COVID-19 pandemic. The use of PPE for the protection of healthcare personnel led us to readapt our protocols and procedures to ensure greater protection and minimize the spread of the virus.

A systematic review found that the use of PPE reduces the quality of compressions compared to CPR in which participants did not wear PPE (61). However, these studies have been performed in single-rescuer situations, without the possibility of rest periods, and in resuscitations of short duration (2-4 minutes) (66,67,72). Due to the decreased quality of CPR evidenced in their systematic review, Sahu et al. recommend finding ways to improve CPR without compromising caregiver safety (61), but only one of those studies used the 30:2 protocol (66). On the other hand, Kienbacher et al. conducted a study with a 12-minute 30:2 protocol performed in pairs, changing roles every 2 minutes. This study did not result in lower CPR quality when PPE was used compared to no PPE (62). This also happens in the study by Rauch et al. (63) in which they also found no significant differences in the quality of CPR when wearing or not wearing PPE. This study also analyzes long resuscitations, of 20 minutes, with a 30:2 protocol, although they only make the comparative study of compressions. Our study confirms the message of these authors (62,63) by providing evidence of long duration resuscitations and, in addition, analyzing ventilations in addition to compressions. The absence of differences in CPR quality when using PPE compared to not using it reinforces the message that health professionals should protect themselves with PPE in risk situations since the quality of care is not negatively affected

## 5.3. PRACTICAL IMPLICATIONS

The results of the studies included in this doctoral thesis can help rescuers understand what physiological effect awaits them when performing CPR at a high altitude, in a hot environment or if they must wear PPE. The main practical recommendations are as follows:

- It is necessary to consider specific adaptive training programs for rescuers who perform or will perform their duties in special environments.

- Hypoxia generated at high altitude has effects on motor skills, so rescuers should practice techniques in this circumstance, emphasizing the use of the Bag-Valve-Mask.

- Performing CPR in these environments generates more fatigue than when performed in a standard environment, so it would be convenient for the personnel in charge of performing resuscitations to be trained so that the role of each rescuer can be managed according to their physical capacity.

- The heat and the use of personal protective equipment generates dehydration and an increase in body temperature, so after CPR in these circumstances, it is recommended that recovery be carried out in an area at room temperature with rehydration so as to be able to continue the working day in a suitable condition.

## 5.4. LIMITATIONS

In general, the main limitation of these three quasi-experimental studies is that they are simulated situations, with relatively small convenience samples.

In our investigation at altitude (73), the fraction of inspired oxygen at 3250m altitude was simulated, but other conditions which could influence the results such as humidity, solar radiation or temperature were not taken into account. In addition, the participants only spent 20 minutes in hypoxic conditions, which could have interfered with CPR performance.

In our second investigation, when performing CPR at a high ambient temperature (74), the participants wore a mask during the test, which could have reduced their comfort when applying resuscitation techniques. In addition, the VO2max of each participant was not calculated, so we cannot reliably know their status at the time of the investigation, although they were all frequently trained lifeguards.

When we carried out the third investigation (64) due to the personal protection measures established during the pandemic, the participants had to wear a surgical mask during the controlled CPR test, which could have reduced comfort when performing the resuscitation maneuvers.

These are three repeatable pilot studies that can generate greater knowledge if they are further studied with other populations, other resuscitations and/or acclimatization or rest times. They are studies carried out using mannequins which could have different results if they are carried out on real patients (or even with animals), although it would certainly be a very difficult sample to obtain.

# 6. CONCLUSIONS

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# 6. CONCLUSIONS

The studies included in this group doctoral thesis reached the following conclusions:

### CONCLUSIONS ACCORDING TO HYPOTHESIS 1

1.1. The hypoxia generated at high altitude has effects on motor skills, so rescuers should practice techniques in this circumstance, emphasizing the use of the Bag-Valve-Mask.

1.2. Trained rescuers are able to perform good quality CPR under simulated hypoxic conditions (14% FiO2), but at the cost of additional physiological demands and a subjective feeling of fatigue.

### CONCLUSIONS ACCORDING TO HYPOTHESIS 2

2.1. Metabolic consumption may remain stable during prolonged resuscitation in extreme heat. However, maintaining quality standards means higher cardiac output, more perceived fatigue, and significant fluid loss through sweating.

2.2. Extreme heat is not a limiting factor for rescuers to perform CPR compared to a neutral temperature environment.

## CONCLUSIONS ACCORDING TO HYPOTHESIS 3

3.1. There is a significant physiological impact related to prolonged exertion when wearing PPE. Therefore, it makes sense to remove PPE, rehydrate and rest in a cool environment in order to reduce body temperature and feel comfortable.

3.2. When healthcare professionals wear PPE, they are able to perform prolonged CPR of comparable quality to when performed in normal clothing, although this involves considerable physiological stress. PPE CPR training is necessary for rescuers to understand this special circumstance and also to improve their physical condition.

# 7. FUTURE PERSPECTIVES BASED ON THIS RESEARCH

# 7. FUTURE PERSPECTIVES BASED ON THIS RESEARCH

This thesis is part of a collaborative and continued line of work between the research groups of SICRUS (from the Santiago de Compostela Research Institute), CLINURSID (from the University of Santiago de Compostela) and REMOSS (from the University of Vigo). As a continuation of this doctoral thesis, work will continue in the area of CPR in different environments and special situations.

Technological progress and the use of new devices will be reflected in our future research as they will allow us to improve the quality of interventions performed. The use of smart glasses will enable us to guide the first responders and make decisions in different scenarios, whether it be on land, in the sea or in the air. They will also be helpful in adverse situations, such as in accidents involving multiple victims on land or at sea.

In addition, by continuing our line of work with rescuers as resuscitation personnel, we will study the quality of CPR in rescue vessels using a new device that offers real-time information, by recording the parameters related to the quality of manual ventilation administered to the patient with a self-inflating bag.

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# APPENDIX I:

## PUBLICATIONS

# APPENDIX I: PUBLICATIONS

Carballo-Fazanes A, Barcala-Furelos R, Eiroa-Bermúdez J, **Fernández-Méndez M**, Abelairas-Gómez C, Martínez-Isasi S, et al. **Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high. A pilot study**. Am J Emerg Med. 219 Dec 24;38(12):2580-5. https://pubmed.ncbi.nlm.nih.gov/31911060/

Barcala-Furelos R, **Fernández-Méndez M**, Cano-Noguera F, Otero-Agra M, Morán-Navarro R, Martínez-Isasi S. **Measuring the physiological impact of extreme heat on lifeguards during cardiopulmonary resuscitation. Randomized simulation study**. Am J Emerg Med. 2020 Jun 26;38(10):2019-27. https://pubmed.ncbi.nlm.nih.gov/33142168/

**Fernández-Méndez, M.**; Otero-Agra, M.; Fernández-Méndez, F.; Martínez-Isasi, S.; Santos Folgar, M.; Barcala-Furelos, R.; Rodríguez-Núñez, A. **Analysis of Physiological Response during Cardiopulmonary Resuscitation with Personal Protective Equipment: A Randomized Crossover Study**. Int. J. Environ. Res. Public Health. 2021 Jul 2. 18, 7093. https://pubmed.ncbi.nlm.nih.gov/34281042/

# APPENDIX II.

## PERMISSION FOR REPRODUCTIONS

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Carballo-Fazanes A, Barcala-Furelos R, Eiroa-Bermúdez J, **Fernández-Méndez M**, Abelairas-Gómez C, Martínez-Isasi S, et al. **Physiological demands of quality cardiopulmonary resuscitation performed at simulated 3250 meters high. A pilot study**. Am J Emerg Med. 219 Dec 24;38(12):2580-5. https://pubmed.ncbi.nlm.nih.gov/31911060/

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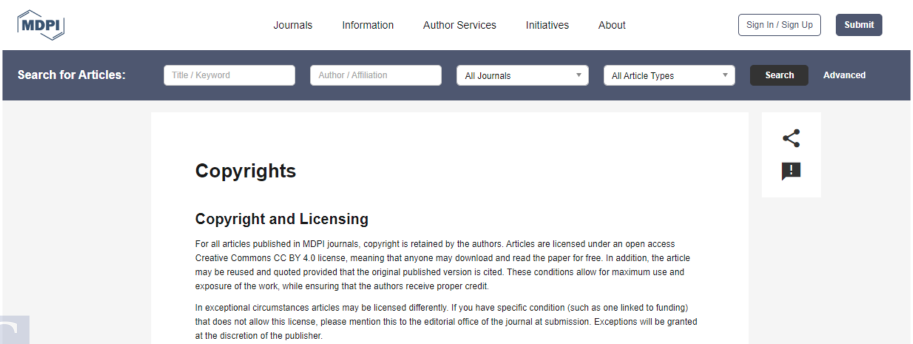

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# APPENDIX III.

## ETHICAL PERMISSION

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HAGO CONSTAR:

Que el proyecto presentado por el equipo investigador formado por ***Roberto Barcala Furelos, María José Fernández Méndez, Francisco Cano Noguera y Jesús G. Pallarés,*** titulado:

**ANÁLISIS DEL RENDIMIENTO DE LA RCP CON DIFERENTE CONCENTRACIÓN DE OXÍGENO (SIMULACIÓN DE ALTITUD). UN ESTUDIO CUASI-EXPERIMENTAL SOBRE MANIQUÍES** ha sido informado por dicho Comité, otorgándosele el siguiente código:

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- **PROYECTO:** Equipos de protección individual en tiempos del COVID-19. análisis fisiológico del reanimador y estudio de la calidad de la reanimación cardiopulmonar en circunstancias especiales

  **INVESTIGADOR PRINCIPAL**: Roberto Barcala Furelos

  **INVESTIGADORES COLABORADORES**: Felipe Fernández Méndez, María Fernández Méndez, Santiago Martínez Isasi, Martín Otero Agra y Antonio Rodriguez Núñez

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The circumstances in which cardiorespiratory arrest may occur and cardiopulmonary resuscitation be necessary are highly variable and in certain conditions, basic life support and advanced life support interventions may require modifications in relation to the general recommendations and have physiological influence on rescuers. For this reason, specific adaptive training programs should be assessed in certain special environments, such as high altitude, high ambient temperatures or when dealing with people with infectious diseases.