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Efecto de la apnea-caminando a diferentes intensidades de esfuerzo percibido sobre la hipoalgesia en sujetos sanos. Un estudio piloto

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RESUMEN

Objetivos: Se realizó un ensayo controlado aleatorizado, en sujetos sanos, para analizar los efectos hipoalgésicos de una intervención de apnea realizada a diferentes intensidades de esfuerzo percibido.

Métodos: Se reclutaron y aleatorizaron 38 participantes. Los participantes del grupo de apnea (AG) realizaron un protocolo de apneas intermitentes a bajo volumen pulmonar en un tapiz rodante, mientras que los del grupo control realizaron un ejercicio aeróbico. Ambos grupos realizaron tres bloques de intervención consecutivos a intensidades crecientes: ligera (Borg CR10: 2-3), moderada (Borg CR10: 5-6) y vigorosa (Borg CR10: 7-8). Se analizaron los cambios en los umbrales de dolor a la presión (PPT) entre los grupos y después de cada bloque de esfuerzo percibido.

Resultados: El modelo ANCOVA no demostró diferencias significativas en los cambios de los PPTs entre los grupos en las diferentes intensidades, excepto en la intensidad ligera (DM = 0,61, SE = 0,23, IC 95% [0,17, 1,11], Z = 2,63, P = 0,0086) a favor del AG. El ANOVA de medidas repetidas reveló un efecto significativo de la intensidad del ejercicio sobre los PPT en el AG para el pulgar ($F(3, 111) = 2,7644$, $p = 0,04532$), C7 ($F(3, 111) = 10,397$, $p < 0,0001$) y tibial ($F(3, 111) = 7,3664$, $p = 0,0002$).

Conclusiones: No hubo diferencias en los PPT entre las intervenciones de apnea y control en ninguno de los estadios de esfuerzo percibido, excepto en la zona del pulgar a intensidad leve. Los resultados mostraron que los cambios en los PPT se incrementaron de forma directamente proporcional a la intensidad percibida en AG, mostrando una hipoalgesia similar, con un menor requerimiento de carga externa.

Palabras clave: contención de la respiración; hipoventilación; ejercicio; dolor.

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Effect of walking-apnea at different intensities of perceived exertion on hypoalgesia in healthy subjects. A pilot study

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ABSTRACT

Objectives: A randomized controlled trial was conducted, in healthy subjects, to analyse the hypoalgesic effects of an apnea intervention performed at different perceived effort intensities.

Methods: Thirty-eight participants were recruited and randomized. Participants in the apnea group (AG) performed a protocol of intermittent walking-apneas at low pulmonary volume on a treadmill, while those in the Control Group (CG) performed an aerobic exercise. Both groups performed three consecutive intervention blocks at increasing intensities: light (Borg CR10: 2-3), moderate (Borg CR10: 5-6), and vigorous (Borg CR10: 7-8). Pressure pain thresholds (PPTs) changes were analysed between groups and after each perceived effort block.

Results: ANCOVA model demonstrated no significant differences in PPTs changes between the groups across different intensities except at light intensity (MD = 0.61, SE = 0.23, 95% CI [0.17, 1.11], Z = 2.63, P = 0.0086) in favour of the AG. The repeated measures ANOVA revealed a significant effect of exercise intensity on PPTs in the AG for thumb ($F(3, 111) = 2.7644$, $p = 0.04532$), C7 ($F(3, 111) = 10.397$, $p < 0.0001$) and tibialis ($F(3, 111) = 7.3664$, $p = 0.0002$).

Conclusion: There were no differences in PPTs between apnea and aerobic interventions in none of the perceived exertion stages, except in the thumb area at light intensity. Results showed that changes in PPTs were increased directly proportional to perceived intensity in AG, showing similar hypoalgesia, with a lower external load requirement.

Keywords: breath holding; hypoventilation; exercise; pain.

INTRODUCTION

When organism is exposed to repeated apnea stimuli, it mainly triggers an increase in carbon dioxide and a reduction in oxygen, stimulating the chemoreceptors in the carotid and aortic arch, causing a response from the endocrine and nervous systems (Lahiri et al., 1981).

With the aim of obtaining the hypoxic training benefits without the need for altitude or devices that create a similar environment, techniques of hypoventilation at low lung volume have emerged. These techniques consist of performing an apnea after a forced expiration, thereby reducing the lung volume (Woorons et al., 2007). A recently conducted systematic review has demonstrated that exercising in apnea at low lung volume is capable of inducing severe hypoxemia (SpO_2 < 88%) (de Asís-Fernández et al., 2022). Additionally, it has been observed by near-infrared spectroscopy a decrease of oxygenation at both muscular and cerebral (prefrontal cortex) (Woorons et al., 2019); furthermore, the increase in blood lactate concentration observed suggests a predominant utilization of anaerobic metabolism during apnea (Woorons, 2010).

An hypoalgesic effect of aerobic exercise has been observed in healthy subjects, which increases as the intensity of the exercise rises (Koltyn, 2002). This hypoalgesic effect has also been observed when performing a series of voluntary apneas (Jafari et al., 2016; Reyes del Paso et al., 2015). However, no study investigating this hypoalgesic effect at different intensities has been identified, similar to what is shown in aerobic

This study aims to analyze the hypoalgesic effects, in healthy participants, of intermittent walking-apneas performed at different intensities.

METHODS

A randomized controlled trial with two arms was conducted according to the CONSORT guidelines (Butcher et al., 2022) (SupM Table1).The study was approved by the Ethics Committee of the Centro Superior de Estudios Universitarios La Salle with reference number CSEULS-PI-007/2023, following the ethical principles of the Declaration of Helsinki.

Participants

Participants were included in the study after signing the informed consent. Participants were recruited using a non-probabilistic convenience sampling at the Centro Superior Universitario La Salle, Madrid, Spain. Healthy subjects between 18 and 60 years old were eligible, considering potential differences in endogenous pain modulation between young and older adults (Hackett et al., 2020). The other inclusion criteria were absence of pain or frequent pain history in the last month and a resting normoxia (≥ 95% SpO_2). Participants were excluded if they presented: cardiac, respiratory, or metabolic pathologies (Sierra-Silvestre et al., 2020), pharmacological treatment, or drug consumption that could have influenced the results, pregnancy (Leźnicka et al., 2022), splenectomy (Shephard, 2016), having engaged in moderate or vigorous physical activity 24 hours before the study (Zheng et al., 2021), lack of sleep the night before (Staffe et al., 2019), with a value over 4 on the Pittsburgh Sleep Quality Index (PSQI), or having ingested alcohol 24 hours before the study (Thompson et al., 2017).

Randomization and blinding

Randomization was conducted by an external researcher before the start of the recruitment process using GraphPad software (GraphPad Software Inc., La Jolla, CA, USA). The sample allocation was 1:1 into apnea group (AG) or control group (CG). Block randomization based on gender was performed due to its potential influence on pressure pain thresholds (Chesterton et al., 2003). The evaluator who measured pressure pain thresholds (PPTs) remained blinded to participant's group allocation

Intervention

Both groups performed an exercise protocol on treadmill with 5° inclination. Three blocks of increasing intensities were conducted in both groups. Participants, previously familiar with the scale,

ç employing the Borg Category Rating scale (Borg CR10) should reach a light (Borg CR10: 2-3), moderate (Borg CR10: 5-6), and vigorous (Borg CR10: 7-8) perceived exertion respectively at the end of each stage (Shariat et al., 2018). All participants started with the light intensity block, followed by the moderate intensity block and finalized with the vigorous intensity block. Each block is stopped immediately when the indicated RPE is exceeded. A 5 min rest period was employed for measurements between blocks.

In the CG, participants maintained usual breathing, while, in the AG, they performed intermittent apneas at low pulmonary volume for 10 seconds, followed by 5 seconds of normal breathing. Subjects were instructed to perform a passive exhalation before the apnea, as previous studies have shown that this maneuver reduces SpO2 (Woorons et al., 2010). The periods of apnea and normal ventilation were repeated cyclically.

To achieve the target perceived exertion, subjects were instructed to walk or run at a speed of 6-8 km/h, 8-10 km/h, and ≥ 11 km/h, respectively, in each block in the CG, and at 4.5 km/h, 5 km/h, and 5.5-6 km/h in the AG. The speed and duration of each block would be modified individually in order to reach the aimed RPE

Outcomes

Subjects were characterized according to their age, sex, body mass index, and dominant side. Physical activity level was analysed using the Global Physical Activity Questionnaire (GPAQ), a questionnaire consisting of 15 questions about physical activity that provides a numerical result in METs over a typical week (Bull et al., 2009). A higher score means higher weekly physical activity. To assess perceived stress, the Perceived Stress Scale (PSS) was used, which is a 14-item scale with a 5-point Likert format. This scale provides a final score indicating higher perceived stress with higher scores obtained (Remor, 2006). The scale has a range of scores from 0 to 56. The lower the score, the more favorable for the patient's health. Sleep quality was measured using the PSQI, a questionnaire containing 19 questions addressing various aspects of sleep, where higher scores indicate poorer sleep quality (Hita-Contreras et al., 2014). The scale has a range of scores from 0 to 21. The lower the score, the more favorable for the patient's health. These variables were controlled for since previous studies had indicated they could influence pain thresholds (Årnes et al., 2023; Staffe et al., 2019; Timmers et al., 2018).

Heart rate (HR) and oxygen saturation (SpO2) were measured in supine position at rest before the interventions using finger pulse oximetry (NONIN Medical Inc., Model 9843, Handheld Pulse Oximeter and CO2 Detector, PLYMOUTH, MN, USA). The formula "208 - (0.7 * age)" was used to calculate the theoretical maximum heart rate (HRmax) (24), and HR data were transformed into %HRmax.

The PPTs refers to the minimum pressure required to elicit the first painful sensation (Fisher, 1987). These were measured twice at the spinous process of C7, the base of the distal phalanx of the thumb, and the muscular belly of the anterior tibialis, both on the dominant side. These body locations have been used in the past for the calculation of pressure pain threshold in patients with chronic pain (Amiri et al., 2021). The measurements order was randomized, with a 30-second rest period between measurements.

The PPTs were measured using a digital algometer (PAIN TEST™ FPX 25, Wagner Instruments, Greenwich, CT, USA) before the intervention (baseline) and after each block, during the 5 min rest period. The algometer has proven to be a tool with high inter-rater reliability for measuring PPTs (Chesterton et al., 2007). Before the first measurement, the locations were marked to ensure measurement at the same site. A constant pressure rate of 0.5 kg/cm2/s ± 0.1 kg/cm2/s was applied following the rhythm of a digital metronome to ensure consistent pressure speed in each trial, as this protocol has demonstrated good test-retest reliability (ICC2,1 > 0.90) (Chesterton et al., 2007).

Statistical analysis

Statistical analyses were conducted using R software (R Core Team, 2022) in RStudio (RStudio, PBC, Boston,MA, USA) version 2023.06.0-431. Categorical variables were analyzed by frequency and continuous variables were presented as the mean and standard deviation. The primary analysis involved an analysis of covariance (ANCOVA), for each PPT region, to evaluate the effect of interaction between the group and different intensities of exercise on the PPTs, adjusting for its baseline value, which were included as a covariate to control for initial differences between subjects (Lai K, et al., 2012). Results of comparison between groups were expressed as mean differences (MD) and 95% confidence intervals (95%CI), considering a p-value less than 0.05 as statistically significant. To account for the repeated measures design, a generalized least squares (GLS) model was applied based on a restricted maximum likelihood estimation (Pinheiro & Bates, 2013). This model incorporated a compound symmetry covariance structure to address the dependency of observations within subjects across different exercise intensity blocks. The model was specified as follows:

*Gls(Score ~ Group*lsp(intensity, 5) + rcs(Thumb.PPT.Basal.Mean, 3), data = data, correlation = corCompSymm(form = ~ intensity|ID))*

where Group is the treatment group (AG or CG), intensity represents the different exercise intensities (light intensity coded as "3", moderate as "5", and vigorous as "7"), Thumb.PPT.Basal.Mean is the baseline measurement of the PPT, and ID identifies each subject. The Gls function from the "nlme" package (https://CRAN.R-project.org/package=nlme) was utilized for this purpose (Harrell, 2015; Pinheiro et al., 1999).

Assumptions of homoscedasticity and normality of residuals were assessed visually. Scatter plots of standardized residuals versus predicted residuals and Q-Q plots were generated to examine these assumptions. Homoscedasticity was also visually evaluated through scatter plots of residuals against fitted values for baseline measurements. Analyses of assumptions will be presented as supplementary material; SupM. Fig 1,2&3). Bonferroni adjustment was used for comparisons derived from the GSL. Additionally, bootstrapping was applied to obtain robust estimates of the confidence intervals for the model parameters. A bias-corrected and accelerated (BCa) bootstrap method with 2000 resamples was employed (Efron & Tibshirani, 1994; Wright et al., 2011). This approach provides more accurate confidence intervals, particularly in the presence of non-normal data or small sample sizes.

Repeated measures ANOVA was conducted for each region (thumb, C7, and tibialis) to analyze the within-group changes over time in apnea group, comparing the baseline measurement with the light, moderate and vigorous intensities. The model included intensity as a fixed effect and subject as a random effect. Post-hoc pairwise comparisons were conducted using the Bonferroni adjustment to control for multiple testing.

RESULTS

Participants characteristics

Thirty-eight subjects (18 males and 20 females) were recruited, with 19 participants assigned to the AG (8 males and 11 females) and another 19 to the CG (10 males and 9 females). Other demographic characteristics and baseline values are described in Table 1.

According to normality test, no baseline differences were detected between the groups for any of the study variables, except for the maximum heart rate percentage variable (%HRmax; p=0.013) (see Table 1).

External load

In general, AG needed more time to reach the target RPE compared to the CG (173 s vs. 115 s at light intensity, 214 s vs. 147 s at moderate intensity, and 271 s vs. 124 s at vigorous intensity, respectively); also, when comparing both groups, differences were observed in the speeds attained during the test. At light intensity, the AG reached 4.59 km/h while the CG reached 6.27 km/h. This pattern also repeated at moderate intensity (5.21 km/h in AG and 8.23 km/h in CG) and vigorous intensity (5.79 km/h in AG and 11 km/h in CG) (see Table 2).

Thumb PPTs

The ANCOVA model revealed that the difference in PPTs between the AG and the CG group at light intensity was significant (MD = 0.61, SE = 0.23, 95% CI [0.17, 1.11], Z = 2.63, p = 0.0086), but not at RPE 5 or RPE 7.

The repeated measures ANOVA for the thumb region showed a significant effect of exercise intensity on PPTs in the AG (F(3, 111) = 2.7644, p = 0.04532). Post-hoc contrasts revealed no significant difference between the different times (Fig. 1 &2).

C7 PPTs

Table 1. Baseline demographic characteristics and descriptive variables of both groups with normality assessed using the Shapiro-Wilk test.

	Group	Min Range	Max Range	Shapiro-Wilk (p-value)	Pairwise comparisons (p-value)
Age	Apnea	21	32	**0.001***	0.465§
	Control	18	30	0.090	
BMI	Apnea	20.88	30.48	**0.005***	0.965§
	Control	19.72	35.14	**0.001***	
GPAQ	Apnea	0	28560	0.412	0.3‡
	Control	960	10560	0.109	
PSQI	Apnea	1	14	0.073	0.873‡
	Control	2	13	0.346	
PSS	Apnea	12	35	0.428	0.430‡
	Control	8	39	0.094	
% HR_{max}	Apnea	26.47	48.45	0.890	**0.013*‡**
	Control	26.15	39.96	0.520	
SpO_2	Apnea	96	99	**0.001***	0.565§
	Control	94	99	**0.011***	
Pre thumb PPT	Apnea	1.50	9.34	0.179	0.635‡
	Control	2.31	8.89	0.510	
Pre tibial PPT	Apnea	1.47	12.66	**0.030***	0.3§
	Control	1.67	9.91	0.828	
Pre C7 PPT	Apnea	1.40	7.61	0.276	0.616‡
	Control	1.67	7.30	0.308	

*, $p<0.05$; ‡, T-Student Test was applied; §, Mann U-Withney test was applied.

BMI, Body Mass Index; GPAQ, Global Physical Activity Questionnaire; PSQI, Pittsburgh Sleep Quality Index; HR_{max}, Maximum Heart Rate; PSS, Perceived Stress Scale; PPT, Pressure Pain Threshold.

For the C7 region, the ANCOVA model demonstrated no significant differences in PPTs changes between the groups across different intensities, with all p-values exceeding 0.05 (Fig. 1b).

The repeated measures ANOVA for the C7 region indicated a significant effect of exercise intensity on PPTs in the AG ($F(3, 111) = 10.397$, $p < 0.0001$). Post-hoc contrasts showed significant increases between baseline and higher exercise intensities: baseline vs. moderate (MD = 0.536, SE = 0.195, 95% CI [0.0109, 1.061], p = 0.0427) and baseline vs. vigorous (MD = 1.046, SE = 0.195, 95% CI [0.5213, 1.572], p <

Table 2. Mixed ANOVA for PPTs of each group per perceived exertion block (EMM ± se). Speed and time of each group in each perceived exertion block (.M± SD).

		RPE												
		Pre	Low (RPE 2-3)			Moderate (RPE 5-6)			Vigorous (RPE 7-8)			Time	Group	Time* Group
		PPT (Kg)	PPT (Kg)	Speed (km/h)	Time (s)	PPT (Kg)	Speed (km/h)	Time (s)	PPT (Kg)	Speed (km/h)	Time (s)	F; (p-value, effect size (η_p^2))		
Thumb	AG	4.56 ± 0.463	4.23 ± 0.466	AG 4.59 ± 0.23	AG 173 ± 106	4.69 ± 0.565	AG 5.21 ± 0.41	AG 214 ± 79	4.64 ± 0.579	AG 5.79 ± 0.40	AG 271 ± 123	2.759; (0.079, 0.071)	0.799; (0.377, 0.022)	0.930; (0.388, 0.025)
	CG	4.87 ± 0.463	5.07 ± 0.466	CG 6.27 ± 0.35	CG 115 ± 61	5.40 ± 0.565	CG 8.23 ± 0.40	CG 147 ± 65	5.31 ± 0.579	CG 11 ± 0	CG 124± 75			
Tibial	AG	4.49 ± 0.586	4.64 ± 0.573			4.71 ± 0.711			4.98 ± 0.738			6.10; (**0.004***, 0.152) **§* 0.035, 0.016**	2.66; (0.112, 0.073)	1.04; (0.355, 0.030)
	CG	5.69 ± 0.554	5.82 ± 0.542			6.31 ± 0.672			6.68 ± 0.698					
C7	AG	3.77 ± 0.354	4.00 ± 0.430			4.02 ± 0.498			4.46 ± 0.624			10.57;(**<.001***, 0.227) **§* 0.006, 0.003, 0.006**	0.854; (0.361, 0.023)	1.62; (0.210, 0.043)
	CG	4.02 ± 0.354	4.34 ± 0.430			4.85 ± 0.498			5.42 ± 0.624					

*p<0.05

AG, apnea group; CG, control group; RPE, rated perceived exertion; EMM, estimated marginal mean; SE, standard error; M, (mean); SD, standard deviation.

§* Post hoc Bonferroni analysis detected significant differences in tibial PPTs (pre-vigorous (p=0.035) and low-vigorous (p=0.016)) and in C7 PPTs (pre-vigorous (p=0.006), low-vigorous (p=0.003), and moderate-vigorous (p=0.006)).

0.0001). Additionally, light and vigorous differences were significant (MD = 0.773, SE = 0.195, 95% CI [0.2476, 1.298], p = 0.0008) (Fig. 1 &2).

Tibialis PPTs

In the tibialis region, the ANCOVA results showed no significant differences in PPTs changes between the groups at different intensities (all p-values > 0.05)

The repeated measures ANOVA for the tibialis region revealed a significant effect of exercise intensity on PPTs in the AG (F(3, 111) = 7.3664, P = 0.0002). Post-hoc contrasts demonstrated significant increments between baseline and vigorous (MD = 0.817, SE = 0.182, 95% CI [0.3278, 1.306], p = 0.0001) and between light and vigorous (MD = 0.594, SE = 0.182, 95% CI [0.1051, 1.084], p = 0.0088) (Fig. 1 &2).

DISCUSSION

The aim of this study was to analyse the hypoalgesic effects of intermittent walking or running apneas, performed at different perceived effort intensities. In contrast to other prescription strategies that compare interventions with the same external load (km/h, watts,volume), this study aimed to equalize the internal load in both groups.

The main finding of the study showed no difference between apnea or aerobic interventions in none of the perceived exertion stages, except in the thumb area at light intensity (Borg CR10: 2-3). Results showed that the change in PPTs were dependent on the perceived intensity in apnea group at the thumb, tibialis, and C7.

PPTs are sensitive to physical condition, stress, or sleep (Hita-Contreras et al., 2014; Timmers et al., 2018). Data collected through the GPAQ, PSS, and

Figure 1. Mean values of PPT for thumb, tibialis, and C7 for each intervention group at rest and for each perceived exertion block. PPT at Basal Rest values, Low (2-3 RPE), Moderate (5-6 RPE) and Vigorous (7-8 RPE).

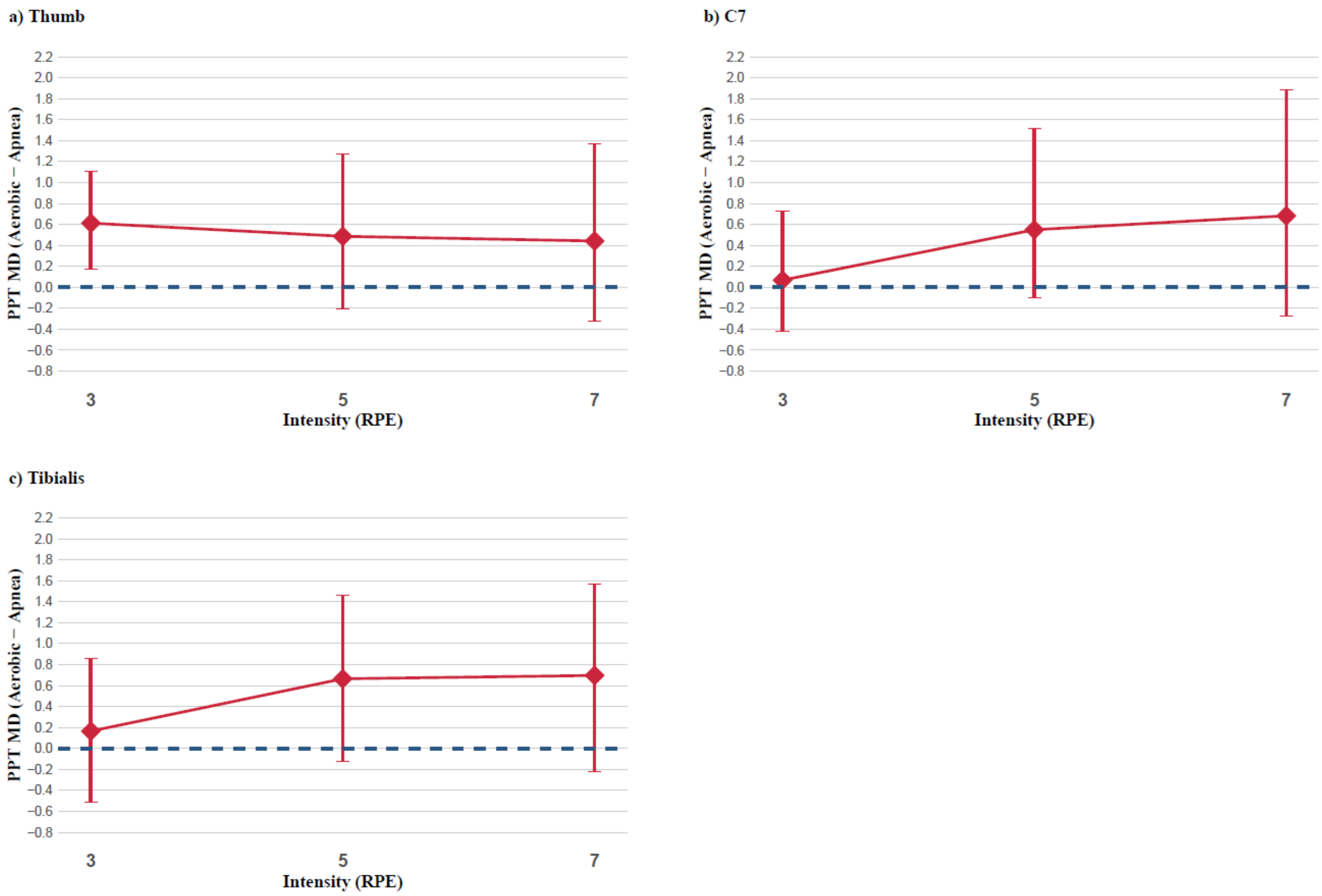
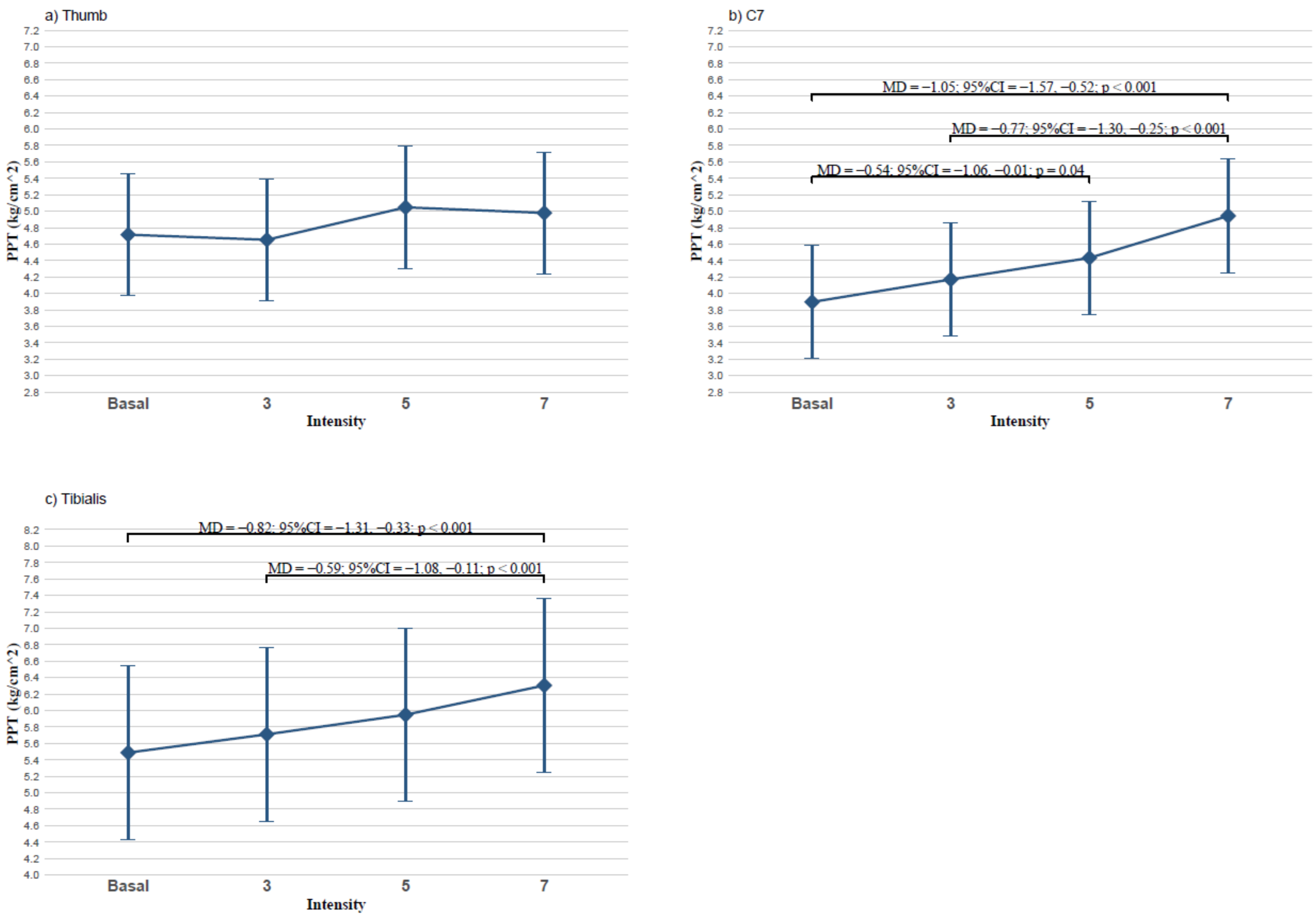


Figure 2. Repeated measures result for each region across the different exercise intensities /RPE 3-5-7) in the apnea group.



PSQI questionnaires demonstrate the intergroup normality of these variables. On the other hand, low lung volume apnea has been shown to induce severe hypoxia in healthy subjects (Woorons et al., 2010). This hypoxemia is sensitive to the participants' basal saturation, with its saturation loss being exponential as it decreases (Woorons et al., 2019). Pulse oximetry tests reveal similar baseline conditions in both study groups.

The results showed no differences in PPTs modulation following repeated wlaking-apnea compared to walking-running under normal breathing conditions, as long as they occur at a similar perceived intensity (0-10). A preliminary study conducted by our research group observed an inverse correlation between oxygen saturation and thumb PPTs (r=-0.551, p=0.033) (Mendoza-Arranz et al., 2024). Another previous study on hypoxemia and RPE showed that perceived effort is related to progressive arterial hypoxemia and a ventilation increase (Jeffries et al., 2019). Other methods of inducing local hypoxemia have been explored (Reyes del Paso et al., 2015), such as blood flow restriction (BFR) training, which involves reducing vascular flow to the extremities using an adjustable pressure cuff, a condition that appears to induce local hypoxia (Hughes & Patterson 2015). BFR has also shown increases in PPTs in quadriceps, biceps, epicondyle, and trapezius compared to groups without BFR (Joshi et al., 2020; Karanasios et al., 2022).

The study results suggest that changes in PPTs are sensitive to the intensity of exercise performed, being greater with higher perceived intensity. A review by Koltyn et al. concluded that exercise-induced hypoalgesia (EIH) is more consistent in high-intensity aerobic exercises compared to lower-intensity exercises (Koltyn 2002).

In our study, PPTs changes appear to occur primarily during vigorous exercise (RPE 7) in AG. However, while in AG the speed reached during the vigorous exercise block averaged 5.79 km/h; in the CG, it reached an average of 11 km/h. This would imply a potential clinical application (we remind that the study and its conclusions are in asymptomatic subjects) in populations with osteomuscular limitations, such as older adults, sedentary or athletes in early stages of rehabilitation. The intervention would involve performing low osteomuscular efforts (walking at 5.5 km/h) producing vigorous cardiorespiratory efforts (RPE 7); i.e, it would induce hypoalgesia similar to that produced by aerobic exercise (Zheng et al., 2021), but with a lower external load. When hypothesizing possible clinical applications, from the observed hypoalgesia (decrease in pain perception to a painful stimulus) no analgesic effects (abolition of pain perception to a stimulus that would normally be painful) can be deduced for patients.

Despite previous studies having examined the physiological effect produced by a series of repeated apneas at low pulmonary volume (De Asís-Fernández 2022), the lack of a physiological analysis of the proposed intervention in this study limits the analysis of the effects on the organism. It is recommended that in future studies, variables such as oxygen saturation, carbon dioxide, and heart rate will be recorded during interventions. Furthermore, the amount of air exhaled by the participants before apnea was not quantified through an objective device; to equalize the exhaled amount participants were asked to perform a passive exhalation, which was visually monitored by the interventionist. Finally, we must interpret the data with caution since the hypoalgesic effect of apnea was explored in healthy volunteers with strict inclusion criteria.

CONCLUSION

Apnea group generated similar PPTs changes as aerobic exercise across light, moderate and severe exercise intensities, except in the thumb area at light intensity. Results showed that changes in PPTs were increased directly proportional to perceived intensity in apnea group, showing similar hypoalgesia, accounted with a lower external load in the apnea group.

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FRASES DESTACADAS

- No se encontraron diferencias en los cambios de los umbrales de dolor (PPT) entre los grupos a intensidades moderadas y vigorosas.
- A una intensidad ligera, el grupo de apnea demostró un aumento significativo en los PPT en comparación con el grupo de control.
- El grupo de apnea mostró un aumento en los PPT proporcional a la intensidad del ejercicio.

HIGHLIGHTS

- No differences in PPTs changes between groups at moderate and vigorous intensities,
- At light intensity, the apnea group demonstrated a significant increase in PPTs compared to the control group
- The apnea group showed increased PPTs proportional to exercise intensity, particularly in the thumb, C7, and tibialis areas,

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SupM Figure1. Pearson correlation of minimum SpO_2 values and thumb PPT change in apnea group. The linear regression line (solid line) and its 95% CI (dotted line) are presented in the plot. Min SpO2, Minimum oxigen saturation