Physiological and psychological determinants of cardiovascular autonomic response in experienced Cold-Water Swimmers

Determinantes fisiológicos y psicológicos de la respuesta autonómica cardiovascular en nadadores experimentados en aguas frías

Authors

Josefa Lillo Bobadilla [1]
Aline Fieldhouse Sandoval [1]
Pedro Fernández Fredes[1]
Paula Bravo Sepúlveda [3]
Matías Castillo-Aguilar [2]
Michele Macedo Moraes [4,5]
Thiago Teixeira Mendes [6]
Cristian Núñez-Espinosa [1,2]

[1] Escuela de Medicina Universidad de Magallanes, Punta Arenas, Chile
[2] Centro Asistencial de Docencia e Investigación (CADI-UMAG), Punta Arenas Chile
[3] Cesfam Dr. Mateo Bencur, Servicio de Salud Magallanes, Punta Arenas, Chile
[4] Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil
[5] Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil (NUPAD-FM/UFMG)
[6] Universidade Federal da Bahia, Salvador, BA, Brazil.

Corresponding author: cristian.nunez@umag.cl; Tel.: +56 61 2201411; Address: Avenida Bulnes 01855, Box 113-D.

How to cite in APA

Lillo Bobadilla, J., Fieldhouse Sandoval, A., Fernández Fredes, P., Bravo Sepúlveda, P., Castillo-Aguilar, M., Macedo Moraes, M., … Núñez Espinosa, C. A. (2025). Physiological and psychological determinants of cardiovascular autonomic response in experienced Cold-Water Swimmers. *Retos*, *69*, 897–910. https://doi.org/10.47197/retos.v69.114955

Abstract

Introduction: The relationship between morphological and psychological parameters and cardiovascular autonomic responses was investigated in experienced cold-water swimmers.
Objective: This study explores how morphological and psychological factors influence cardiovascular autonomic responses in experienced cold-water swimmers.
Methodology: Conducted as a cross-sectional observational study, the research involved 18 training swimmers who regularly engage in icy-water swimming (below 5°C). Participants were assessed at four key time points: baseline, pre-dive, post-dive, and recovery. Cardiovascular parameters, heart rate variability (HRV), and psychological states were measured using validated tools.
Results: Cold-water immersion triggered significant reductions in HRV, particularly in RMSSD and SDNN ($p < 0.01$), indicating elevated sympathetic activity and decreased parasympathetic modulation. Notably, overall autonomic function, reflected by a decline in the PNS index ($\beta = -0.73$, $p < 0.01$), was inversely associated with anxiety ($\beta = -0.64$, $p < 0.01$) and depression levels ($\beta = -0.49$, $p < 0.05$). These findings underscore the essential role of mental health in shaping physiological resilience in extreme environments. Body composition, especially visceral fat, was also found to significantly influence autonomic regulation ($\beta = -0.77$, $p < 0.01$).
Conclusions: This study emphasizes the importance of integrated training strategies that address both physiological conditioning and psychological support to enhance performance and ensure safety in cold-water environments. The results provide deeper insight into the multifaceted challenges cold-water swimmers face and highlight the need for tailored interventions to support their unique physiological demands.

Keywords

cardiovascular recovery; cold water; extreme environments; physiological adaptation; swimming.

Resumen

Introducción: Se investigó la relación entre los parámetros morfológicos y psicológicos y las respuestas autonómicas cardiovasculares en nadadores experimentados en aguas frías.
Objetivo: Este estudio explora cómo los factores morfológicos y psicológicos influyen en las respuestas autonómicas cardiovasculares en nadadores experimentados en aguas frías.
Metodología: Realizado como un estudio observacional transversal, la investigación involucró a 18 nadadores entrenados que practican natación regularmente en agua helada (por debajo de 5 °C). Los participantes fueron evaluados en cuatro momentos clave: inicial, antes de la inmersión, después de la inmersión y en la recuperación. Se midieron los parámetros cardiovasculares, la variabilidad de la frecuencia cardíaca (VFC) y los estados psicológicos mediante herramientas validadas. Resultados: La inmersión en agua fría provocó reducciones significativas de la VFC, especialmente en RMSSD y SDNN ($p < 0,01$), lo que indica un aumento de la actividad simpática y una disminución de la modulación parasimpática. Cabe destacar que la función autonómica general, reflejada por una disminución en el índice PNS ($\beta = -0,73$, $p < 0,01$), se asoció inversamente con los niveles de ansiedad ($\beta = -0,64$, $p < 0,01$) y depresión ($\beta = -0,49$, $p < 0,05$). Estos hallazgos subrayan el papel esencial de la salud mental en el desarrollo de la resiliencia fisiológica en entornos extremos. La composición corporal, especialmente la grasa visceral, también influyó significativamente en la regulación autonómica ($\beta = -0,77$, $p < 0,01$).
Conclusiones: Este estudio enfatiza la importancia de las estrategias de entrenamiento integradas que abordan tanto el acondicionamiento fisiológico como el apoyo psicológico para mejorar el rendimiento y garantizar la seguridad en entornos de agua fría. Los resultados brindan una comprensión más profunda de los desafíos multifacéticos que enfrentan los nadadores de agua fría y resaltan la necesidad de intervenciones personalizadas para satisfacer sus demandas fisiológicas específicas.

Palabras clave

Adaptación fisiológica; agua fría; ambientes extremos; natación; recuperación cardiovascular.

Introduction

Immersion in cold water, particularly in polar environments, poses a substantial challenge to human homeostasis, especially during demanding physical activities such as swimming (Manolis et al., 2019; Mercer, 2001). In such extreme conditions, the body initiates a series of acute physiological responses, including peripheral vasoconstriction and elevated heart rate, aimed at preserving core body temperature and maintaining oxygen delivery to vital organs. These responses are primarily regulated by the autonomic nervous system (ANS), which plays a critical role in sustaining homeostasis during environmental stress.

Exposure to cold temperatures and physical exertion both independently increase sympathetic nervous activity while simultaneously suppressing parasympathetic outflow (Christensen & Galbo, 1983; Kane & Davis, 2018; Lundell, Räisänen-Sokolowski, Wuorimaa, Ojanen, & Parkkola, 2020). The combined stress of exercise in cold water can lead to heightened autonomic output, potentially triggering arrhythmias and negatively affecting cardiovascular performance and long-term health (Kane & Davis, 2018; Lundell et al., 2020). Athletes who routinely swim in icy waters must develop specialized physiological adaptations, particularly involving cardiovascular and nervous system regulation. However, these adaptations are not solely determined by environmental exposure or training; they are also shaped by intrinsic and extrinsic factors such as body composition and psychological state. These factors can influence the autonomic response to cold exposure and may affect the long-term physiological resilience of cold-water swimmers (Kim, Shin, & Woo, 2023; Mabe-Castro et al., 2024). Among the various tools for assessing autonomic function, heart rate variability (HRV) has emerged as a key indicator, reflecting the body's ability to respond to and recover from physiological stress.

Despite the increasing popularity of cold-water swimming, little is known about how psychological variables, such as anxiety and depression, interact with autonomic function in this population. Prior research has shown that psychological stressors can enhance sympathetic dominance and suppress parasympathetic activity, thereby impairing cardiovascular recovery and performance (Berthelsen et al., 2023; Rosenwinkel, Bloomfield, Arwady, & Goldsmith, 2001). Similarly, body composition, particularly visceral fat and muscle mass, has been shown to modulate autonomic regulation, suggesting a complex interplay between physical fitness and autonomic balance in individuals exposed to extreme environmental conditions (Belinchón-deMiguel, Navarro-Jiménez, Laborde-Cárdenas, & Clemente-Suárez, 2024; Habib, Alkahtani, Aljawini, Habib, & Flatt, 2024). Therefore, this study aims to investigate whether morphological and psychological variables can predict cardiovascular autonomic responses in experienced cold-water swimmers. By deepening our understanding of how these factors influence autonomic modulation, this research provides a foundation for designing optimized training and recovery strategies that promote both physiological adaptation and mental well-being in athletes facing extreme environmental stressors.

Method

Study Design

This research was conducted as a cross-sectional observational study aimed at evaluating cardiovascular autonomic responses in experienced cold-water swimmers from the extreme southern latitudes (52.5°S). A randomized, non-probabilistic sampling approach was employed. Prior to data collection, all participants received a detailed explanation of the study's procedures, risks, and potential benefits. Written informed consent was obtained from each participant.

Participants

The study sample consisted of 20 swimmers, from whom complete records were obtained from 18 experienced cold water swimmers (mean age: 39.1 ± 9.0 years; mean weight: 75.8 ± 17.1 kg; mean height: 168.9 ± 10.7 cm). To be eligible, participants were required to have completed at least one session of open-water swimming in temperatures below 5°C, lasting at 10 minutes, within the past 12 months. In addition, all participants were assessed to ensure their physical and mental health were compatible with engaging in sports under such extreme conditions. This evaluation was conducted through interviews with the aquatic activities coordinator, who routinely monitors the health status of swimmers.

Individuals were excluded from the study if they failed to complete all stages of the experimental protocol or had consumed caffeine or other stimulants within 72 hours before testing.

The study protocol was approved by the Ethics Committee of the Clinical Hospital of the University of Chile (Approval No. 072/2022) and followed the ethical principles outlined in the Declaration of Helsinki. The study also includes a data availability statement regarding human subjects.

Procedure

Measurements were carried out at four time points: baseline (rest), pre-swimming, immediately post-swimming, and after a 10-minute recovery period. All assessments took place in a single morning session to minimize potential circadian variability. Participants were instructed to wear appropriate sports attire (e.g., swim trunks), abstain from stimulants, including caffeine, for at least 16 hours before testing, and get a minimum of 7 hours of sleep the night before.

At each of the four time points, the following measurements were collected: cardiovascular metrics, heart rate variability (HRV), body temperature, and psychological evaluations (see the "Assessments" section for details). Figure 1 summarizes the study design and the timing of evaluations.

Figure 1. The study design and evaluations were conducted. HRV: Heart rate variability. The auricular temperature was obtained as a representative measure of internal body temperature. In winter, the ten-minute free swimming was conducted in open waters in the Estrecho de Magallanes.

Sport period	Baseline (rest)	Pre-swimming	Ten-minute free swimming	Post-swimming	Post-recovery
Time	1-2 weeks before swimming. 10-minute recording	10-minutes before swimming		10-minutes immediately after swimming	10 minutes after swimming, recording 10-minues
Evaluation	Baseline conditions	Before immersion		After immersion	Recovery evaluation
Protocol	Anthropometry Blood pressure HRV Body temperature Psychological assessment	Blood pressure HRV Body temperature		Blood pressure HRV Body temperature	Blood pressure HRV Body temperature

The baseline assessments took place under controlled lab conditions (21 °C air temperature) at the Teaching and Research Assistance Center (CADI-UMAG). Participants remained seated for five minutes before physiological measurements were initiated. HRV was recorded for 10 minutes (with five minutes of clean data selected for analysis), followed by blood pressure readings and completion of psychological questionnaires.

The pre-swim assessment was conducted outdoors at the Strait of Magellan. Participants, wearing comfortable clothing, were seated in chairs while data were collected (see Figure 2). The swimming session consisted of 10 minutes of open-water swimming in winter conditions, with ambient temperatures averaging -3 ± 2°C and water temperatures at 5 ± 3°C, monitored using a Garmin Descent™ Mk1.

Figure 2. Data collection was performed outdoors. Each subject wore comfortable clothing and was seated in a chair for the measurements to be taken.

Post-swimming: Data collection was conducted immediately

Immediately after the swim, post-immersion measurements were conducted in the same outdoor setting using the same instruments. Ten minutes later, during the recovery phase, a final set of measurements was taken.

Assessments

Anthropometry

Anthropometric measurements were obtained using the Tanita BC-558 Ironman® segmental body composition monitor to determine total body mass (kg), body fat percentage (%), and visceral fat (%). Height was measured using a Charder® HM230M manual stadiometer. These data were used to calculate body mass index (BMI).

Cardiovascular

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using an Omron® blood pressure monitor. Cardiac autonomic modulation was assessed by recording RR intervals with a Polar Electro Oy® H10 chest strap and the ELITE HRV app (Elite HRV, n.d.). A continuous 10-minute HRV recording was performed at each phase, of which 5 minutes of data were selected for analysis based on data quality and cleanliness. The following time-domain variables were considered: the root mean square of successive differences of RR intervals (RMSSD, expressed in ms), reflecting parasympathetic influence (Buchheit et al., 2010) , and the standard deviation of RR intervals (SDNN), representing total heart rate variability and reflecting the contributions of both the sympathetic and parasympathetic branches of the autonomic nervous system (Berntson et al., 1997; Buchheit & Gindre, 2006). In the frequency-domain analysis, the variables included the high-frequency (HF) power band, indicating parasympathetic influence and respiratory sinus arrhythmia (Akselrod et al., 1981); the low-frequency (LF) band, associated with baroreflex activity (Goldstein, Bentho, Park, & Sharabi, 2011); and the very-low-frequency (VLF) band, which is intrinsically generated by the heart and modulated by efferent sympathetic activity (Malik, 1996; McCraty & Shaffer, 2015). In addition, composite indices of autonomic activity, Parasympathetic Nervous System (PNS) and Sympathetic Nervous System (SNS), were calculated. All HRV data were processed using Kubios HRV® software. (Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, n.d.).

Body temperature

Core body temperature was estimated by measuring tympanic temperature in both ears using a Braun® Thermoscan 3 IRT 3030 thermometer. Auricular temperature was considered a reliable proxy for internal body temperature, in accordance with established standards (Livingstone, Grayson, Frim, Allen, & Limmer, 1983; Taylor, Tipton, & Kenny, 2014).

Psychological evaluation

A professional in the field conducted psychological evaluations during the reference session at CADI-UMAG. Depressive symptoms were measured using the Beck Depression Inventory-II (BDI-II), a self-report questionnaire consisting of 21 items rated on a 0–3 Likert scale, with a maximum possible score of 63 points (Sanz, Perdigón, & Vázquez, 2003). Anxiety symptoms were evaluated using the Spanish-translated Beck Anxiety Inventory (BAI), also comprising 21 items rated on a 0–3 scale, with a clinical cutoff score of 16 indicating significant anxiety (Sanz & Navarro, 2003).

Statistical analysis

The statistical analysis employed a Bayesian approach due to its ability to model uncertainty in complex parameters and its flexibility in interpreting small or subtle effects. Descriptive statistics included the mean ± standard deviation for continuous variables and absolute and relative frequencies for categorical variables.

Multivariate Bayesian generalized linear models were employed to investigate the impact of body composition and psychological variables on autonomic modulation. Regular priors centered at zero, with normal distributions ($\beta \sim N(0,3)$), were applied for the linear coefficients, reducing the impact of influential observations. The models were estimated using the No-U-Turn (NUTS) algorithm, with 10,000 iterations, and the convergence process was assessed by the R-hat value (<1.01) and the effective sample size (>1000).

The analysis was performed in R (v.4.0.5) using the brms package (v2.21.0), and the medians and 95% credibility intervals were reported for the main effects.

Index Report

Following the Sequential Effect eXistence and sIgnificance Testing (SEXIT) framework for describing effects from Bayesian models (Makowski, Ben-Shachar, Chen, & Lüdecke, 2019), we reported the median and 95%CI (using the highest density interval) as a measure of centrality and uncertainty, the direction probability (pd) as a measure of existence, the proportion of the posterior probability distribution of the sign of the median that falls outside the region of practical equivalence (ROPE) as a measure of practical significance (ps), estimated as one-tenth (1/10 = 0. 1) of the SD of the response variable, and the Bayes factor (BF10) using the Savage-Dickey density ratio against the null point indicating whether the null value has become less or more likely given the observed data (Heck, 2019), using this as a measure of the absolute magnitude of evidence for or against the null hypothesis (no effect).

For the interpretation of BF we have considered: BF = 1, no evidence; 1 < BF <= 3, anecdotal; 3 < BF <= 10, moderate; 10 < BF <= 30, strong; 30 < BF <= 100, very strong; and BF > 100, as extreme evidence . For the proportion of the posterior in the ROPE we considered: < 1%, significant; < 2.5%, probably significant; ≤ 97.5% & ≥ 2.5%, undecided significance; > 97.5%, probably insignificant; > 99%, insignificant (Makowski et al., 2019).

Convergence

The convergence and stability of Bayesian sampling has been assessed by R-hat, which should be less than 1.01(Vehtari, Gelman, Simpson, Carpenter, & Bürkner, 2019), effective sample size (ESS), which should be greater than 1000 (Bürkner, 2017), and visual inspection of trace plots and subsequent predictive checks. All statistical analyses were calculated and implemented in the R programming language (The R Project for Statistical Computing, n.d.)

Results

Sample characterization

The study included 18 experienced cold-water swimmers (8 men and 10 women). Table 1 summarizes their anthropometric characteristics, including comparisons by sex. On average, men presented with greater body mass, height, and muscle mass, while women had higher body fat percentages.

Table 1. Anthropometric characteristics. In addition to the overall characteristics of the sample, the standardized mean differences between sex groups are presented. Data presented as Mean ± SD; n (%). Standardized Mean Difference. CI = Confidence interval.

Characteristic	All	Sex			
	N = 18[1]	Men N = 8[1]	Women N = 10[1]	Difference[2]	95% CI[2,3]
Age (years)	39.1 ± 9.0	38.9 ± 7.9	39.3 ± 10.3	-0.05	-0.98, 0.88
Body mass (kg)	75.8 ± 17.1	87.5 ± 16.3	66.4 ± 11.3	1.6	0.53, 2.7
Height (cm)	168.9 ± 10.7	177.1 ± 7.6	162.3 ± 8.0	2.0	0.88, 3.2
Body fat (%)	22.4 ± 8.9	17.6 ± 9.2	26.3 ± 6.8	-1.1	-2.1, -0.14
Muscle mass (kg)	56.0 ± 13.4	68.2 ± 8.1	46.2 ± 7.0	3.1	1.7, 4.5
Bone mass (%)	3.0 ± 0.7	3.6 ± 0.4	2.5 ± 0.4	3.0	1.7, 4.4
Body water (%)	57.6 ± 6.1	61.2 ± 5.9	54.7 ± 4.6	1.3	0.28, 2.3
Visceral fat (%)	6.4 ± 5.5	6.8 ± 5.1	6.1 ± 6.0	0.13	-0.80, 1.1

Cardiovascular and autonomic parameters are detailed in Table 2. Men showed higher systolic and diastolic blood pressure, but women demonstrated higher HRV values such as RMSSD and SDNN, suggesting greater parasympathetic activity. Women also exhibited higher HF power and lower stress indices, while men showed higher sympathetic activation (SNS index).

Table 2. Cardiovascular and autonomic control variables.

Characteristic	All N = 181	Men N = 81	Sex Women N = 101	Difference2	95% CI2,3
SBP (mmHg)	125.4 ± 16.7	137.3 ± 16.1	116.0 ± 10.1	1.7	0.60, 2.8
DBP (mmHg)	77.8 ± 10.1	80.4 ± 8.9	75.8 ± 11.0	0.48	-0.46, 1.4
R-R interval duration (ms)	910.9 ± 123.8	908.0 ± 145.2	914.1 ± 105.6	-0.05	-1.1, 0.96
Mean HR (bpm)	67.1 ± 10.1	67.8 ± 12.3	66.3 ± 7.7	0.15	-0.86, 1.2
RMSSD (ms)	38.7 ± 17.6	31.8 ± 13.2	46.5 ± 19.6	-0.95	-2.0, 0.12
SDNN (ms)	47.0 ± 19.7	39.8 ± 17.8	55.2 ± 19.7	-0.88	-1.9, 0.18
SNS index	0.4 ± 1.6	0.8 ± 2.0	-0.1 ± 0.8	0.62	-0.42, 1.7
PNS index	-0.2 ± 0.9	-0.4 ± 0.9	0.1 ± 1.0	-0.51	-1.5, 0.52
Stress index	11.0 ± 6.6	13.3 ± 8.3	8.4 ± 2.4	0.85	-0.21, 1.9
HF (ms^2)	643.5 ± 577.0	506.5 ± 367.3	800.1 ± 752.2	-0.53	-1.6, 0.50
LF (ms^2)	1,695.3 ± 1,435.2	1,235.6 ± 1,208.7	2,220.6 ± 1,580.6	-0.75	-1.8, 0.30
VLF (ms^2)	138.9 ± 145.1	80.0 ± 57.4	206.3 ± 188.0	-0.98	-2.1, 0.09

In addition to the overall characteristics of the sample, the standardized mean differences between sex groups are presented. Abbreviations: SBP: systolic blood pressure. DBP: diastolic blood pressure. Mean HR: Mean Heart Rate; RMSSD: Root Mean Square of Successive Differences; SDNN: Standard Deviation of NN Intervals; SNS index: Sympathetic Nervous System Index; PNS index: Parasympathetic Nervous System Index; HF: High Frequency; LF: Low Frequency; VLF: Very Low Frequency. 1Data presented as Mean ± SD; n (%). Standardized Mean Difference. CI = Confidence interval.

Psychological measures are presented in Table 3. The majority of participants reported very low levels of anxiety and minimal depressive symptoms, with no significant sex-based differences in psychological scores.

Table 3. Psychological parameters. In addition to the overall characteristics of the sample, the standardized mean differences between sex groups are presented.

Characteristic	All N = 181	Men N = 81	Sex Women N = 101	Difference2	95% CI2,3
BAI score	4.6 ± 6.0	4.5 ± 5.8	4.7 ± 6.5	-0.03	-0.96, 0.90
BDI score	5.9 ± 5.6	4.6 ± 5.6	6.9 ± 5.7	-0.42	-1.4, 0.52
BAI category					
Very low	14 (93%)	6 (100%)	8 (89%)		
Moderate	1 (6.7%)	0 (0%)	1 (11%)		
Severe	0 (0%)	0 (0%)	0 (0%)		
BDI category					
Minimal depression	16 (89%)	7 (88%)	9 (90%)		
Mild depression	2 (11%)	1 (13%)	1 (10%)		
Moderate depression	0 (0%)	0 (0%)	0 (0%)		
Severe depression	0 (0%)	0 (0%)	0 (0%)		

Abbreviations: BAI score: Beck Anxiety Inventory; BDI score: Beck Depression Inventory. Data presented as Mean ± SD; n (%). Standardized Mean Difference. CI = Confidence interval.

Table 4 presents the temporal changes in hemodynamic and autonomic parameters across the four study phases. Immersion in cold water induced notable physiological shifts: Blood Pressure, both systolic and diastolic pressures significantly increased from baseline to pre-swim, then slightly decreased during the post-dive and recovery phases, though without fully returning to baseline levels; Tympanic Temperature, auricular temperatures dropped significantly post-immersion, indicating a reduction in core body temperature, which persisted even after 10 minutes of recovery; Heart Rate and HRV, markers such as RMSSD and SDNN decreased significantly immediately after immersion, reflecting a shift toward sympathetic dominance. These values recovered partially during the recovery phase but remained below baseline; Autonomic Indices, the SNS index and stress index rose sharply post-dive, while the PNS index dropped, supporting evidence of sympathetic predominance during and shortly after cold exposure

Table 4. Temporal variations in parameters of hemodynamic regulation, cardiac autonomic regulation, and tympanic temperature.

	Basal vs Pre				Pre vs Post-0'				Post-0' vs Post-10'			
Characteristic	Basal N = 181	Pre N = 181	Diff.2	95% CI2,3	Pre N = 181	Post-0' N = 181	Diff.2	95% CI2,3	Post-0' N = 181	Post-10' N = 181	Diff.2	95% CI2,3
Diastolic Blood Pressure	77.8 ± 10.1	89.2 ± 8.4	-1.3	-2.0, -0.49	89.2 ± 8.4	85.8 ± 16.1	0.28	-0.49, 1.10	85.8 ± 16.1	87.8 ± 15.4	-0.13	-0.90, 0.64
Systolic Blood Pressure	125.4±16.7	139.1±16.1	-0.86	-1.60, -0.11	139.1 ± 16.1	142.9 ± 27.0	-0.18	-0.95, 0.59	142.9 ± 27.0	138.4 ± 16.9	0.21	-0.56, 0.98

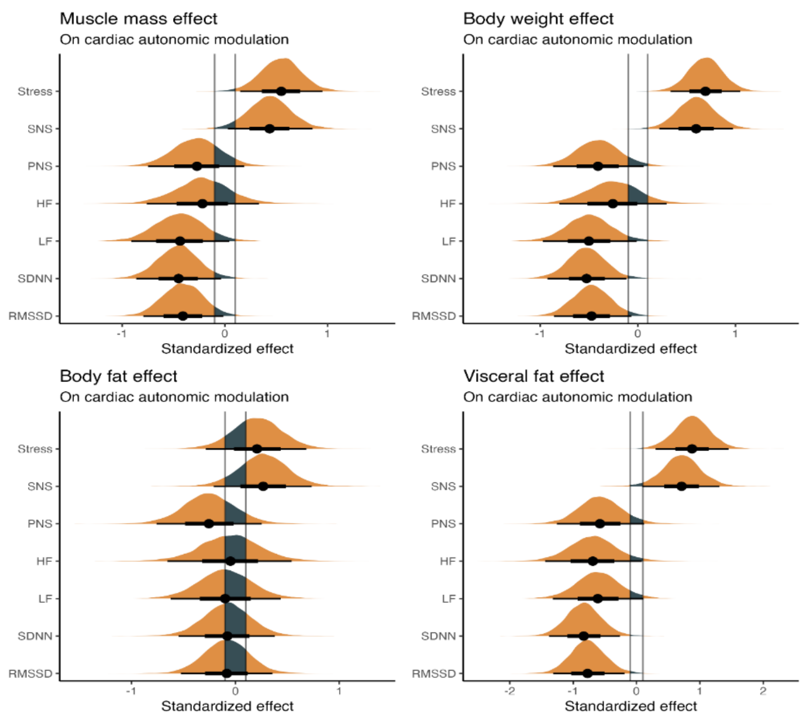
Right tympanic temperature	37.1 ± 0.4	36.0 ± 0.8	2.0	1.10, 2.80	36.0 ± 0.8	35.5 ± 0.7	0.69	-0.10, 1.50	35.5 ± 0.7	36.2 ± 0.8	-0.90	-1.70, -0.10
Left tympanic temperature	37.0 ± 0.2	36.0 ± 0.6	2.1	1.20, 3.00	36.0 ± 0.6	35.7 ± 0.7	0.53	-0.25, 1.30	35.7 ± 0.7	36.3 ± 0.6	-0.91	-1.70, -0.10
R-R interval Duration	910.9±123.8	815.0±100.6	0.88	0.10, 1.70	815.0 ± 100.6	639.5 ± 94.6	1.9	0.95, 2.80	639.5 ± 94.6	761.8 ± 111.4	-1.2	-2.10, -0.39
RMSSD	38.7 ± 17.6	42.1 ± 25.6	-0.17	-0.91, 0.58	42.1 ± 25.6	14.9 ± 14.8	1.4	0.51, 2.20	14.9 ± 14.8	36.7 ± 24.0	-1.1	-2.00, -0.31
SDNN	47.0 ± 19.7	42.4 ± 23.0	0.22	-0.52, 0.97	42.4 ± 23.0	19.7 ± 13.0	1.3	0.42, 2.10	19.7 ± 13.0	44.5 ± 22.0	-1.4	-2.30, -0.57
HF	643.5 ± 577.0	1034.1±1055.4	-0.48	-1.20, 0.28	1034.1±1055.4	157.0±294.9	1.2	0.35, 2.00	157.0 ± 294.9	844.9 ± 870.2	-1.1	-1.90, -0.28
LF	1695.3±1435.2	1643.2±1301.7	0.04	-0.70, 0.78	1643.2±1,301.7	380.5±456.1	1.3	0.50, 2.20	380.5 ± 456.1	1446.5±1180.4	-1.2	-2.10, -0.40
VLF	138.9 ± 145.1	194.5 ± 166.7	-0.37	-1.10, 0.38	194.5 ± 166.7	75.5 ± 108.5	0.88	0.08, 1.70	75.5 ± 108.5	267.0 ± 257.7	-1.0	-1.80, -0.19
PNS index	-0.2 ± 0.9	2.1 ± 10.0	-0.34	-1.10, 0.41	2.1 ± 10.0	0.9 ± 11.8	0.12	-0.65, 0.88	0.9 ± 11.8	2.1 ± 11.5	-0.11	-0.88, 0.66
SNS index	0.4 ± 1.6	5.9 ± 17.7	-0.46	-1.20, 0.30	5.9 ± 17.7	9.4 ± 15.4	-0.22	-0.99, 0.55	9.4 ± 15.4	6.2 ± 16.3	0.21	-0.56, 0.98
Stress index	11.0 ± 6.6	11.1 ± 6.0	-0.03	-0.77, 0.72	11.1 ± 6.0	26.1 ± 12.1	-1.6	-2.50, -0.74	26.1 ± 12.1	12.7 ± 6.8	1.4	0.55, 2.30

Pairwise comparisons of evaluative instances are also presented. Present all the abbreviations in the table: LF, HF, PNS, SNS, etc Data presented as Mean ± SD; n (%). Standardized Mean Difference. CI = Confidence interval

Effect of body composition on autonomic control

Figure 3 illustrates the standardized linear effects of body composition on autonomic modulation. Key findings include: Body Mass, negatively associated with HRV metrics (RMSSD, SDNN, LF), while positively linked to sympathetic activation (SNS index) and stress index; Muscle Mass, showed a similar pattern, negatively influencing HRV and positively correlating with sympathetic markers; Visceral Fat, had the most pronounced effect, showing strong negative associations with parasympathetic markers and positive effects on sympathetic activity and stress responses; Total Body Fat, interestingly, did not demonstrate a significant relationship with autonomic outcomes.

Figure 3. Standardized linear effects of body composition parameters on cardiac autonomic modulation, obtained from multivariate Bayesian generalized linear models. The darkened area represents the region of practical equivalence (ROPE).

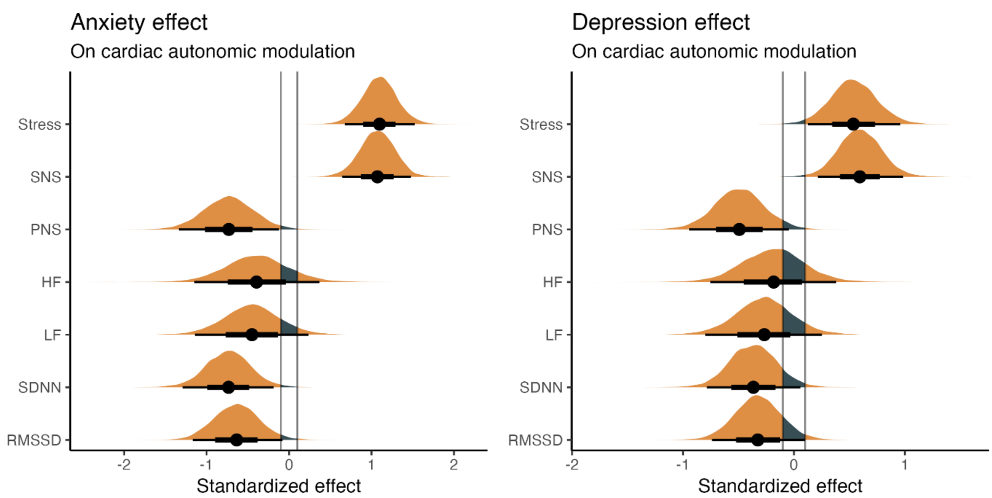


When evaluating the effect of body composition, we observed that body mass generated a negative effect on cardiac autonomic parameters, specifically RMSSD (β = -0.48, CI95%[-0.86, -0.07], pd = 0.99, ps = 0.97, ROPE = 0.01, BF10 = 1.088), SDNN (β = -0.53, CI95%[-0.93, -0.12], pd = 0.99, ps = 0.98, ROPE = 0, BF10 = 1.703), LF (β = -0.5, CI95%[-0.97, -0.01], pd = 0.98, ps = 0.95, ROPE = 0.02, BF10 = 0.784). Despite the above, we observed that body weight was positively associated with a higher index of sympathetic activity (β = 0.6, CI95%[0.22, 0.97], pd = 1, ps = 0.99, ROPE = 0, BF10 = 7.062), and with greater evidence in favor of the autonomic stress index (β = 0.69, CI95%[0.33, 1.05], pd = 1, ps = 1, ROPE = 0, BF10 = 29.344). A similar effect was observed when considering the influence of muscle mass at the level of RMSSD (β = -0.41, CI95%[-0.79, -0.01], pd = 0.98, ps = 0.94, ROPE = 0.04, BF10 = 0.593), SDNN (β = -0.45, CI95%[-0.86, -0.04], pd = 0.98, ps = 0.96, ROPE = 0.02, BF10 = 0.793), SNS index (β = 0.44, CI95%[0.03, 0.85], pd = 0.98, ps = 0.95, ROPE = 0.03, BF10 = 0.626) and finally autonomic stress index (β = 0.55, CI95%[0.15, 0.95], pd = 1, ps = 0.99, ROPE = 0, BF10 = 2.435).

Visceral fat also had a negative effect on HRV markers including RMSSD (β = -0.77, 95%CI[-1.31, -0.19], pd = 1, ps = 0.99, ROPE = 0, BF10 = 2.779), SDNN (β = -0.83, 95%CI[-1.38, -0.26], pd = 1, ps = 0.99, ROPE = 0, BF10 = 5.262), and sympathetic autonomic (β = 0.71, 95%CI[0.09, 1.31], pd = 0.99, ps = 0.97, ROPE = 0, BF10 = 1.51) and autonomic stress indices (β = 0.88, 95%CI[0.3, 1.45], pd = 1, ps = 1, ROPE = 0, BF10 = 5.983). However, despite the existing relationship with visceral fat, this effect was not observed about total body fat.

Effect of anxiety and depression on autonomic control

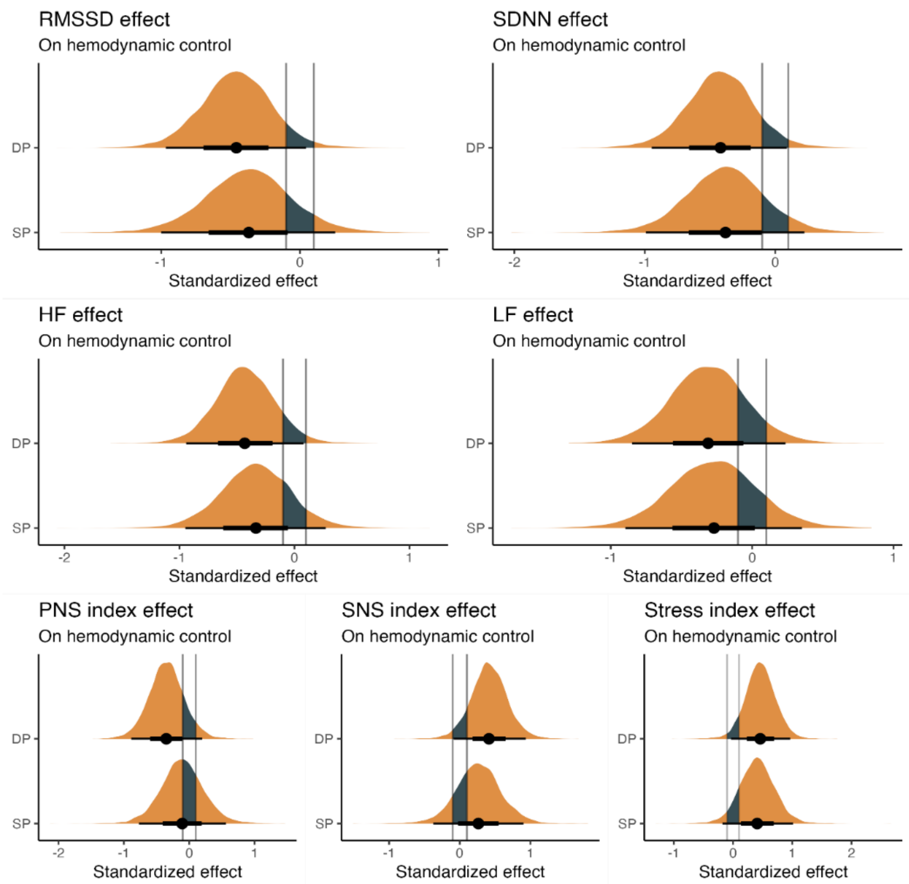
Figure 4. Standardized linear effects of anxiety and depression parameters on cardiac autonomic modulation, obtained from multivariate Bayesian generalized linear models. The darkened area represents the region of practical equivalence (ROPE).



Anxiety, represented as the total score of the instrument, was inversely associated with the activity of cardiac autonomic markers such as RMSSD (β = -0.64, CI95%[-1.17, -0.08], pd = 0.99, ps = 0.97, ROPE = 0, BF10 = 1.336), SDNN (β = -0.73, CI95%[-1.29, -0.19], pd = 1, ps = 0.99, ROPE = 0, BF10 = 2.976), autonomic indices such as PNS (β = -0.73, CI95%[-1.34, -0.12], pd = 0.99, ps = 0.98, ROPE = 0, BF10 = 1.932) and directly with much more evidence in favor of activity indices sympathetic (β = 1.07, CI95%[0.64, 1.48], pd = 1, ps = 1, ROPE = 0, BF10 = 1135.605) and autonomic stress (β = 1.1, CI95%[0.68, 1.52], pd = 1, ps = 1, ROPE = 0, BF10 = 317.26). In the case of depression, assessed in the same way as the total score of the Beck questionnaire, it was clearly and inversely associated with a lower index of parasympathetic activity (β = -0.49, CI95%[-0.95, -0.05], pd = 0.98, ps = 0.95, ROPE = 0.02, BF10 = 0.892), and directly with a higher SNS index (β = 0.59, CI95%[0.22, 0.98], pd = 1, ps = 0.99, ROPE = 0, BF10 = 5.37) and autonomic stress (β = 0.54, CI95%[0.13, 0.96], pd = 0.99, ps = 0.98, ROPE = 0, BF10 = 1.82).

Influence of autonomic control on hemodynamic control

Figure 5. Standardized linear effects of HRV parameters on hemodynamic control, obtained from multivariate Bayesian generalized linear models. The darkened area represents the region of practical equivalence (ROPE).



.

Finally, and about the indices of cardiac autonomic activity and hemodynamic control, we observed that to systolic pressure, there is a globally negative effect of the time indices such as RMSSD (β = -0.37, CI95%[-1, 0.25], pd = 0.89, ps = 0.82, ROPE = 0.12, BF10 = 0.247) and SDNN (β = -0.38, CI95%[-0.99, 0.22], pd = 0.9, ps = 0.83, ROPE = 0.12, BF10 = 0.237), as well as the frequency axes such as HF (β = -0.33, CI95%[-0.95, 0.27], pd = 0.88, ps = 0.78, ROPE = 0.15, BF10 = 0.187) and LF (β = -0.27, CI95%[-0.9, 0.35], pd = 0.81, ps = 0.71, ROPE = 0.18, BF10 = 0.149). On the other hand, there is a tendency for a higher sympathetic tone to be associated with a higher systolic pressure, at least on the part of the SNS index (β = 0.26, CI95%[-0.38, 0.9], pd = 0.81, ps = 0.71, ROPE = 0.19, BF10 = 0.151) and the autonomic stress index (β = 0.41, CI95%[-0.18, 1.01], pd = 0.92, ps = 0.86, ROPE = 0.1, BF10 = 0.285). However, our data provide greater support for the null hypothesis than the posterior probability of the null value after incorporating the data. In the case of diastolic pressure, it seems that the different HRV exert a similar influence to that observed in systolic control, where both the RMSSD (β = -0.46, CI95%[-0.97, 0.04], pd = 0.96, ps = 0.93, ROPE = 0.05, BF10 = 0.482), and SDNN (β = -0.42, CI95%[-0.95, 0.09], pd = 0.95, ps = 0.9, ROPE = 0.08, BF10 = 0.378) show a greater effect than that seen in systolic pressure. At the frequency axis level, we observe that HF exerts a negative effect (β = -0.43, CI95%[-0.94, 0.08], pd = 0.95, ps = 0.9, ROPE = 0.07, BF10 = 0.367) more likely than LF does (β = -0.31, CI95%[-0.85, 0.24], pd = 0.88, ps = 0.79, ROPE = 0.15, BF10 = 0.178). Although, at the level of cardiac autonomic indices, we observed that a higher parasympathetic tone would be associated with lower diastolic pressure (β = -0.35, CI95%[-0.89, 0.2], pd = 0.91, ps = 0.83, ROPE = 0.12, BF10 = 0.228), the evidence provided provides greater support in favor of the absence of an effect on diastolic pressure. On the other hand, both the SNS (β = 0.41, CI95%[-0.09, 0.93], pd = 0.95, ps = 0.9, ROPE = 0.08, BF10 = 0.366) and autonomic stress indices (β = 0.46, CI95%[-0.03, 0.96], pd = 0.97, ps = 0.93, ROPE = 0.05, BF10 = 0.545), exert an effect that proportionally increases diastolic arteriole pressure, which although it provides insufficient evidence in favor of the presence of an effect, this is greater than that observed at the level of systolic control.

Discussion

The findings of this study emphasize the importance of monitoring cardiovascular autonomic function and body temperature in cold-water swimmers, particularly in polar environments, where exposure to extreme cold presents unique physiological challenges. Athletes engaged in this activity experience considerable cardiovascular stress, as evidenced by notable fluctuations in heart rate variability (HRV) and core temperature. These outcomes underscore the importance of continuous monitoring to ensure health and optimize performance in such demanding settings.

Cardiovascular responses to cold immersion are primarily driven by the activation of the sympathetic nervous system, resulting in increased heart rate and peripheral vasoconstriction. In this study, significant reductions in RMSSD and SDNN following immersion indicated decreased parasympathetic activity and enhanced sympathetic dominance. These findings align with previous research showing similar autonomic shifts in cold-water athletes and suggesting that chronic exposure to low temperatures may lead to sustained sympathetic activation, potentially increasing long-term cardiovascular risk (Bruzzi et al., 2022).Although aerobic capacity (e.g., VO_2 max) is known to influence autonomic regulation (athletes with higher maximal oxygen consumption typically have stronger parasympathetic tone at rest and more resilient sympathovagal balance during stress), this study did not evaluate these parameters or an equivalent surrogate measure in our cohort. Future studies should include VO_2 data to clarify the extent to which aerobic capacity modulates cold-induced autonomic adaptations.

Visceral fat emerged as a key factor in autonomic regulation, negatively impacting HRV markers such as RMSSD and SDNN. This is consistent with prior studies demonstrating that elevated visceral adiposity is associated with impaired autonomic balance (Kiviniemi, Hautala, Kinnunen, & Nissila, 2010). These results underscore the relevance of body composition, not only for thermoregulation and physical performance, but also for the cardiovascular adaptation process. As previous research has indicated, reductions in parasympathetic markers during cold-water exposure often occur alongside decreases in both high-frequency (HF) and low-frequency (LF) components of HRV, shifting the sympathovagal balance and increasing heart rate. The Bainbridge reflex may also play a role in this response, as increased venous return during immersion stimulates heart rate through intrinsic mechanisms (Harrison et al., 1986; Mccally, 1964; Pakkam & Brown, 2023).

Core temperature measurements further corroborated the physiological strain induced by cold-water exposure. Significant reductions in tympanic temperature were maintained even after the recovery period, indicating that the body's thermal regulation was compromised. These findings align with earlier studies validating tympanic temperature as a reliable surrogate for internal body temperature under cold stress (Taylor et al., 2014, Hayward et al., 2020). Given the risks of hypothermia, this reinforces the need for proactive rewarming strategies and continuous thermal monitoring in training and competition settings.

Psychological variables also played a pivotal role in modulating autonomic function. Elevated levels of anxiety and depression were associated with decreased parasympathetic tone and increased autonomic stress, mirroring findings from prior studies that link emotional stress to heightened sympathetic output (Koch, Wilhelm, Salzmann, Rief, & Euteneuer, 2019). This underscores the need to integrate psychological assessments into routine evaluations of athletes exposed to extreme environments. Mental health directly influences autonomic balance, which in turn affects cardiovascular performance and recovery.

By simultaneously analyzing physiological, psychological, and morphological variables, this study provides a more comprehensive perspective on the adaptive challenges faced by cold-water swimmers. Our results support a multidimensional approach to training and recovery, one that combines physical conditioning, emotional resilience, and regular monitoring of HRV and body temperature.

To our knowledge, very little research has evaluated long-term autonomic and thermal adaptations in habitual swimmers in polar cold waters under realistic training conditions. Existing protocols, such as short-term cold water immersion in the laboratory or intermittent cold exposure in athletes from temperate climates, do not capture the chronic stressors present in polar environments (Cain et al., 2025; Esperland, de Weerd, & Mercer, 2022). Therefore, our longitudinal field design is novel in that it integrates continuous monitoring of HRV and core temperature with psychological and morphological profiling in an ecologically valid setting. Future work should expand the sample to include comparison groups (e.g., temperate water swimmers or sedentary controls) and swimmers with different experience levels to assess the generalizability and dose-response effects of cold water training. Furthermore, multicenter studies with different age ranges and sports disciplines would help determine whether tailored cold exposure protocols can optimize autonomic resilience in diverse populations.

The lack of direct or indirect measurements of aerobic capacity (VO_2 max) in our cohort represents a limitation, as differences in baseline fitness could partially explain the interindividual variability in autonomic responses to cold stress. We recommend that future research incorporate standardized VO_2 max testing to isolate better the independent effects of cold exposure on autonomic regulation.

Conclusions

This study highlights the intricate interplay between morphological, psychological, and autonomic factors in shaping cardiovascular responses among experienced cold-water swimmers. The findings demonstrate that both body composition, particularly visceral fat, and psychological states such as anxiety and depression significantly influence autonomic regulation during exposure to extreme cold.

These insights underscore the importance of developing integrated strategies that support the physical and emotional well-being of athletes operating in high-stress environments. Personalized training programs that incorporate emotional regulation techniques, targeted physical conditioning, and continuous monitoring of heart rate variability can serve as valuable tools to enhance performance while minimizing health risks.

Furthermore, identifying specific physiological and psychological predictors of autonomic response opens new avenues for optimizing recovery and adaptation in athletes routinely exposed to frigid conditions. By tailoring interventions to individual profiles, practitioners can improve resilience, safety, and athletic outcomes in challenging environments.

Acknowledgements

We thank the swimmers of Club Aguas Abiertas de Magallanes for their willingness and help in carrying out this research.

Financing

This research was self-funded by the researchers themselves.

References

Akselrod, S., Gordon, D., Ubel, F., Shannon, D., Berger, A., & Cohen, R. (1981). Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. Science, 213(4504), 220–222. doi:10.1126/SCIENCE.6166045

Belinchón-deMiguel, P., Navarro-Jiménez, E., Laborde-Cárdenas, C. C., & Clemente-Suárez, V. J. (2024). Evolutionary Echoes: A Four-Day Fasting and Low-Caloric Intake Study on Autonomic Modulation and Physiological Adaptations in Humans. Life 2024, Vol. 14, Page 456, 14(4), 456. doi:10.3390/LIFE14040456

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., … VanderMolen, M. W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. Psychophysiology, 34(6), 623–648.DOI: 10.1111/j.1469-8986.1997.tb02140.x

Berthelsen, L. F., Douglas, A. J. M., Dawkins, T. G., Curry, B. A., Philips, D., Zaidi, A., … Steinback, C. D. (2023). The influence of training status and parasympathetic blockade on the cardiac rate, rhythm, and functional response to autonomic stress. Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition et Metabolisme, 48(3), 270–282. doi:10.1139/APNM-2022-0340

Bruzzi, R. S., Moraes, M. M., Martins, Y. A. T., Hudson, A. S. R., Ladeira, R. V. P., Núñez-Espinosa, C., … Arantes, R. M. E. (2022). Heart rate variability, thyroid hormone concentration, and neuropsychological responses in Brazilian navy divers: A case report of diving in Antarctic freezing waters. Anais Da Academia Brasileira de Ciencias, 94, 1–19. doi:10.1590/0001-3765202120210501

Buchheit, M., Chivot, A., Parouty, J., Mercier, D., Al Haddad, H., Laursen, P. B., & Ahmaidi, S. (2010). Monitoring endurance running performance using cardiac parasympathetic function. European Journal of Applied Physiology, 108(6), 1153–1167. DOI: 10.1007/s00421-009-1317-x

Buchheit, M., & Gindre, C. (2006). Cardiac parasympathetic regulation: respective associations with cardiorespiratory fitness and training load. American Journal of Physiology-Heart and Circulatory Physiology, 291(1), H451–H458.DOI: 10.1152/ajpheart.00008.2006

Bürkner, P. C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. Journal of Statistical Software, 80, 1–28. doi:10.18637/JSS.V080.I01

Cain, T., Brinsley, J., Bennett, H., Nelson, M., Maher, C., & Singh, B. (2025). Effects of cold-water immersion on health and wellbeing: A systematic review and meta-analysis. PLOS ONE, 20(1), e0317615. doi:10.1371/JOURNAL.PONE.0317615

Christensen, N. J., & Galbo, H. (1983). Sympathetic nervous activity during exercise. Annual Review of Physiology, 45, 139–153. doi:10.1146/ANNUREV.PH.45.030183.001035

Elite HRV. (n.d.). Best Heart Rate Variability Monitor & App | Elite HRV. Retrieved 4 November 2024, from https://elitehrv.com/

Esperland, D., de Weerd, L., & Mercer, J. B. (2022). Health effects of voluntary exposure to cold water – a continuing subject of debate. International Journal of Circumpolar Health, 81(1), 2111789. doi:10.1080/22423982.2022.2111789

Goldstein, D. S., Bentho, O., Park, M.-Y., & Sharabi, Y. (2011). Low-frequency power of heart rate variability is not a measure of cardiac sympathetic tone but may be a measure of modulation of cardiac autonomic outflows by baroreflexes. Experimental Physiology, 96(12), 1255–1261. doi:10.1113/expphysiol.2010.056259

Habib, S. S., Alkahtani, S., Aljawini, N., Habib, S. M., & Flatt, A. A. (2024). Resting Heart Rate Variability is Independently Associated with Visceral Fat Rating Scores in Saudi Adult Males. Arquivos Brasileiros de Cardiologia, 121(5), e20220780. doi:10.36660/ABC.20220780

Harrison, M. H., Keil, L. C., Wade, C. A., Silver, J. E., Geelen, G., & Greenleaf, J. E. (1986). Effect of hydration on plasma volume and endocrine responses to water immersion. Journal of Applied Physiology (Bethesda, Md. : 1985), 61(4), 1410–1417. doi:10.1152/JAPPL.1986.61.4.1410

Hayward, G., Verbakel, J. Y., Ismail, F. A., Edwards, G., Wang, K., Fleming, S., … van den Bruel, A. (2020). Non-contact infrared versus axillary and tympanic thermometers in children attending primary care: a mixed-methods study of accuracy and acceptability. The British Journal of General Practice : The Journal of the Royal College of General Practitioners, 70(693), E236–E244. doi:10.3399/BJGP20X708845

Heck, D. W. (2019). A caveat on the Savage-Dickey density ratio: The case of computing Bayes factors for regression parameters. The British Journal of Mathematical and Statistical Psychology, 72(2), 316–333. doi:10.1111/BMSP.12150

Kane, S. M., & Davis, J. (2018). Cardiac Arrest and Death Attributable to the 'Diving Response' Triggered During Incision and Debridement of an Abscess of the Forehead. J Craniofac Surg, 29(5), e507–e509. doi:10.1097/SCS.0000000000004555

Kim, T., Shin, M., & Woo, M. (2023). Autonomic nervous system activity in response to stress and cardiac coherence breathing exercise depending on body composition differences. International Journal of Sport and Exercise Psychology. 23(9):1-17. doi:10.1080/1612197X.2023.2287505

Kiviniemi, A. M., Hautala, A. J., Kinnunen, H., & Nissila, J. (2010). Daily Exercise Prescription on the Basis of, 1355–1363. doi:10.1249/MSS.0b013e3181cd5f39
Koch, C., Wilhelm, M., Salzmann, S., Rief, W., & Euteneuer, F. (2019). A meta-analysis of heart rate variability in major depression. Psychological Medicine, 49(12), 1948–1957. doi:10.1017/S0033291719001351
Livingstone, S. D., Grayson, J., Frim, J., Allen, C. L., & Limmer, R. E. (1983). Effect of cold exposure on various sites of core temperature measurements. Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology, 54(4), 1025–1031. doi:10.1152/JAPPL.1983.54.4.1025
Lundell, R. V., Räisänen-Sokolowski, A. K., Wuorimaa, T. K., Ojanen, T., & Parkkola, K. I. (2020). Diving in the Arctic: Cold Water Immersion's Effects on Heart Rate Variability in Navy Divers. Frontiers in Physiology, 10. doi:10.3389/FPHYS.2019.01600
Mabe-Castro, D., Castillo-Aguilar, M., Mabe-Castro, M., Muñoz, R. M., Basualto-Alarcón, C., & Nuñez-Espinosa, C. A. (2024). Associations between physical fitness, body composition, and heart rate variability during exercise in older people: exploring mediating factors. PeerJ, 12(9), e18061. doi:10.7717/PEERJ.18061/SUPP-6
Makowski, D., Ben-Shachar, M. S., Chen, S. H. A., & Lüdecke, D. (2019). Indices of Effect Existence and Significance in the Bayesian Framework. Frontiers in Psychology, 10, 498833. doi:10.3389/FPSYG.2019.02767/BIBTEX
Malik, M. (1996). Guidelines Heart rate variability, 354–381.
Manolis, A. S., Manolis, S. A., Manolis, A. A., Manolis, T. A., Apostolaki, N., & Melita, H. (2019). Winter Swimming: Body Hardening and Cardiorespiratory Protection Via Sustainable Acclimation. Current Sports Medicine Reports, 18(11), 401–415. doi:10.1249/JSR.0000000000000653
Mccally, M. (1964). PLASMA VOLUME RESPONSE TO WATER IMMERSION: IMPLICATIONS FOR SPACE FLIGHT. Aerospace Medicine.
McCraty, R., & Shaffer, F. (2015). Heart rate variability: New perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. Global Advances In Health and Medicine, 4(1), 46–61. doi:10.7453/gahmj.2014.073
Mercer, J. B. (2001). Tackling Cold Stress. Thermotherapy for Neoplasia, Inflammation, and Pain, 112–117. doi:10.1007/978-4-431-67035-3_13
Pakkam, M. L., & Brown, K. N. (2023). Physiology, Bainbridge Reflex. StatPearls. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK541017/
Rosenwinkel, E. T., Bloomfield, D. M., Arwady, M. A., & Goldsmith, R. L. (2001). Exercise and autonomic function in health and cardiovascular disease. Cardiology Clinics, 19(3), 369–387. doi:10.1016/S0733-8651(05)70223-X
Sanz, J., & Navarro, M. E. (2003). Propiedades psicométricas de una versión española del inventario de ansiedad de beck (BAI) en estudiantes universitarios. [The psychometric properties of a spanish version of the Beck Anxiety Inventory (BAI) in a university students sample.]. Ansiedad y Estrés, 9(1), 59–84.
Sanz, J., Perdigón, A. L., & Vázquez, C. (2003). Adaptación española del Inventario para la Depresión de Beck-II (BDI-II):2. Propiedades psicométricas en población general The spanish adaptation of Beck's Depression Inventory-II (BDI-II): Clinica y Salud, 14(3), 249–280.
Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-Aho, P. O., & Karjalainen, P. A. (n.d.). Kubios HRV–heart rate variability analysis software. Computer Methods and Programs in Biomedicine, 113(1), 210–220.
Taylor, N. A. S., Tipton, M. J., & Kenny, G. P. (2014). Considerations for the measurement of core, skin and mean body temperatures. Journal of Thermal Biology, 46, 72–101. doi:10.1016/J.JTHERBIO.2014.10.006
The R Project for Statistical Computing. (n.d.). R: The R Project for Statistical Computing. Retrieved 4 November 2024, from https://www.r-project.org/
Vehtari, A., Gelman, A., Simpson, D., Carpenter, B., & Bürkner, P.-C. (2019). Rank-normalization, folding, and localization: An improved R for assessing convergence of MCMC. Bayesian Analysis, 16(2), 667–718. doi:10.1214/20-BA1221

Authors and translators' details:

Josefa Lillo Bobadilla	jlillo@umag.cl	Author
Aline Fieldhouse Sandoval	afieldho@umag.cl	Author
Pedro Fernández Fredes	pefernan@umag.cl	Author
Paula Bravo Sepúlveda	paulabravosep@gmail.com	Author
Matías Castillo-Aguilar	matias.castillo@umag.cl	Author
Michele Macedo Moraes	michelemacedo.moraes@gmail.com	Author
Thiago Teixeira Mendes	thiagotemendes@gmail.com	Author
Cristian Núñez-Espinosa	cristian.nunez@umag.cl	Author