

RESEARCH

Open Access



Influence of breathing strategies on maximal strength output and hemodynamic parameters during bench press exercise

Ismail Emre Deniz¹ and Ibrahim Erdemir^{2*}

Abstract

Background The role of breathing strategy during high-intensity resistance training remains underexplored in the literature, particularly in relation to performance outcomes and cardiovascular modulation. This study aimed to examine the acute effects of three distinct breathing techniques—*inhalation*, *exhalation*, and *breath-holding* (Valsalva maneuver)—on performance parameters and heart rate variability (HRV) during maximal bench-press exercise in resistance-trained males.

Methods Twelve healthy, non-smoking male participants (age: 27.92 ± 7.38 years), with at least two years of consistent isotonic resistance training experience, were recruited. Exclusion criteria included chronic disease and prior or current use of hormone-based substances. Each participant completed three testing sessions in a counterbalanced order, with one breathing condition applied per session. Breathing techniques were standardized via instructional videos and monitored during testing. Performance was assessed by the total number of sets completed and total volume lifted (kg). Cardiovascular responses were measured via a Holter monitor for HRV parameters—standard deviation of normal-to-normal intervals (SDNN), root mean square of successive differences (RMSSD), percentage of NN intervals differing by > 50 ms (pNN50), low-frequency power (LF), high-frequency power (HF), and LF/HF ratio—and heart rate. Blood pressure was recorded at three time points: pre-exercise, after the third set, and post-exercise. Statistical analyses included the Friedman test, Dunn–Bonferroni post hoc, and Kendall's W for effect size.

Results Breathing strategy had a statistically significant effect on SDNN ($\chi^2 = 6.00, p = 0.05, W = 0.273$), while other HRV and blood pressure measures showed no significant changes ($p > 0.05$). Performance metrics differed significantly across conditions, with *inhalation* resulting in lower set completion ($\chi^2 = 13.86, p < 0.001, W = 0.578$) and training volume ($\chi^2 = 13.07, p < 0.001, W = 0.544$).

Conclusion Breathing technique influenced both autonomic and performance responses. *Inhalation* during lifting was associated with reduced performance and lower SDNN values. These findings are preliminary and limited by small sample size and the use of a single exercise modality.

Keywords Heart rate variability, Breathing technique, Resistance exercise, Valsalva maneuver, Autonomic modulation

*Correspondence:

Ibrahim Erdemir
ierdemir@balikesir.edu.tr

¹Department of Biostatistics, Institute of Health Sciences, Bursa Uludag University, Gorukle, Bursa, Turkey

²Faculty of Sport Sciences, Department of Coaching Education, Balikesir University, Balikesir, Turkey



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

Background

Athletes and people generally prefer resistance training to increase their performance. Because the capacity of the muscles and the way they show resistance during performance are important for the sustainability of sports activities. Strength during exercise is associated with high performance. Being able to gain resistance depends on the intensity, frequency, rest and duration of the exercise. The order, type and frequency of exercises also affect these variables [1]. There is not much research available to observe the autonomic responses of these different variants. The type of muscle contraction can change the autonomic modulation. For this, it can be said that it is useful to follow some variables (heart rate variability (HRV), blood pressure (BP)).

Maximal resistance exercise is an exercise method applied with high intensity and low repetitions, increasing strength and maximum power. In maximal resistance exercises, since the athlete exercises with high efficiency by using his maximum power, circulation and respiratory resources may be limited during rest. In this case, it is thought that the athlete's stretching and breathing exercises are effective [2].

The breathing technique used during the exercise is also very important within the scope of the exercise. Changes in BP are also observed during the athlete's inhalation, exhalation or breath-holding. The load on the heart and BP increases during exhalation or holding the breath. On the other hand, breathing can also contribute to decreasing intrathoracic pressure during resistance exercise and reducing the rise in BP [3]. During exercise, the need for oxygen increases. This need is met by the increase in cardiac output. This continues throughout the exercise. When the aerobic threshold is crossed, the relationship between cardiac output and oxygen consumption begins to diverge at the level at which anaerobic respiration appears. Cardiac output rises during maximal exercise. This causes an increase in BP. With the onset of exercise, there are some changes in heart rate as well as cardiac output in the cardiovascular system.

HRV has been used as a noninvasive method of heart rate (HR) regulation by the parasympathetic and sympathetic divisions of the autonomic nervous system. Acute resistance exercise appeared to reduce cardiac parasympathetic modulation more than aerobic exercise in young healthy adults, suggesting an increased risk of cardiovascular dysfunction after resistance exercise. Regardless of age, resistance exercises seem to reduce parasympathetic activity. Evaluating BP with HRV is useful for assessing autonomous cardiovascular control [4].

Individuals who exercise aim to improve their maximum performance within the framework of body and heart health. The primary adaptive system in responding to increased demands during exercise is the

cardiovascular system. The cardiovascular system plays a key role in many adaptation responses during exercise [5, 6]. Considering that acute effects during exercise can cause chronic effects in the long term, it can be said that the factors in this acute process are very important. At this point, it should be investigated how the variables on the cardiovascular system (HRV, HR, slowing capacity of heart rate, BP) affect the athlete's recovery and regeneration times, as well as what consequences they cause in terms of heart health.

A review of the existing literature indicates a lack of comprehensive studies examining the effects of different breathing strategies during maximal resistance exercises on heart rate variability (HRV), performance, and cardiovascular responses. Previous research has provided limited and inconsistent findings regarding how specific breathing techniques influence autonomic modulation and exercise performance under maximal loading conditions.

Therefore, the present study aimed to investigate the acute effects of three distinct breathing techniques—exhalation, inhalation, and breath-holding (Valsalva maneuver)—on HRV parameters and performance outcomes during maximal bench-press exercise in resistance-trained individuals. Rather than identifying the “most suitable” technique, this study sought to provide preliminary evidence on how different breathing strategies may affect cardiovascular regulation and performance during high-intensity resistance efforts.

Methods

Subjects

Twelve healthy male volunteers, aged between 20 and 45 years, participated in the study. All participants had been regularly engaged in isotonic resistance training (bodybuilding-focused) for a minimum of two years, with an average training experience of 8.17 ± 3.12 years and a weekly training frequency of 4.50 ± 0.80 days. Inclusion criteria required participants to be non-smokers (lifetime and current), to be free of any chronic disease, and to have no history of using hormone-based medications or supplements on a regular basis.

Participants' breathing habits during routine resistance exercise were also recorded prior to the experimental sessions. Seven individuals reported that they typically exhaled during the lifting phase, while five reported using breath-holding (Valsalva maneuver) in their regular training. However, because these breathing habits were based on self-reported data, the potential for reporting bias must be acknowledged. The absence of objective verification (e.g., observational pre-testing or video-based assessment) may limit the precision of participant characterization. Age distribution, body composition, and training background were collected and

reported to characterize the sample, although statistical analyses focused on within-subject comparisons due to the limited sample size ($n=12$). Although the sample size was determined through an a priori power analysis, the relatively small number of participants ($n=12$) represents a limitation. As such, statistical analyses focused on within-subject comparisons, and the generalizability of the findings—particularly considering possible inter-individual variability in physiological responses—should be interpreted with caution.

This study was conducted in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Ethical approval was obtained from the Balikesir University Ethics Committee (08/03/2022 2022/30). Written informed consent was obtained from all individual participants included in the study.

Data collection tools

Body mass index and body fat percentage

Body fat percentage and body mass index (BMI) were determined by the bioelectric impedance method (Tanita BC 545 N, Tanita Corporation, Tokyo, Japan).

Heart Rate Variability (HRV) and Heart Rate (HR)

HRV and HR were continuously recorded throughout each testing session using a three-channel Holter monitor (DMS 300–3 A, DM Software, Nevada, USA). To ensure consistency across all breathing conditions, HRV analysis was based on short-term time-domain and frequency-domain parameters, calculated from standardized 5-minute segments obtained at three specific time points: (1) pre-exercise (baseline), following attachment of the Holter device and before the warm-up; (2) mid-exercise, immediately after completion of the third set; and (3) post-exercise, beginning 5 min after the sixth set during recovery. The primary time-domain indices extracted were SDNN and rMSSD, which are widely accepted markers of autonomic modulation. Frequency-domain measures—LF, HF, and LF/HF ratio—were derived using fast Fourier transformation to characterize sympathetic–parasympathetic balance.

These methodological clarifications were implemented to enhance reproducibility and to ensure accurate interpretation of autonomic responses across the different breathing strategies.

Blood Pressure (BP)

Blood Pressure (BP)

Measurements were taken using a validated wrist-based oscillometric device (Nais EW2720, Düsseldorf,

Germany). To ensure accuracy, participants were seated and instructed to keep the measurement wrist at heart level, with arm support and minimal movement. Although wrist-based oscillometric monitors offer practical and noninvasive advantages, they are not considered the gold standard for BP assessment compared to upper-arm cuff devices [7]. This limitation introduces the possibility of measurement error, particularly during exercise-induced hemodynamic fluctuations. Therefore, BP findings should be interpreted with caution, as potential device-related underestimation or overestimation may have influenced the magnitude of observed changes. Blood pressure was monitored and recorded from the participants' left wrist at the beginning (pre-test), middle (between 3 and 4) and end of exercise (post-test).

The Rating of Perceived Exertion (RPE)

Perceived exertion was assessed immediately after each bench-press session using a modified 1–10 category-ratio RPE scale, which offers a simplified alternative to the traditional Borg 6–20 scale. This format has been frequently used in resistance training studies due to its ease of understanding and practical application [8]. RPE is how hard the participants feel like their body is working the maximal bench-press performed by applying different breathing types (in exhalation, in breath-holding, in inhalation) during maximal bench-press on every set after the sets. The scores of the participants at the end of each set for maximal bench-press application were collected. It was then divided by the number of sets and the RPE value of the entire exercise was determined.

Bench-press

The bench-press exercise was intentionally chosen because it is a multi-joint, upper-body compound movement that elicits consistent cardiovascular and hemodynamic responses, making it suitable for examining the influence of breathing strategies on maximal strength output and acute cardiovascular parameters. Additionally, the bench-press is one of the most widely studied resistance exercises, allowing for better comparison with existing literature.

Equipment of exercise

Exercises were performed using free weights, Olympic bench-press, Olympic bar (20 kg) and weight plates (20 kg, 10 kg, 5 kg, 2.5 kg, and 1 kg) in the bodybuilding and fitness center.

1 Repetition Maximum (RM) test

One RM test was applied to the participants to calculate their maximal strength in the bench-press exercise 1 week before the first exercise day. During the 1 RM test, the athlete breathed as he preferred. Participants were

ensured that they did not pause between repetitions in the set and that they completed the range of motion defined for the exercise.

During the test, participants rested for no less than 10 min before each trial. 1 RM trials were performed 3 times, and their averages were taken [9]. In the calculation, the formula developed by Brzycki [10] “(1 RM = (Lifted weight)/[1.0278 - (Number of repetitions x 0.0278)])” was used.

Exercise: bench-press, 6 sets of 4 RM, 5 min. rest between sets.

Volume = (4 RM) load X repetition X set.

Example 1 RM = 100 kg; 4 RM = 90 kg; repetition = 4; set = 6.

Volume = 90 × 4 × 6 = 2160 kg.

Resistance training

All participants performed a standardized resistance exercise protocol focusing exclusively on the flat barbell bench-press. This exercise was selected due to its relevance as a multi-joint upper-body movement that elicits substantial cardiovascular, neuromuscular, and hemodynamic responses, making it well-suited for investigating the effects of breathing strategies on acute physiological outcomes. The protocol consisted of three phases:

Warm-Up phase

Participants began with 15 min of light jogging followed by 2 sets of 15 repetitions at 50% of their predetermined 1-repetition maximum (1RM) on the bench-press. This phase was designed to increase core temperature, activate relevant musculature, and promote neuromuscular readiness.

Main exercise phase

Participants performed 6 sets of 4 repetitions at 90% of their 1RM (approximating a 4RM load). Between each set, 5 min of passive rest were given to allow for sufficient recovery and minimize cumulative fatigue. The tempo of the bench-press movement was standardized as 2/0/3, indicating a 2-second eccentric (lowering) phase, 0-second transition, and a 3-second concentric (lifting) phase. This controlled tempo was employed to regulate time under tension and ensure consistency across trials.

Cool-down phase

The session concluded with 15 min of low-intensity jogging and static stretching, focusing on the major upper-body muscle groups.

Breathing strategies

Exhalation strategy

Participants exhaled during the concentric phase (lifting the weight) and inhaled during the eccentric phase (lowering the weight). This technique reflects the most commonly recommended breathing pattern in resistance training, facilitating intra-abdominal pressure control and movement rhythm.

Inhalation strategy

Participants inhaled during the concentric phase and exhaled during the eccentric phase. This reverse breathing pattern was included to investigate potential hemodynamic and performance differences when air intake occurs during force generation.

Breath-holding (Valsalva) strategy

Participants held their breath during the concentric phase (i.e., performed a Valsalva maneuver) and inhaled/exhaled during the eccentric phase. The Valsalva technique increases intra-thoracic pressure, providing core stabilization but potentially influencing cardiovascular responses.

All participants received standardized verbal instructions and familiarization sessions before testing. However, no objective verification method (e.g., respiratory sensors, video analysis, or airflow monitoring) was used to confirm precise adherence to the assigned breathing patterns during execution. This limitation should be considered when interpreting the findings, as minor deviations in breathing behavior may introduce variability in physiological responses.

Experimental procedures

The present study was conducted using a within-subject (repeated-measures) design, wherein all participants completed the bench-press exercise under three distinct breathing conditions: (1) inhalation during the concentric phase, (2) exhalation during the concentric phase, and (3) breath-holding via the Valsalva maneuver. To minimize potential order effects, the sequence of breathing conditions was counterbalanced across participants using a Latin square design.

To ensure consistent and accurate execution of the breathing strategies, participants were provided with standardized instructions and practical guidance on how to perform each breathing technique. Beginning one week prior to the initial testing session, participants were instructed to incorporate the designated breathing patterns into their regular bench-press training as a familiarization protocol. Verbal confirmation of adherence was obtained from each participant at the start of every test session.

Additionally, participants were instructed to abstain from strenuous physical activity for a minimum of 72 h before each test. Compliance was confirmed via self-report upon arrival. All tests were performed at the same time of day on each testing session to control for circadian variations. The study lasted 4 weeks.

1 RM test was applied in the first week. The 1 RM of the participants was determined by the bench-press. The weights they would work with (4 RM) were determined.

In the second week, the participants had a special warm-up with 2 × 15 repetitions with 50% of the weight they would use on the bench-press. Then, a rhythm holter monitor was connected to the participant and their BP (pre-test) was measured with a sphygmomanometer. Participants exhaled while lifting (concentric phase) and inhaled while lowering (eccentric phase) the weight (4 RM) during the bench-press. Participants performed the same procedure over 6 sets of 4 RM. At the end of each set, participants evaluated the difficulty level of the set according to the Borg RPE scale [11]. Participants rested for 5-min. between sets. BP measurement was taken again between the 3rd set and 4th set (inter-test). At the end of the 6th set, BP measurement was taken again (post-test). After 5 min., the Rhythm holter device was removed and cooled down.

In the third week, the same test procedure was applied by changing the breathing type. Participants inhaled

while lifting (concentric phase) and exhaled while lowering (eccentric phase) the weight (4 RM) during the bench-press.

In the fourth week participants performed the same test by changing the breathing type. Participants breath holding while lifting (concentric phase) and inhaled and exhaled while lowering (eccentric phase) the weight (4 RM) during the bench-press.

Although the use of a within-subject design minimizes inter-individual differences, variations in neuromuscular efficiency and fatigue resistance may still influence acute physiological responses. Standardized rest intervals, controlled movement tempo, and fixed relative intensity (4RM load) were implemented to mitigate this limitation. The exclusive use of a single exercise (bench-press) increases internal validity but limits generalizability to other resistance movements involving different muscle groups or kinetic demands.

As shown in Fig. 1, the experimental protocol spanned four consecutive weeks, each involving distinct breathing strategies and consistent testing procedures.

Statistical analyses

Prior to data collection, a power analysis was conducted using the G*Power 3.1.9.7 software to determine the minimum required sample size. For a within-subjects repeated-measures design with a medium effect size

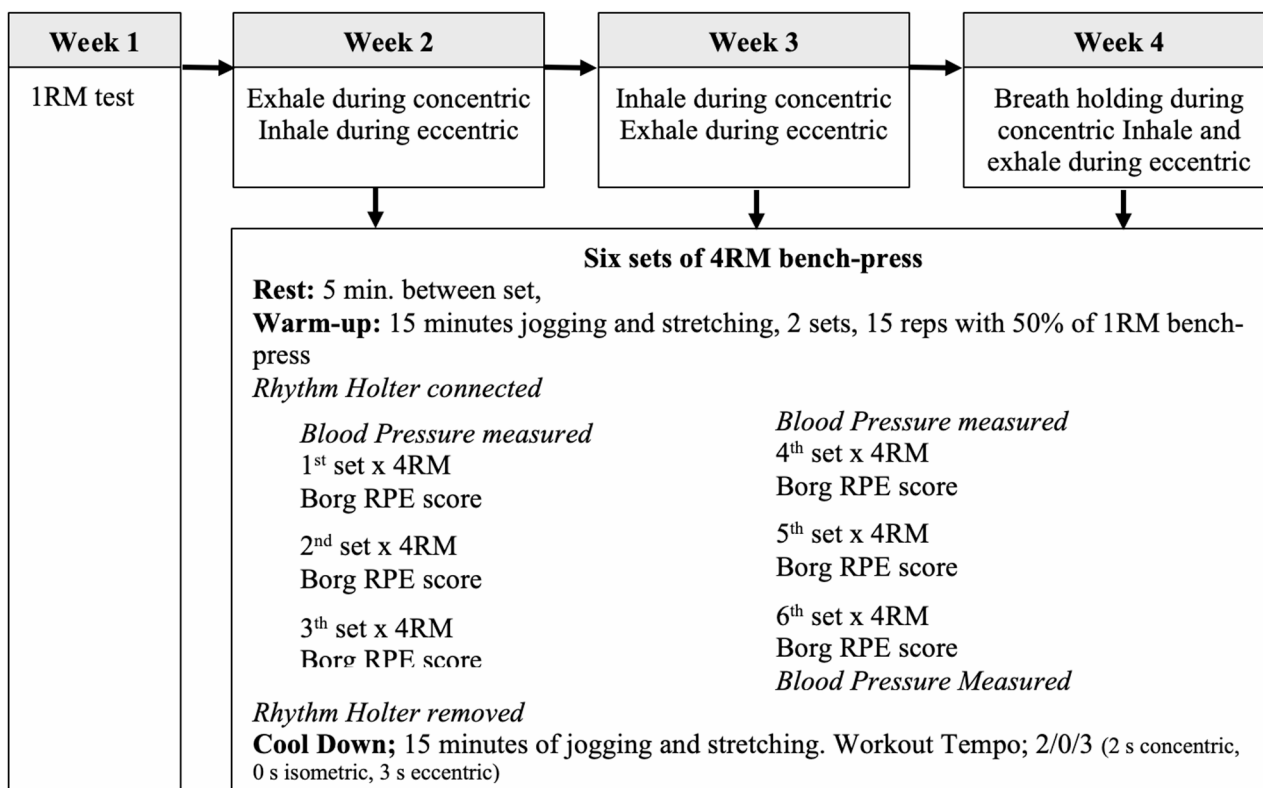


Fig. 1 Experimental design diagram. RPE = Rating of Perceived Exertion; RM = Repetition Maximum

($f=0.50$), power $(1-\beta)=0.95$ $\alpha=0.05$, three measurements, an inter-correlation among repeated measures of 0.50, and a nonsphericity correction (ϵ) of 1, the required sample size was estimated as 12 participants. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize the data obtained in the study. The Shapiro–Wilk test was applied to assess the normality of data distribution. As the data were not normally distributed, the Friedman test was employed to determine the significance of differences among the three test conditions. The Kendall's W coefficient of concordance was calculated to evaluate the effect size associated with the Friedman test. To identify the source of significant differences, the Dunn–Bonferroni post hoc test was performed. For pairwise comparisons showing statistical significance in the Dunn–Bonferroni test, effect sizes were calculated using the formula $r = \frac{|Z|}{\sqrt{N}}$. Additionally, the Spearman rank-order correlation test was used to examine the relationships among variables. All results were evaluated at 95% Confidence Intervals (CI), with statistical significance accepted at $p \leq 0.05$.

Results

Descriptive parameters of the participants in our research; age (27.92 ± 7.38 years), height (174.08 ± 5.60 cm), body weight (81.56 ± 8.23 kg), BMI (26.86 ± 1.90 kg/m²), body fat % ($13.88 \pm 3.22\%$), training history (8.17 ± 6.94 years) and weekly exercise numbers (4.50 ± 0.80 #) were determined.

The Friedman test was conducted to examine the effects of different breathing techniques on the participants' heart rate variability (HRV) parameters during the maximal bench-press exercise. The results revealed a significant difference in the standard deviation of N–N

intervals (SDNN) among the breathing conditions [$\chi^2 = 6.00$, $p=0.050$, Kendall's $W=0.250$]. The calculated effect size ($W=0.250$) indicates a moderate level of agreement, suggesting that the measurements were consistent across conditions. To identify the source of the difference, a Dunn–Bonferroni post hoc test was performed. A significant difference was observed between the breath-holding and inhalation conditions in SDNN values ($Z=2.449$, $r=0.707$, $p=0.043$, 95% CI=[0.201, 1.799]) during the maximal bench-press. The obtained effect size ($r=0.707$) demonstrates a large effect magnitude. However, no significant differences were detected between the exhalation and breath-holding conditions ($Z=-1.225$, $p>0.05$, 95% CI=[-0.299, 1.299]) or between the exhalation and inhalation conditions ($Z=1.225$, $p>0.05$, 95% CI=[-1.299, 0.299]). No statistically significant differences were found in other HRV parameters, including the percentage of successive NN intervals that differ by more than 50 ms (pNN50), root mean square of successive differences (rMSSD), low-frequency power (LF), high-frequency power (HF), LF/HF ratio, average HR, maximum HR, and deceleration capacity (DC) ($p>0.05$) (Table 1).

Friedman test was applied to determine the effect of different breathing types on BP after maximal bench-press. As a result, no significant differences were detected in the systolic BP and diastolic BP parameters ($p>0.05$) (Table 2).

The Friedman test was conducted to examine the effects of different breathing techniques on performance parameters—namely, the number of completed sets, total training volume, and the RPE score—during the maximal bench-press exercise. The results revealed statistically significant differences among breathing conditions for the number of completed sets [$\chi^2 = 13.86$, $p<0.001$, Kendall's $W=0.578$], total volume lifted [$\chi^2 = 13.07$, $p<0.001$, Kendall's $W=0.544$], and RPE scores [$\chi^2 = 13.68$, $p<0.001$, Kendall's $W=0.570$]. The corresponding

Table 1 Comparison of participants' HRV parameters according to breathing types during maximal bench-press

Parameters	Exhalation (n = 12)		Breathe holding (n = 12)		Inhalation (n = 12)		χ^2	p	Kendall's W
	$\bar{X} \pm SD$	Median (IQR)	$\bar{X} \pm SD$	Median (IQR)	$\bar{X} \pm SD$	Median (IQR)			
SDNN (ms)	79.17 ± 24.03	84.00 (46.00)	80.25 ± 21.32*	85.00 [†] (36.75)	76.58 ± 19.84*	82.50 [†] (27.00)	6.00	0.050*	0.250
pNN50 (%)	9.50 ± 9.59	6.00 (11.75)	7.42 ± 6.13	5.00 (7.50)	6.67 ± 4.75	5.50 (9.50)	0.55	0.761	0.023
rMSSD (ms)	28.83 ± 14.11	25.00 (27.25)	26.25 ± 9.32	24.00 (10.00)	25.33 ± 7.90	25.00 (14.00)	0.89	0.640	0.037
LF (ms ²)	928.05 ± 477.71	860.00 (703.10)	878.97 ± 330.13	863.40 (537.70)	812.18 ± 409.51	765.20 (737.08)	1.17	0.558	0.049
HF (ms ²)	199.74 ± 135.39	159.25 (277.90)	199.88 ± 112.92	182.85 (188.10)	168.76 ± 85.57	172.10 (144.25)	1.17	0.558	0.049
Ratio LF/HF	6.08 ± 3.72	4.83 (4.42)	5.45 ± 2.37	4.94 (4.37)	5.27 ± 1.89	5.23 (3.20)	0.17	0.920	0.007
\bar{X} HR #	91.14 ± 10.84	89.95 (19.24)	92.26 ± 8.33	91.92 (11.04)	91.38 ± 8.11	89.88 (11.60)	0.67	0.640	0.037
Max. HR #	130.83 ± 16.68	129.00 (24.00)	130.08 ± 17.27	125.00 (30.54)	129.50 ± 13.81	130.00 (26.00)	0.67	0.717	0.028
DC (ms)	6.08 ± 1.58	6.20 (2.42)	6.16 ± 1.30	6.39 (2.06)	6.26 ± 1.55	6.17 (2.47)	0.50	0.779	0.021

Abbreviations: DC deceleration capacity, HF High-frequency power, HR Heart rate, LF Low-frequency power, LF/HF High-frequency power/Low-frequency power, pNN50 Percentage of successive NN intervals that differ by more than 50 ms, rMSSD Root mean square of successive N–N interval differences, SDNN Standard deviation of N–N intervals

* $p \leq 0.05$, χ^2 : Chi-Square Test, Kendall's W: Effect size of Friedman Test, #: number, IQR: Interquartile Range

Table 2 Comparison of systolic and diastolic BP parameters according to the types of breath during maximal bench-press

Parameters	Exhalation (n = 12)		Breath-holding (n = 12)		Inhalation (n = 12)		χ^2	p	Kendall's W
	$\bar{X} \pm SD$	Median (IQR)	$\bar{X} \pm SD$	Median (IQR)	$\bar{X} \pm SD$	Median (IQR)			
Pre-exercise SBP (mmHg)	131.17 ± 10.59	132.50 (17.00)	128.25 ± 12.60	125.00 (19.00)	126.08 ± 9.20	125.50 (16.00)	2.65	0.266	0.111
Between 3 & 4 sets SBP (mmHg)	131.67 ± 12.41	135.00 (15.00)	129.67 ± 11.77	130.00 (18.00)	124.92 ± 9.09	124.50 (12.00)	2.43	0.297	0.101
Post-exercise SBP (mmHg)	128.50 ± 8.88	128.00 (18.00)	125.00 ± 9.40	121.00 (8.00)	124.50 ± 7.59	123.00 (4.00)	2.74	0.254	0.114
Pre-exercise DBP (mmHg)	78.58 ± 8.82	78.50 (13.00)	81.25 ± 10.20	81.50 (13.00)	79.42 ± 8.27	77.00 (13.00)	0.31	0.856	0.013
Between 3 & 4 sets DBP (mmHg)	76.00 ± 10.60	76.00 (7.00)	87.42 ± 18.26	85.00 (18.00)	74.83 ± 8.82	73.00 (12.00)	5.15	0.076	0.215
Post-exercise DBP (mmHg)	83.33 ± 10.35	81.50 (12.00)	78.67 ± 6.11	78.00 (7.00)	76.58 ± 12.96	78.00 (12.00)	3.30	0.192	0.114

Abbreviations: DBP Diastolic Blood Pressure, SBP Systolic Blood Pressure

* $p \leq 0.05$; χ^2 : Chi-Square Test, Kendall's W: Effect size of Friedman Test, IQR: Interquartile Range

Table 3 Comparison of training parameters and BORG scale parameters according to breathing types during maximal bench-press

Parameters	Exhalation (n = 12)		Breath-holding (n = 12)		Inhalation (n = 12)		χ^2	p	Kendall's W
	$\bar{X} \pm SD$	Median (IQR)	$\bar{X} \pm SD$	Median (IQR)	$\bar{X} \pm SD$	Median (IQR)			
Set (#)	23.50 ± 1.00	24.00 (0.75)	23.83 ± 0.58	24.00 (0.00)	20.75 ± 4.03	22.00 (2.75)	13.86	0.001*	0.578
Volume (kg)	2410.42 ± 395.06	2280.00 (675.00)	2437.92 ± 361.38	2280.00 (585.00)	2132.71 ± 555.08	2032.50 (681.88)	13.07	0.001*	0.544
RPE score (#)	7.14 ± 1.51	7.58 (2.29)	5.96 ± 2.21	6.50 (3.46)	7.24 ± 1.74	7.00 (3.13)	13.68	0.001*	0.570

Abbreviations: RPE Rating of Perceived Exertion, SDNN Standard deviation of N-N intervals, Volume total weight lifted in the exercise

* $p \leq 0.05$, χ^2 : Chi-Square Test, Kendall's W: Effect size of Friedman Test, #: number, IQR: Interquartile Range

effect size values ($W = 0.578$, $W = 0.544$, and $W = 0.570$, respectively) indicate a higher-than-moderate level of agreement, thereby confirming the consistency and reliability of the measurements (Table 3).

A Dunn–Bonferroni post hoc test was performed to determine which breathing technique accounted for the observed differences. A statistically significant difference was found between the breath-holding and inhalation conditions in the total number of sets completed during the maximal bench-press ($Z = 2.756$, $r = 0.796$, $p = 0.006$, 95% CI = [0.331, 1.929]). The calculated effect size ($r = 0.796$) demonstrates a large effect magnitude. Additionally, a significant difference was observed between the exhalation and inhalation techniques ($Z = 2.143$, $r = 0.618$, $p = 0.032$, 95% CI = [0.081, 1.679]), indicating a large effect ($r = 0.618$). However, no significant difference was detected between the breath-holding and exhalation conditions ($Z = -0.612$, $p > 0.05$, 95% CI = [-1.049, 0.549]).

Furthermore, in the maximal bench-press volume, a significant difference was observed between the exhalation and inhalation conditions ($Z = 2.245$, $r = 0.648$, $p = 0.025$, 95% CI = [0.121, 1.719]), with a large effect size. A significant difference was also found between breath-holding and inhalation techniques ($Z = 2.654$, $r = 0.766$, $p = 0.008$, 95% CI = [0.291, 1.889]), again indicating a large effect magnitude ($r = 0.766$). However, no significant difference was identified between exhalation and breath-holding conditions ($Z = -0.408$, $p > 0.05$, 95% CI = [-0.629, 0.969]). These findings suggest that the type of breathing

technique employed during the maximal bench-press substantially influences both performance volume and perceived exertion (Table 3).

A significant difference was observed in the RPE values between the exhalation and breath-holding conditions during the maximal bench-press ($Z = 2.347$, $r = 0.677$, $p = 0.019$, 95% CI = [0.161, 1.759]). The calculated effect size ($r = 0.677$) demonstrates a large effect magnitude. Furthermore, a significant difference was found between the breath-holding and inhalation conditions ($Z = 3.470$, $r = 1.000$, $p < 0.001$, 95% CI = [0.621, 2.219]), with an extremely large effect size ($r = 1.000$). However, no significant difference was detected between the exhalation and inhalation conditions ($Z = -1.123$, $p > 0.05$, 95% CI = [-0.339, 1.259]). These findings indicate that breathing technique significantly affects perceived exertion levels during maximal bench-press performance. Detailed results are presented in Table 3.

A significant, above moderate and negative correlation ($r = -0.676$, $p \leq 0.05$) was found between volume (inhalation) and SDNN (breath-holding) values while lifting weights during the bench-press. In addition, a significant, strong and negative correlation was observed between volume (inhalation) and SDNN (inhalation) values ($r = -0.713$, $p \leq 0.01$) (Table 4).

Table 4 Correlation analysis among the HRV (SDNN), RPE and volume

Parameters	SDNN (Exhalation)	SDNN (Breath-holding)	SDNN (Inhalation)	RPE (Exhalation)	RPE (Breath-holding)	RPE (Inhalation)	Volume (exhalation)	Volume (Breath-holding)
SDNN (Breath-holding)	0.329							
SDNN (Inhalation)	0.622*	0.883**						
RPE (Exhalation)	-0.071	0.387	0.397					
RPE (Breath-holding)	0.172	0.286	0.449	0.836**				
RPE (Inhalation)	0.116	0.402	0.484	0.915**	0.908**			
Volume(Exhalation)	0.000	-0.240	-0.218	0.429	0.498	0.470		
Volume(Breath-holding)	-0.123	-0.354	-0.380	0.353	0.388	0.363	0.963**	
Volume (Inhalation)	-0.266	-0.676*	-0.713**	-0.142	-0.144	-0.179	0.669*	0.728**

Abbreviations: RPE Rating of Perceived Exertion, SDNN Standard deviation of N-N intervals, Volume total weight lifted in the exercise

* $p \leq 0.05$, ** $p \leq 0.01$,

Discussion

The present study examined the acute effects of three distinct breathing strategies—exhalation during lifting, inhalation during lifting, and breath-holding (Valsalva)—on cardiovascular responses and performance during maximal bench-press exercise. This investigation contributes to the growing literature on the interaction between respiratory mechanics and autonomic regulation during resistance exercise, offering new insights into how breathing patterns may modulate both physiological stress and exercise output.

Heart rate variability

A significant difference was detected in SDNN values across breathing strategies [$X^2=6.00$, $p = 0.050$, Kendall's $W = 0.250$], with post hoc analyses revealing a notable decrease during inhalation compared to breath-holding ($Z = 2.449$, $r = 0.707$, $p = 0.043$, 95% CI=[0.201–1.799]). SDNN, pNN50, and rMSSD decreased during inhalation, suggesting reduced parasympathetic modulation and elevated physiological stress during concentric inhalation. These time-domain indices reflect the stability of the autonomic nervous system and the body's ability to cope with both physical and emotional stress, and decreases in these measures are associated with impaired autonomic balance and increased cardiovascular strain [12, 13].

These findings align with prior research demonstrating reduced HRV in individuals exposed to intense resistance training or competitive stress, such as judo athletes [14] and subjects performing moderate- to high-volume resistance exercise [15–17]. The observed reductions during inhalation may indicate suboptimal synchronization between respiratory phases and sympathetic activation during exertion. This supports the notion that breathing

technique influences exercise-induced autonomic responses, particularly at high intensities.

Frequency-domain indices (LF, HF, LF/HF) did not differ significantly between breathing strategies ($p > 0.05$). While LF and HF averages were highest during breath-holding—indicating increased autonomic demand—these values remained statistically equivalent across conditions. Similar studies have questioned the reliability of HRV frequency-domain analysis during dynamic exercise, citing potential interference from mechanical and respiratory artifacts [18–21]. Therefore, the limited discrimination observed in the present data may be attributable to the acute nature of the exercise stimulus and the high intensity of the bench-press protocol.

Blood pressure and Deceleration Capacity (DC)

Systolic and diastolic BP values demonstrated no significant differences among breathing conditions ($p > 0.05$). Nonetheless, mean BP values were lowest during inhalation while lifting, consistent with patterns of altered thoracic pressure and reduced mechanical stabilization. These observations are consistent with studies reporting nonsignificant BP changes during high-intensity resistance exercise with similar rest intervals [22–24].

DC values did not differ significantly ($p > 0.05$), although higher averages were observed during inhalation. Elevated DC may reflect increased cardiac workload combined with insufficient autonomic recovery following maximal efforts. Comparable findings have been documented in populations exposed to hypoxic conditions or increased ventilatory demands, indicating a potential link between altered respiratory patterns and cardiac deceleration capacity [25].

Performance

Significant differences were observed in both total set completion [$X^2=13.86$, $p < 0.001$] and exercise volume [$X^2=13.07$, $p < 0.001$], with breath-holding yielding the highest performance and inhalation producing the lowest. These outcomes are supported by prior evidence that the Valsalva maneuver enhances trunk rigidity, increases intra-abdominal pressure, and facilitates force transfer during heavy lifts, enabling athletes to lift heavier loads or maintain higher volumes [26–28].

In contrast, inhalation during the concentric phase appears to disrupt force production by reducing mechanical stability and increasing perceived difficulty. This is consistent with research showing that reverse-breathing strategies impair lifting performance, particularly during maximal loads [29].

RPE values mirrored performance findings, with breath-holding producing lower perceived exertion and inhalation the highest [$X^2=13.68$, $p < 0.001$]. Since RPE correlates with physiological stress and mechanical strain [8, 30], these results suggest that breathing patterns directly influence both subjective and objective exercise difficulty.

A strong negative correlation between SDNN and total volume during inhalation ($r=-0.713$, $p \leq 0.01$) further indicates that reduced parasympathetic activity during concentric inhalation coincides with diminished performance capacity. This relationship underscores the importance of maintaining an autonomically favorable breathing pattern during resistance exercise.

Collectively, the findings suggest that breathing strategy exerts meaningful influence on autonomic regulation, cardiovascular responses, and performance outcomes during maximal bench-press exercise. Breath-holding and exhalation during lifting appear to support greater mechanical efficiency and autonomic stability, whereas inhalation during the concentric phase heightens physiological stress and compromises performance.

These results emphasize the critical role of breathing mechanics in resistance training and suggest that improper breathing—particularly inhalation during force generation—may impose unnecessary cardiovascular strain and reduce exercise capacity. Future research should explore chronic adaptations to structured breathing training and investigate the neuromechanical mechanisms underlying these acute responses.

Conclusion

Overall, breathing patterns influenced both cardiovascular responses and perceived exertion during maximal bench-press performance. Specifically, inhalation during the concentric phase was associated with significant reductions in HRV parameters, indicating decreased parasympathetic activity and increased physiological

stress [31, 32]. This shift may lead to enhanced sympathetic dominance, reflected by shortened R-R intervals, which can transiently elevate blood pressure.

Performance outcomes were also affected by breathing strategy. Inhalation during lifting reduced exercise volume and total sets, whereas exhalation and breath-holding (Valsalva maneuver) did not significantly affect these parameters. Only the RPE during breath-holding was significantly lower, suggesting reduced perceived effort compared to inhalation. These findings are consistent with previous recommendations that exhaling during the concentric phase and inhaling during the eccentric phase optimizes intra-abdominal pressure, movement rhythm, and neuromuscular efficiency [33–35].

Although breath-holding can provide temporary core stabilization and facilitate lifting heavier loads, it may increase internal pressure and pose risks to organs and tissues. Athletes tend to use breath-holding selectively, typically under heavy loads, while exhalation remains the safest and most effective strategy for maintaining performance and minimizing cardiovascular strain [34]. Improper breathing, particularly inhalation during forceful concentric movements, may exacerbate cardiovascular stress and limit oxygen delivery to working muscles.

Finally, participants' perceptual responses (RPE) indicated that inhalation while lifting was perceived as more strenuous, emphasizing that breathing strategy directly influences both physiological stress and subjective effort. Overall, these findings suggest that proper breathing technique is a critical component of resistance training, with inhalation during lifting potentially inducing a catabolic response and excessive stress, while exhalation or controlled breath-holding may support performance and safety [36].

Practical applications

The findings of this study suggest that breath-holding during resistance exercise may not provide a significant advantage in terms of performance compared to exhalation and may be associated with adverse cardiovascular effects due to increased intrathoracic pressure. Exhalation during the lifting phase appears to be a safer breathing strategy, as it does not substantially compromise performance and may minimize cardiovascular strain. Therefore, exhalation should be encouraged during strength training, and athletes may need to be informed that inappropriate breathing patterns during lifting could reduce performance and negatively impact cardiac function.

Abbreviations

HRV	Heart rate variability
SDNN	Standard deviation of normal-to-normal intervals
rMSSD	Root mean square of successive N-N interval differences
pNN50	Percentage of NN intervals differing by >50 ms

LF	Low-frequency power
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
HF	High-frequency power
LF/HF	High-frequency power/Low-frequency power
HR	Heart rate
BP	Blood pressure
RPE	Rating of perceived exertion
RM	Repetition maximum
CI	Confidence intervals
DC	Deceleration capacity

Acknowledgements

The authors would like to thank all participants for their valuable contribution to this study.

Authors' contributions

Ismail Emre DENIZ conceived and designed the study, collected and analyzed the data, and drafted the manuscript. Ibrahim ERDEMIR designed the study, supervised the project, contributed to study design, and critically revised the manuscript for important intellectual content. Both authors read and approved the final manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Balıkesir University Ethics Committee (Approval Date: March 8, 2022; Approval No: 2022/30). All procedures involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Written informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 12 August 2025 / Accepted: 25 November 2025

Published online: 10 December 2025

References

- Kraemer WJ, Ratames NA. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc.* 2004;36:674–88. <https://doi.org/10.1249/01.mss.0000121945.36635.61>.
- Karlsen T, Helgerud J, Støylen A, Lauritsen N, Hoff J. Maximal strength training restores walking mechanical efficiency in heart patients. *Int J Sports Med.* 2009;30(5):337–42. <https://doi.org/10.1055/s-0028-1105946>.
- Linsenbardt ST, Thomas TR, Richard WM. Effect of breathing techniques on blood pressure response to resistance exercise. *Br J Sports Med.* 1992;26(2):97.
- Cloarec-Blanchard L, Funck-Brentano C, Lipski J, Jaillon P, Macquin-Mavier I. Repeatability of spectral components of short-term blood pressure and heart rate variability during acute sympathetic activation in healthy young male subjects. *Clin Sci.* 1997;93(1):21–8.
- Uzun M. Cardiovascular system and exercise. *J Cardiovasc Nurs.* 2016;7(2):48–53. <https://doi.org/10.5543/khd.2016.77487>.
- Wang T, Mao J, Bo S, et al. Acute effects of resistance-type and cycling-type high-intensity interval training on arterial stiffness, cardiac autonomic modulation and cardiac biomarkers. *BMC Sports Sci Med Rehabil.* 2024;16:14. <https://doi.org/10.1186/s13102-024-00806-8>.
- Stergiou GS, Palatini P, Parati G, O'Brien E, Januszewicz A, Lurbe E, et al. 2018 European society of hypertension practice guidelines for office and out-of-office blood pressure measurement. *J Hypertens.* 2018;36(7):1305–36. <https://doi.org/10.1097/HJH.0000000000001730>.
- Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, et al. A new approach to monitoring exercise training. *J Strength Cond Res.* 2001;15(1):109–15. <https://doi.org/10.1519/00124278-200102000-00019>.
- Simão R, Farinatti P, Polito M, Viveiros L, Fleck S. Influence of exercise order on the number of repetitions performed and perceived exertion during resistance exercise in women. *J Strength Cond Res.* 2007;21(1):23–8. <https://doi.org/10.1519/00124278-200702000-00005>.
- Brzycki M. Strength testing—predicting a one-rep max from reps-to-fatigue. *J Phys Educ Recreat Dance.* 1993;64(1):88–90. <https://doi.org/10.1080/07303084.1993.10606684>.
- Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14(5):377–81. <https://doi.org/10.1249/00005768-198205000-00012>.
- Rezk C, Marrache R, Tinucci T, Mion D. Post-resistance exercise hypotension, hemodynamics, and heart rate variability: influence of exercise intensity. *Eur J Appl Physiol.* 2006;98(1):105–12. <https://doi.org/10.1007/s00421-006-0257-y>.
- Medicore. Heart Rate Variability Analysis System. Available at: http://medi-core.com/download/HRV_clinical_manual_ver3.0.pdf [Accessed 14 Oct 2015].
- Morales J, Alamo J, García-Massó X, Buscà B, López J, et al. Use of heart rate variability in monitoring stress and recovery in judo athletes. *J Strength Cond Res.* 2014;28(7):1896–905. <https://doi.org/10.1519/JSC.0000000000000328>.
- Holmes CJ, MacDonald H, Esco M, Fedewa M, Wind S, et al. Comparison of heart rate variability responses to varying resistance exercise volume-loads. *Res Q Exerc Sport.* 2022;93(2):391–400.
- Gambassi BB, Queiroz C, Muniz D, Conceição A. Acute effect of German volume training method on autonomic cardiac control of apparently healthy young. *J Exerc Physiol Online.* 2019;22(2):49–57.
- Kingsley JD, Hochgesang S, Brewer A, Buxton E. Autonomic modulation in resistance-trained. *Int J Sports Med.* 2014;35(10):851. <https://doi.org/10.1055/s-0034-1371836>.
- Figueiredo T, Willardson J, Miranda H, Bentes CM, Reis VM, et al. Influence of rest interval length between sets on blood pressure and heart rate variability after a strength training session performed by prehypertensive men. *J Strength Cond Res.* 2016;30(7):1813–24. <https://doi.org/10.1519/JSC.00000000000001302>.
- Vesterinen V, Nummela A, Heikura I, Laine T, Hynynen E, et al. Individual endurance training prescription with heart rate variability. *Med Sci Sports Exerc.* 2016;48(7):1347–54. <https://doi.org/10.1249/MSS.00000000000000910>.
- Marasingha-Arachchige SU, Rubio-Arias J, Alcaraz P, Chung L. Factors that affect heart rate variability following acute resistance exercise: a systematic review and meta-analysis. *J Sport Health Sci.* 2022;11:376–92. <https://doi.org/10.1016/j.jshs.2020.11.008>.
- Songsorn P, Somnarin K, Jaitan S, Kupradit A. The effect of whole-body high-intensity interval training on heart rate variability in insufficiently active adults. *J Exerc Sci Fit.* 2020;20:48–53. <https://doi.org/10.1016/j.jesf.2021.10.003>.
- Bentes CM, Costa P, Neto G, Costa SG, Salles BF, et al. Hypotensive effects and performance responses between different resistance training intensities and exercise orders in apparently healthy women. *Clin Physiol Funct Imaging.* 2015;35(3):185–90. <https://doi.org/10.1111/cpf.12144>.
- João GA, Bocalini D, Rodriguez D, Charro M. Powerlifting sessions promote significant post-exercise hypotension. *Rev Bras Med Esporte.* 2017;23(2):118–22. <https://doi.org/10.1590/1517-869220172302166667>.
- Lepley AS, Hatzel B. Effects of weightlifting and breathing technique on blood pressure and heart rate. *J Strength Cond Res.* 2010;24(8):2179–83. <https://doi.org/10.1519/JSC.0b013e3181e2741d>.
- Hamm W, Stülpnagel L, Klemm M, Baylacher M, Rizas K, et al. Deceleration capacity of heart rate after acute altitude exposure. *High Alt Med Biol.* 2018;19(3):299–302. <https://doi.org/10.1089/ham.2018.0041>.
- Lamberg EM, Hagins M. Breath control during manual free-style lifting of a maximally tolerated load. *Ergonomics.* 2010;53(3):385–92. <https://doi.org/10.1080/00140130903420228>.
- Kumar R, Sharma S. Comparative analysis of strength and cardiovascular endurance among weight lifters and power lifters. *Aut Aut Res J.* 2020;11(8):537–44. <https://doi.org/10.0001865.AutAut.2020.V11I8.463782.00719>.

28. Hackett DA, Chow CM. The valsava maneuver: its effect on intra-abdominal pressure and safety issues during resistance exercise. *J Strength Cond Res.* 2013;27(8):2338–45. <https://doi.org/10.1519/JSC.0b013e31827de07d>.
29. Hlava KD. The effect of breathing strategy on lifted load during the bench press [Bachelor's thesis]. Charles University; 2019. Available from: <https://dspace.cuni.cz/bitstream/handle/20.500.11956/105991/130251021.pdf>.
30. Sweet TW, Foster C, McGuigan M, Brice G. Quantitation of resistance training using the session rating of perceived exertion method. *J Strength Cond Res.* 2004;18(4):796–802. <https://doi.org/10.1519/14153.1>.
31. Lutfi MF, Sukkar M. Effect of blood pressure on heart rate variability. *Khartoum Med J.* 2011;4(1):548–9.
32. Marques AH, Silverman M, Sternberg E. Evaluation of stress systems by applying noninvasive methodologies: measurements of neuroimmune biomarkers in the sweat, heart rate variability and salivary cortisol. *Neuroimmunomodulation.* 2010;17(3):205–8. <https://doi.org/10.1159/000258725>.
33. Pongpanit K, Korakot M, Nitilap P, Puplab N, Charususin N, Yuenyongchaiwat K. Acute cardiac autonomic and hemodynamic responses to resistive breathing: effect of loading type and intensity. *Clin Physiol Funct Imaging.* 2024;44(4):313–23.
34. Lone FA, Hurah N. Effect of weight training on breath holding capacity among sedentary students. *Int J Phys Educ Sports.* 2018;5(6):113.
35. Devor ST. Proper breathing during exercise: importance for safety and performance. 2022. Available from: <https://www.copcp.com/Media/9b5954b7-dce3-43b5-b1a9-2a8913d7cae7.pdf>. Cited 14 Nov 2022.
36. Gailliot M, Baumeister RF. The physiology of willpower: linking blood glucose to self-control. *Pers Soc Psychol Rev.* 2007;11(4):303–27. <https://doi.org/10.1177/1088868307303030>.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.