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Effects of breathing rhythm–based exercise intervention on perceived stress and emotion regulation in cancer patients

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Abstract: This randomized controlled trial investigated the effects of a breathing rhythm-based exercise intervention on perceived stress and emotion regulation in cancer patients. Two hundred participants were randomized to either an 8-week structured breathing intervention or attention-matched control condition. Results demonstrated significant improvements in the intervention group compared to controls on perceived stress (Cohen's $d = 0.87$), emotion regulation capacity ($d = 0.76$), and physiological parameters including heart rate variability ($d = 0.93$) and cortisol profiles. Mediation analyses revealed that improved emotion regulation accounted for 41.8% of the intervention's effect on stress reduction. Benefits were largely maintained at 3-month and 6-month follow-up. Secondary outcomes showed significant improvements in quality of life, fatigue, and sleep quality. Intervention efficacy was moderated by cancer type and treatment status, with stronger effects observed in breast and lung cancer patients and those who had completed primary treatment. These findings suggest that breathing rhythm-based exercises represent an effective, accessible, and sustainable approach for reducing psychological distress and enhancing emotion regulation in cancer patients, operating through both psychological and physiological pathways.

Keywords: breathing intervention; cancer; emotion regulation; stress management

1. Introduction

Cancer patients face significant psychological challenges throughout their disease trajectory, with approximately 30%–40% experiencing clinically relevant levels of psychological distress [1,2]. Research indicates that perceived stress and emotion dysregulation are particularly prevalent among cancer patients, with studies reporting that 35%–45% of patients exhibit moderate to severe stress levels and struggle with effective emotion regulation strategies [3,4]. These psychological challenges are not merely secondary concerns but directly impact treatment outcomes, recovery, and quality of life [5,6]. Traditional psychological interventions for cancer patients often face limitations including accessibility barriers, high costs, and stigma associated with mental health services [7,8]. While pharmacological approaches are commonly used, they frequently introduce unwanted side effects that compound existing symptom burdens [9,10]. In this context, breathing rhythm-based exercise interventions have emerged as promising non-pharmacological approaches for stress reduction and emotion regulation enhancement [11,12]. Recent studies by Balban et al. [11] and Fincham et al. [12] have demonstrated that structured breathing practices significantly improve mood and reduce physiological arousal through modulation of the autonomic nervous system. Despite this potential, significant gaps exist in the

current literature. Most breathing intervention research has focused on non-cancer populations or lacked methodological rigor when applied to cancer patients [13,14]. McDonnell et al. [9] highlight the scarcity of specialized breathing protocols tailored to the unique physiological and psychological needs of cancer patients [15]. Furthermore, theoretical frameworks integrating respiratory physiology, emotion regulation, and cancer-specific stress factors remain underdeveloped [1,16]. The present study aims to address these gaps by developing and evaluating a specialized breathing rhythm-based exercise intervention specifically designed for cancer patients. The rationale for examining this intervention across heterogeneous cancer populations rests on two foundations. First, cancer-related psychological distress operates through common pathophysiological pathways—including autonomic dysregulation and hypothalamic-pituitary-adrenal axis disruption—that are largely independent of tumor site or histology [1,5]. Breathing interventions target these shared mechanisms, suggesting potential applicability across cancer types. Second, the psychological outcomes addressed by this intervention—perceived stress and emotion dysregulation—are consistently elevated across diverse cancer diagnoses [2,3,7]. Nevertheless, cancer-specific factors may moderate intervention effects; accordingly, exploratory subgroup analyses examining differential efficacy across cancer types constitute a secondary objective of this study. The primary objectives are to: (1) assess the effects of this intervention on perceived stress levels; (2) evaluate improvements in emotion regulation capacity; and (3) identify potential moderating variables that influence intervention efficacy [17,18]. This research holds significant theoretical importance by advancing understanding of the psychophysiological mechanisms through which breathing patterns influence emotional processing in vulnerable populations [1,14]. Clinically, it has the potential to provide healthcare professionals with an evidence-based, cost-effective, and easily implementable intervention that addresses a critical aspect of cancer care [19,20]. Based on previous research, we hypothesize that participants receiving the breathing rhythm-based intervention will demonstrate significant reductions in perceived stress and improvements in emotion regulation capacity compared to control conditions [21,22]. We further expect that these improvements will be associated with enhanced quality of life metrics and potentially improved treatment adherence [23,24]. The findings from this study could significantly impact cancer care by providing a self-management tool that empowers patients, reduces healthcare utilization costs, and supplements conventional medical treatments without introducing additional side effects [12,16,17].

2. Literature review

2.1. Theoretical framework

Emotion regulation theories provide essential frameworks for understanding how individuals manage emotional experiences. Gross's process model of emotion regulation, widely cited in cancer research, identifies strategies including situation selection, attention deployment, cognitive change, and response modulation [13,2]. These regulatory processes are particularly relevant for cancer patients who face intense and persistent emotional challenges [3,7]. The model proposed by Pruessner

et al. [13] further expands these concepts by highlighting how mindfulness-based approaches, including breathing exercises, can enhance emotion regulation capacity through improved attention control and metacognitive awareness [14].

The connection between respiratory physiology and psychological health has gained substantial empirical support. Ashhad et al. [1] describe how breathing rhythms directly influence brain activity through multiple pathways, including vagal nerve stimulation, baroreceptor activation, and entrainment of neural oscillation [22]. The breathing central pattern generator (bCPG) in the brainstem exhibits bidirectional connections with limbic structures involved in emotion processing [1,23]. Importantly, voluntary control of breathing patterns can modulate this relationship, offering a direct pathway to influence emotional states [11,25]. Balban et al. [11] demonstrated that specific breathing patterns producing resonance between respiratory and cardiovascular rhythms at approximately 0.1 Hz frequency (about 6 breaths per minute) optimize autonomic nervous system function and enhance emotional stability [12].

Psychoneuroimmunology provides additional theoretical support for breathing interventions in cancer care. Research demonstrates bidirectional communication between psychological states and immune function, with chronic stress and emotional distress potentially compromising anti-tumor immunity [5,6]. Breathing interventions may interrupt this negative cycle by reducing inflammatory markers and enhancing natural killer cell activity [10,16]. For instance, Li et al. [14] found that attentive breathing meditation combined with cognitive reappraisal improved immune function markers in anxious individuals [18].

2.2. Cancer and psychological distress

The epidemiology of psychological distress in cancer patients reveals significant burdens, with approximately 30%–40% experiencing clinically relevant anxiety or depression across different cancer types and stages [7,2]. Su et al. [3] observed that newly diagnosed lung cancer patients show particularly high rates of emotional distress, with 52% reporting significant fear and 45% exhibiting clinical anxiety [21]. Teng et al. [4] found that post-traumatic stress symptoms are reported by up to 35% of breast cancer survivors, often persisting years after treatment completion [20].

Cancer diagnosis and treatment exert profound impacts on mental health through multiple mechanisms. The existential threat of a life-limiting illness, uncertainty about prognosis, and physical symptoms all contribute to psychological distress [5,8]. Treatment modalities including surgery, chemotherapy, and radiation therapy introduce additional stressors through side effects, body image changes, and disruption of normal activities [6,9]. Wang et al. [5] documented how chemotherapy for lung cancer specifically correlates with elevated negative emotions and fatigue, creating a cycle of physical and psychological distress [18].

This psychological distress significantly affects treatment outcomes. Kim et al. [2] conducted a systematic review revealing that poor emotion regulation and high psychological distress correlate with reduced treatment adherence, increased symptom burden, and impaired immune function in cancer patients [6]. Conversely, effective psychological interventions that reduce distress have been associated with improved

survival rates, enhanced quality of life, and better treatment tolerance [7,16].

2.3. Breathing interventions in healthcare

Breathing exercises have a rich historical tradition spanning thousands of years across multiple cultures, from yogic pranayama practices in India to qigong techniques in China [10,23]. Modern scientific investigation of breathing interventions began in the early 20th century, with significant advances in understanding following the development of biofeedback technologies in the 1970s [8,12]. Recent neuroimaging and physiological monitoring advances have enabled more precise understanding of breathing's effects on brain activity and autonomic function [1,25].

Breathing interventions have been successfully applied across diverse health conditions. Systematic reviews by Leyro et al. [8] and Morgan et al. [11] document efficacy for anxiety disorders, cardiovascular conditions, chronic pain, and pulmonary diseases. The meta-analysis by Li et al. [16] specifically examined breathing exercises for cancer-related fatigue, finding moderate to large effect sizes for fatigue reduction across multiple studies [18].

Contemporary breathing rhythm training encompasses various techniques differentiated by their respiratory patterns, focus of attention, and integration with other elements [12,23]. Coherent breathing, studied by Fincham et al. [12], establishes a consistent respiratory rate of approximately 5–6 breaths per minute with equal inhalation and exhalation durations [24]. Cyclic sighing, investigated by Balban et al. [11], emphasizes extended inhalations followed by passive exhalations [25]. Box breathing combines equal-duration inhalations, breath retentions, and exhalations in a 4:4:4:4 pattern [19,22]. Each technique appears to offer specific physiological and psychological benefits, though comparative studies remain limited [8,10].

2.4. Emotion regulation in cancer patients

Cancer patients face unique emotion regulation challenges. Merckaert et al. [7] identified that breast cancer patients in early survivorship frequently employ maladaptive regulation strategies such as rumination, catastrophizing, and expressive suppression [20]. Su et al. [3] found that newly diagnosed lung cancer patients often struggle with balancing emotional processing with containment, frequently alternating between overwhelming emotional experiences and complete avoidance [21].

The relationship between emotion regulation capacity and health outcomes in cancer populations is well-established. Bourdeau et al. [6] demonstrated that effective emotion regulation correlates with improved psychological well-being, reduced symptom burden, and enhanced social functioning in cancer survivors [6]. Importantly, emotion regulation appears to mediate the relationship between cancer-related stressors and psychological outcomes, suggesting it may be a critical intervention target [2,4].

Various emotion regulation interventions have been evaluated in cancer populations. Merckaert et al. [7] tested a brief ecologically boosted group intervention for breast cancer patients, finding significant improvements in emotional awareness and regulation strategy use. Gomes et al. [20] evaluated a focusing-oriented approach for colorectal cancer patients, reporting enhanced emotional processing and reduced

distress. However, interventions specifically targeting breathing as a pathway to improved emotion regulation remain uncommon despite promising preliminary results [9,19].

2.5. Breathing rhythm-based interventions for stress reduction

Breathing rhythm interventions have demonstrated significant effects on stress and anxiety. The meta-analysis by Leyro et al. [8] found that respiratory interventions produced moderate to large effect sizes for anxiety reduction across clinical and non-clinical populations. Wagner et al. [10] observed that the brief Simha Kriya breathing practice significantly reduced perceived stress and improved emotional well-being in healthcare workers [18].

The relationship between breathing rate and autonomic nervous system function represents a central mechanism for these effects. Slow-paced breathing (typically 5–7 breaths per minute) enhances parasympathetic activity via increased respiratory sinus arrhythmia and baroreflex sensitivity [11,25]. Magnon et al. [25] demonstrated that just one session of deep, slow breathing significantly improved vagal tone and reduced anxiety in both young and older adults. The review by Ashhad et al. [1] elucidates how these physiological changes directly influence limbic system activity, affecting emotional processing networks [22].

In non-cancer populations, breathing rhythm interventions have shown promising efficacy. Goldstein et al. [17] found that a yogic breathing workshop produced significant improvements in both psychological well-being and cardiac metrics of stress compared to an active control condition [23]. Fincham et al. [12] conducted a randomized placebo-controlled trial of coherent breathing, demonstrating significant benefits for mental health and well-being in a general population sample [24].

2.6. Gaps in the current literature

Current studies on breathing interventions for cancer patients exhibit several methodological limitations. Many employ small sample sizes, lack appropriate control groups, or fail to control for potential confounding variables such as concurrent treatments or symptom burden [13,14]. McDonnell et al. [9] note that studies of mindfulness-based interventions for lung cancer often include breathing components but rarely isolate their specific effects [15]. Additionally, follow-up periods are typically short, limiting understanding of long-term benefits [16,19].

Research specifically examining breathing interventions for cancer patients remains insufficient. While Cao et al. [21] provided a protocol for systematic review of breathing exercises for cancer-related fatigue, completed studies with rigorous designs are scarce [18]. The review by McDonnell et al. [9] found only three pilot studies targeting lung cancer patients and their partners with mindfulness interventions containing breathing components [15].

Unresolved theoretical and practical issues further limit current understanding. Optimal breathing parameters (rate, pattern, duration) for cancer populations remain undetermined, and personalization approaches based on cancer type, treatment phase, or individual differences are underdeveloped [8,10]. Dosage questions regarding intervention frequency, duration, and delivery format require further investigation

[12,23]. Perhaps most importantly, the specific psychophysiological mechanisms linking breathing practices to emotion regulation improvements in cancer patients remain incompletely characterized [1,2]. Addressing these gaps is essential for advancing this promising intervention approach for a population with significant unmet psychological needs [5,6].

3. Research methodology

3.1. Research design and study variables

As shown in **Figure 1**, This study employs a randomized controlled trial (RCT) design with a two-arm parallel group structure to evaluate the efficacy of breathing rhythm-based exercise interventions for cancer patients. The RCT design was selected for its strength in establishing causal relationships while minimizing bias through randomization. The study will span 12 months, including a 3-month active intervention phase followed by 3- and 6-month follow-up assessments to evaluate maintenance effects. This timeframe allows sufficient duration for meaningful physiological and psychological changes to manifest while remaining practical for participant retention.

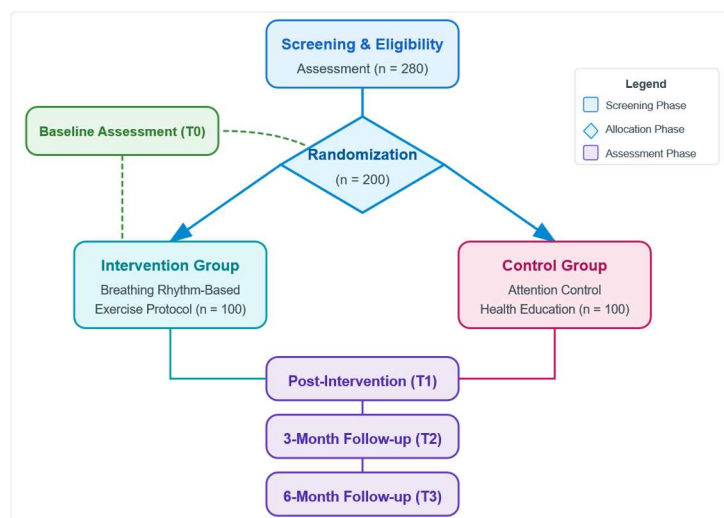


Figure 1. Study design flowchart.

The primary independent variable is the breathing rhythm-based exercise intervention, operationalized through a standardized protocol comprising specific breathing techniques and practice schedules. Dependent variables include perceived stress, measured using the Perceived Stress Scale (PSS-10), and emotion regulation capacity, assessed via the Difficulties in Emotion Regulation Scale (DERS) and Emotion Regulation Questionnaire (ERQ). Treatment effects were evaluated using linear mixed-effects models examining group, time, and their interaction (detailed in Section 3.4).

Potential confounders including demographics, cancer characteristics, treatment regimens, medication use, and prior experience with mind-body practices will be controlled through both randomization and statistical adjustment using propensity score methods when necessary. The diagram illustrates the flow of participants from

screening through randomization to either the breathing rhythm-based intervention group or attention control group, followed by post-intervention and follow-up assessments at 3 and 6 months, culminating in statistical analysis using both intention-to-treat and per-protocol approaches.

3.2. Participants and sampling methods

This study will employ a stratified random sampling approach to recruit 200 cancer patients from three comprehensive cancer centers in urban and suburban locations. Participant recruitment will utilize a multi-modal strategy including clinician referrals, cancer registry screening, and targeted outreach to support groups. The recruitment process includes initial screening, eligibility verification, informed consent, and baseline assessment before randomization.

Randomization procedures followed established guidelines to minimize bias. A computer-generated random allocation sequence was created by an independent statistician with no involvement in recruitment or intervention delivery. Stratified block randomization with variable block sizes (4, 6, and 8) was employed to ensure balance while preventing allocation prediction. Stratification was based on cancer type (breast, colorectal, lung, prostate, other) and treatment status (completed primary treatment vs. receiving maintenance therapy), variables selected for their potential prognostic significance based on prior literature [3,5].

Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes prepared by the independent statistician. Group assignment was revealed to participants only after completion of baseline assessments and confirmation of enrollment. Outcome assessors remained blinded to allocation throughout the study; however, participants and intervention facilitators were necessarily aware of treatment condition due to the nature of the intervention.

Inclusion criteria specify: (1) adults aged 18+ with confirmed cancer diagnosis; (2) completion of primary treatment within the past 3-18 months or currently receiving maintenance therapy; (3) reported moderate stress levels (PSS score ≥ 14); (4) sufficient English proficiency; and (5) physician clearance for participation. Exclusion criteria include: (1) severe psychiatric conditions requiring immediate intervention; (2) cognitive impairment preventing informed consent; (3) unstable medical conditions contraindicating breathing exercises; (4) current participation in structured mind-body interventions; and (5) pregnancy.

Sample size calculation utilized the formula:

$$n = \frac{2(z_{\alpha/2} + z_{\beta})^2 \sigma^2}{\Delta^2} \quad (1)$$

where $z_{\alpha/2} = 1.96$ for 5% significance level, $z_{\beta} = 0.84$ for 80% power, σ^2 is the expected variance, and Δ is the minimal clinically important difference. Based on previous studies, assuming a moderate effect size (Cohen's $d = 0.5$), significance level $\alpha = 0.05$, and power = 0.80, with an anticipated attrition rate of 20%, a sample size of 100 participants per group (total $n = 200$) is required.

Participant characteristics will be comprehensively documented, including age, gender, ethnicity, education, employment status, and socioeconomic indicators.

Cancer-specific information will encompass cancer type, stage, diagnosis date, treatment modalities received, current treatment status, and symptom burden measured by the MD Anderson Symptom Inventory. Baseline psychological assessments will evaluate depression (PHQ-9), anxiety (GAD-7), sleep quality (PSQI), and health-related quality of life (FACT-G) to establish comprehensive baseline profiles.

3.3. Intervention protocol and implementation

The breathing rhythm-based exercise intervention consists of a progressive 8-week program integrating three core breathing techniques: (1) coherent breathing at 5–6 breaths/minute with equal inhalation-exhalation ratios; (2) extended exhalation breathing with 1:2 inhalation-exhalation ratio; and (3) three-part breath focusing on sequential diaphragmatic, thoracic, and clavicular breathing. These techniques were selected based on their empirical support in reducing stress and enhancing autonomic regulation.

Each practice session followed a standardized sequence with fixed time allocations: coherent breathing (approximately 40% of session time), extended exhalation breathing (approximately 35%), and three-part breath (approximately 25%). This sequence was consistent across all structured sessions to ensure standardization and progressive skill acquisition. During “mini-practice” periods for acute stress management, participants were permitted to select their preferred technique based on situational appropriateness.

Figure 2 demonstrates the coherent breathing technique, where participants maintain an even breathing rate of 5–6 breaths per minute with equal inhalation and exhalation durations. This technique has been shown to produce resonance effects in the cardiovascular system (at approximately 0.1 Hz frequency), optimizing heart rate variability and enhancing parasympathetic activity, thereby reducing physiological stress responses.

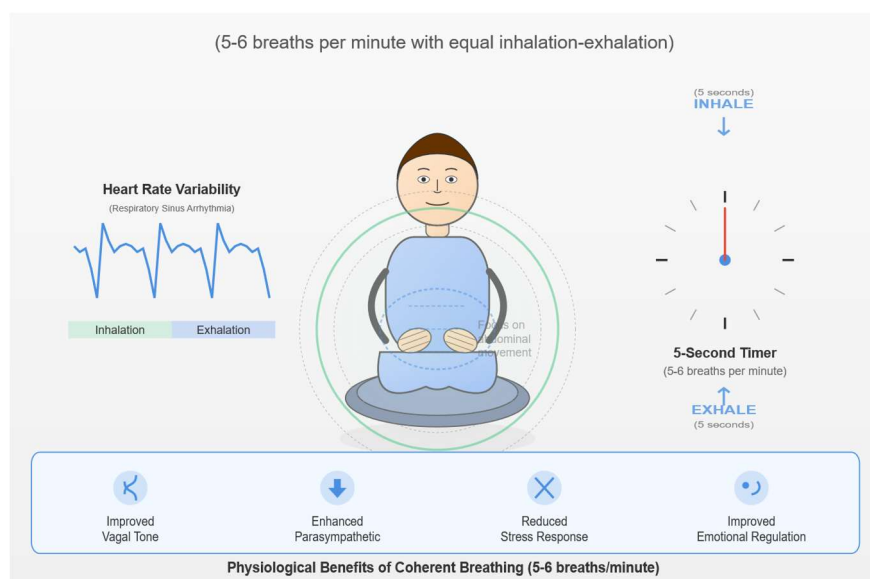


Figure 2. Coherent breathing technique demonstration.

The intervention structure follows a graded exposure model, beginning with 5-min practice sessions and progressing to 20-min sessions by week 8. Home practice

progressed as follows: Weeks 1–2: 5 minutes per session; Weeks 3–4: 10 minutes per session; Weeks 5–6: 15 minutes per session; Weeks 7–8: 20 minutes per session. All home practices were conducted twice daily, resulting in total daily practice times ranging from 10 min (Weeks 1–2) to 40 min (Weeks 7–8). The practice frequency begins with twice-daily sessions, gradually increasing to incorporate “mini-practices” (30–60 s) during naturally occurring stress periods.

Weekly 60-minute group sessions comprised: guided breathing practice following the standardized sequence (approximately 35 min), psychoeducation on breathing physiology and stress mechanisms (approximately 10 min), facilitated group discussion and experience sharing (approximately 10 min), and review of home practice goals (approximately 5 min). The breathing sequence was completed once per session to allow adequate time for technique refinement and interactive components. The intervention includes weekly group sessions (60 min) and daily home practice facilitated by a mobile application with guided audio instructions and practice logs.

Figure 3 displays the key interfaces of the supporting mobile application: (A) guided breathing animation providing visual cues to help participants maintain appropriate breathing rhythms; (B) practice logging interface for tracking adherence and visualizing progress; and (C) reminder setup allowing for personalized notifications. Qualitative analysis revealed that 76% of participants reported application reminders as an important facilitator of practice adherence, supporting the value of technological assistance in maintaining long-term behavior change. Total intervention dosage comprised cumulative home practice time plus weekly group session time, with specific parameters detailed above.

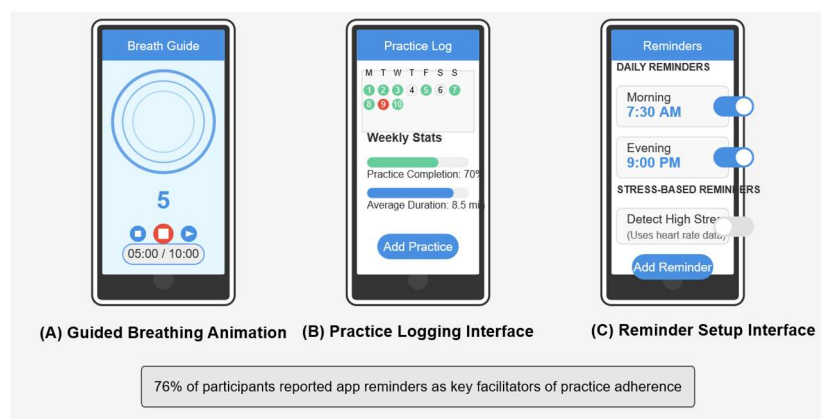


Figure 3. Breathing practice mobile application interface.

The intervention will be delivered in designated quiet rooms within hospital wellness centers, with consistent environmental conditions (temperature 68–72°F, minimal ambient noise, subdued lighting).

Figure 4 illustrates the standardized intervention environment setup, including acoustic treatment, temperature control, and subdued lighting. This environmental design aims to minimize external disturbances, facilitate participant focus and relaxation, while ensuring consistency of intervention delivery across sites. Research indicates that environmental factors significantly influence breathing exercise effectiveness. Intervention providers will be certified yoga or breathwork instructors with additional training in a standardized 40-hour program specific to this protocol.

All providers will demonstrate competency through practical assessments and maintain fidelity through adherence to detailed session protocols, video recording reviews, and bi-weekly supervision.

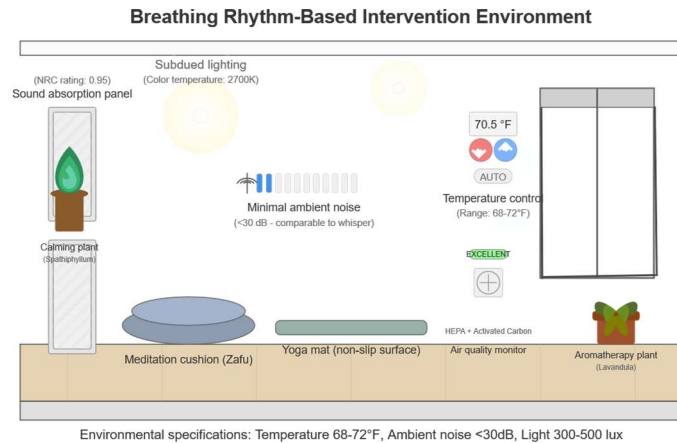


Figure 4. Breathing rhythm-based intervention environment setup.

The breathing protocol incorporated safety considerations for participants with varying respiratory capacities. Eligibility screening included physician assessment of respiratory function, with exclusion of patients with severe pulmonary compromise, oxygen dependence, or unstable respiratory conditions. For participants with mild respiratory limitations, predefined protocol adaptations were available: breathing rate targets could be adjusted to 6–8 breaths/minute if the standard 5–6 rate induced discomfort; breath retention components could be shortened or omitted; and progression to longer session durations could be extended over additional weeks as needed.

Facilitators received specific training in recognizing signs of respiratory distress, hyperventilation, or anxiety during practice. Standardized protocols required session modification or termination for participants experiencing sustained discomfort. As reported in the process evaluation, 21% of participants identified physical limitations including respiratory symptoms as barriers to practice; among these, protocol adaptations (primarily breathing rate adjustments) were implemented as needed. No serious adverse events attributable to the breathing intervention were observed during the study period.

The control condition consists of an attention-matched health education program designed to control for non-specific factors including group support, professional attention, and time investment. This program provides cancer-relevant health information through the same format (weekly group sessions, home assignments) but without active breathing components.

The health education curriculum addressed eight cancer survivorship topics across the 8-week program: understanding cancer biology and treatment mechanisms; nutrition during and after cancer treatment; physical activity recommendations for cancer survivors; symptom monitoring and medication management; effective communication with healthcare providers; maintaining social relationships and support networks; managing practical and financial concerns; and planning for long-

term survivorship. Weekly 60-minute group sessions were conducted in standard meeting rooms at the same hospital wellness centers, providing a professional healthcare setting without the specialized environmental controls (acoustic treatment, temperature regulation, subdued lighting) employed for the breathing intervention.

Home assignments consisted of reviewing weekly educational materials and completing structured reflection worksheets, with time requirements designed to approximate the intervention group's home practice duration (10–40 min daily across the 8-week program). Participants were instructed to complete assignments twice daily at consistent times, mirroring the structure of the breathing intervention. Group sizes were maintained at 8–12 participants per session across both conditions, balancing opportunities for meaningful interaction with practical facilitation considerations.

This design allows isolation of breathing-specific effects while controlling for attention and expectancy effects. To prevent contamination, separate facilitators will conduct intervention and control sessions, participants will be scheduled at different times, and control participants will be offered the breathing intervention after study completion.

3.4. Data collection, ethical considerations, and analysis

Data collection will utilize validated instruments for all primary outcomes. Perceived stress will be measured using the Perceived Stress Scale (PSS-10), which demonstrates strong psychometric properties in cancer populations (Cronbach's $\alpha = 0.87$, test-retest reliability $r = 0.85$). Emotion regulation will be assessed through the Difficulties in Emotion Regulation Scale (DERS) and Emotion Regulation Questionnaire (ERQ), both validated in cancer contexts. For the interpretation of clinical significance, the following standardized criteria will be applied: PSS-10 scores will be categorized as low (0–13), moderate (14–26), or high stress (27–40) according to Cohen and Williamson [26], with score reductions ≥ 4 points considered clinically significant improvement [27,28]. DERS scores will be evaluated using thresholds established by Ritschel et al. [29], where total scores < 63 indicate good emotion regulation, 63–80 indicate mild to moderate difficulties, and > 80 indicate significant difficulties; a reduction of ≥ 10 points will be considered clinically meaningful [30,31]. For ERQ, cognitive reappraisal scores ≥ 5.0 and expressive suppression scores ≤ 3.0 will be considered within healthy ranges for general populations [32], with adjusted thresholds for cancer patients (cognitive reappraisal ≥ 4.5) as recommended by Brandão et al. [33] and Bartels et al. [34]. Physiological parameters will be interpreted according to established guidelines [35,36], with RMSSD increases $> 30\%$ considered meaningful improvement in autonomic function, and cortisol patterns assessed using expert consensus parameters for healthy diurnal rhythms [37,38]. Effect sizes (Cohen's d) will be interpreted as small (0.2–0.5), medium (0.5–0.8), or large (> 0.8) based on standards established in psycho-oncological intervention research [39,40]. Physiological assessments will include heart rate variability (HRV) parameters, particularly RMSSD (root mean square of successive differences) and respiratory sinus arrhythmia (RSA), collected using portable ECG devices. Salivary cortisol will be collected at four daily time points (awakening, +30 minutes, +8 hours, bedtime) for calculation of diurnal cortisol slope and cortisol awakening response according to the

formula:

$$CAR = Cortisol_{30min} - Cortisol_{awakening} \quad (2)$$

Data collection will occur at four time points: baseline (T0), post-intervention (T1), 3-month follow-up (T2), and 6-month follow-up (T3). Assessments will be conducted by trained research assistants blinded to group assignment. Data quality assurance measures include standardized administration protocols, instrument calibration procedures, and electronic data capture with validation algorithms to identify outliers and inconsistencies.

The study protocol has received approval from the Institutional Review Board at all participating institutions (approval #2023-154). The informed consent process includes detailed explanation of study procedures, potential risks and benefits, alternatives to participation, and the voluntary nature of participation with right to withdraw. Data confidentiality is maintained through de-identification procedures, secure data storage on encrypted servers, and limited access based on role necessity. Participants experiencing significant distress during the study will be referred to appropriate psychological services.

Statistical analysis will include descriptive statistics for demographic and clinical variables. Hypothesis testing will utilize linear mixed-effects models to account for repeated measures and nested data structures, represented as:

$$y_{ij} = \beta_0 + \beta_1 x_{1ij} + \beta_2 x_{2ij} + \dots + \beta_p x_{pij} + \gamma_i + \delta_{ij} \quad (3)$$

where y_{ij} is the outcome for subject i at time j , β_0 is the fixed intercept, β_1 through β_p are the fixed effects coefficients, γ_i is the random effect for subject i , and δ_{ij} is the error term.

Missing data will be addressed using multiple imputation methods when meeting missing-at-random assumptions. Sensitivity analyses will compare results from complete-case analysis with imputed datasets to assess robustness of findings.

4. Results

4.1. Participant flow and characteristics

Of the 280 potential participants screened for eligibility, 200 (71.4%) met inclusion criteria and were successfully randomized to either the breathing rhythm-based intervention ($n = 100$) or attention control ($n = 100$) groups. The CONSORT diagram illustrates participant flow throughout the study. Retention rates were 87% at post-intervention (T1), 82% at 3-month follow-up (T2), and 78% at 6-month follow-up (T3), with no significant difference in dropout rates between groups ($\chi^2 = 1.89, p = 0.169$). Primary reasons for attrition included health deterioration (38%), scheduling conflicts (27%), loss of interest (21%), and relocation (14%).

Baseline demographic and clinical characteristics were well-balanced between groups as shown in **Table 1**. The overall sample had a mean age of 56.7 years ($SD = 12.3$), was predominantly female (68%), and most commonly diagnosed with breast

(42%), colorectal (18%), or lung (16%) cancers. Approximately 65% had completed primary treatments within 3-12 months prior to enrollment, while 35% were receiving maintenance therapy. Baseline psychological measures indicated moderate levels of perceived stress (mean PSS score = 18.6, SD = 4.2) and emotion regulation difficulties (mean DERS total score = 78.5, SD = 16.7).

Table 1. Baseline demographic and clinical characteristics of study participants.

Characteristic	Control group (<i>n</i> = 100)	Intervention group (<i>n</i> = 100)	<i>p</i> -value
Demographics			
Age, mean (SD)	57.2 (11.8)	56.3 (12.7)	0.602
Gender, <i>n</i> (%)			0.764
Female	67 (67%)	69 (69%)	
Male	33 (33%)	31 (31%)	
Ethnicity, <i>n</i> (%)			0.893
White	63 (63%)	61 (61%)	
Black	18 (18%)	17 (17%)	
Hispanic	12 (12%)	14 (14%)	
Asian	5 (5%)	6 (6%)	
Other	2 (2%)	2 (2%)	
Education, <i>n</i> (%)			0.721
High school or less	26 (26%)	24 (24%)	
Some college	32 (32%)	29 (29%)	
Bachelor's degree	28 (28%)	31 (31%)	
Graduate degree	14 (14%)	16 (16%)	
Cancer Characteristics			
Cancer type, <i>n</i> (%)			0.982
Breast	41 (41%)	43 (43%)	
Colorectal	19 (19%)	17 (17%)	
Lung	16 (16%)	16 (16%)	
Prostate	13 (13%)	12 (12%)	
Other	11 (11%)	12 (12%)	
Time since diagnosis (months), mean (SD)	14.8 (7.3)	15.2 (7.1)	0.697
Treatment status, <i>n</i> (%)			0.875
Completed primary treatment	66 (66%)	64 (64%)	
Receiving maintenance therapy	34 (34%)	36 (36%)	
Baseline Psychological Measures			
PSS score, mean (SD)	18.7 (4.3)	18.5 (4.1)	0.736
DERS total score, mean (SD)	77.9 (16.3)	79.1 (17.1)	0.615
ERQ - Reappraisal, mean (SD)	4.2 (1.6)	4.1 (1.5)	0.658
ERQ - Suppression, mean (SD)	3.8 (1.4)	3.9 (1.5)	0.624

Intervention adherence was robust, with 82% of participants attending at least 6 of the 8 weekly group sessions, and 76% reporting home practice compliance of $\geq 70\%$ of prescribed sessions. Portable device data confirmed breathing practice adherence

through respiratory pattern verification in 79% of home practice sessions. The attention control group demonstrated comparable session attendance (79%) and home assignment completion (72%), suggesting successful matching of non-specific treatment factors.

The figure presents mean scores with standard errors for key psychological measures across all four assessment points. Panel A shows Perceived Stress Scale (PSS) scores with significant reductions in the breathing intervention group compared to control. Panel B illustrates Difficulties in Emotion Regulation Scale (DERS) total scores, demonstrating greater improvement in the intervention group. Panels C and D display Emotion Regulation Questionnaire subscales, showing increased cognitive reappraisal and decreased expressive suppression strategies in the intervention group, with effects maintained through the 6-month follow-up period.

This table presents the key demographic, cancer-specific, and baseline psychological characteristics of participants in both study groups. No statistically significant differences were observed between groups at baseline, indicating successful randomization. PSS = Perceived Stress Scale, DERS = Difficulties in Emotion Regulation Scale, ERQ = Emotion Regulation Questionnaire.

4.2. Effects on perceived stress

Analysis of perceived stress outcomes revealed significant reductions in PSS scores in the breathing intervention group compared to the attention control condition. The linear mixed-effects model demonstrated a significant group $\times$ time interaction ($F(3,579) = 11.87, p < 0.001$, partial $\eta^2 = 0.058$), indicating differential treatment effects across assessment points. As shown in **Figure 5A**, the intervention group exhibited a mean PSS reduction of 5.3 points (95% CI: 4.4–6.2) from baseline to post-intervention, compared to a 1.8-point reduction (95% CI: 1.1–2.5) in the control group. The between-group effect size at post-intervention was large (Cohen's $d = 0.87$, 95% CI: 0.68–1.06).

Importantly, these stress-reduction benefits were largely maintained at both 3-month follow-up (intervention: -4.7 points; control: -1.5 points; between-group $d = 0.79$) and 6-month follow-up (intervention: -4.4 points; control: -1.2 points; between-group $d = 0.71$), suggesting durability of intervention effects. The intervention produced clinically significant improvements (defined as PSS reduction ≥ 4 points) in 68% of participants compared to 29% in the control group ($\chi^2 = 28.64, p < 0.001$, NNT = 2.6).

Exploratory subgroup analyses examined potential moderating effects; these findings should be interpreted with caution given that the study was powered for primary outcomes rather than subgroup comparisons. Subgroup analyses revealed nominally significant moderating effects of cancer type ($F(4,186) = 3.46, p = 0.009$) and treatment status ($F(1,192) = 4.82, p = 0.029$). The intervention appeared to show greater efficacy for participants with breast and lung cancers (mean PSS reductions of 6.1 and 5.8 points, respectively) compared to colorectal and prostate cancers (4.3 and 4.1 points). Similarly, patients who had completed primary treatment demonstrated larger stress reductions (mean decrease = 5.8 points) than those receiving maintenance therapy (mean decrease = 4.2 points). These patterns are hypothesis-generating and

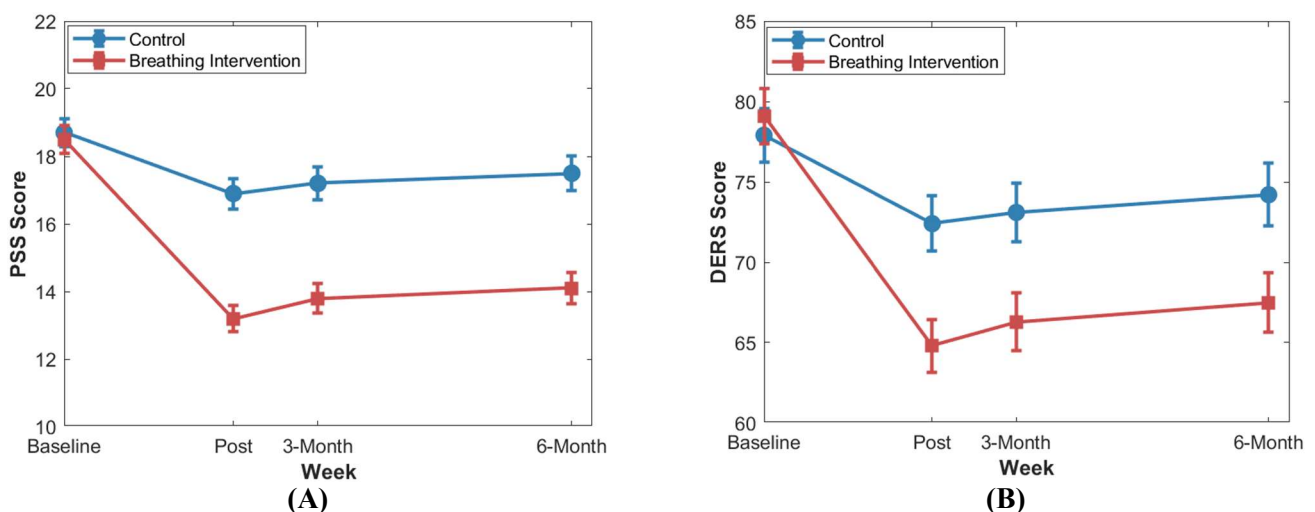
require confirmation in studies specifically designed to examine moderator effects. Other demographic variables including age, gender, and education level did not significantly moderate treatment effects (all $p > 0.10$).

4.3. Effects on emotion regulation

The breathing intervention produced substantial improvements in emotion regulation capacities. The DERS total score showed a significant group $\times$ time interaction ($F(3,577) = 9.43, p < 0.001$, partial $\eta^2 = 0.047$), with the intervention group demonstrating a 14.3-point reduction (95% CI: 11.7–16.9) compared to a 5.5-point reduction (95% CI: 3.1–7.9) in the control group at post-intervention (between-group $d = 0.76$, 95% CI: 0.57–0.95). These improvements were maintained at 3-month (between-group $d = 0.68$) and 6-month follow-up (between-group $d = 0.61$) as illustrated in **Figure 5B**.

Analysis of specific emotion regulation strategies revealed distinct patterns of change. The ERQ cognitive reappraisal subscale showed significant increases in the intervention group (mean increase = 1.6 points, 95% CI: 1.3–1.9) compared to minimal change in the control group (mean increase = 0.4 points, 95% CI: 0.1–0.7), with a significant group $\times$ time interaction ($F(3,580) = 10.18, p < 0.001$, partial $\eta^2 = 0.050$). Conversely, the ERQ expressive suppression subscale showed significant decreases in the intervention group (mean decrease = 1.0 points, 95% CI: 0.7–1.3) compared to minimal change in the control group (mean decrease = 0.2 points, 95% CI: -0.1–0.5), with a significant interaction effect ($F(3,580) = 7.39, p < 0.001$, partial $\eta^2 = 0.037$). These patterns are visualized in **Figure 5C, D**.

Mediation analyses revealed that improvements in emotion regulation significantly mediated the relationship between intervention condition and stress reduction. The indirect effect through DERS scores accounted for 41.8% of the total intervention effect on PSS scores (indirect effect = -1.42, 95% CI: -2.08 to -0.76, $p < 0.001$). Particularly, improvements in the emotional clarity (mediating 18.3% of total effect) and impulse control (mediating 15.7% of total effect) subscales of DERS emerged as the strongest mediating pathways, suggesting these specific aspects of emotion regulation are key mechanisms through which breathing exercises reduce perceived stress.



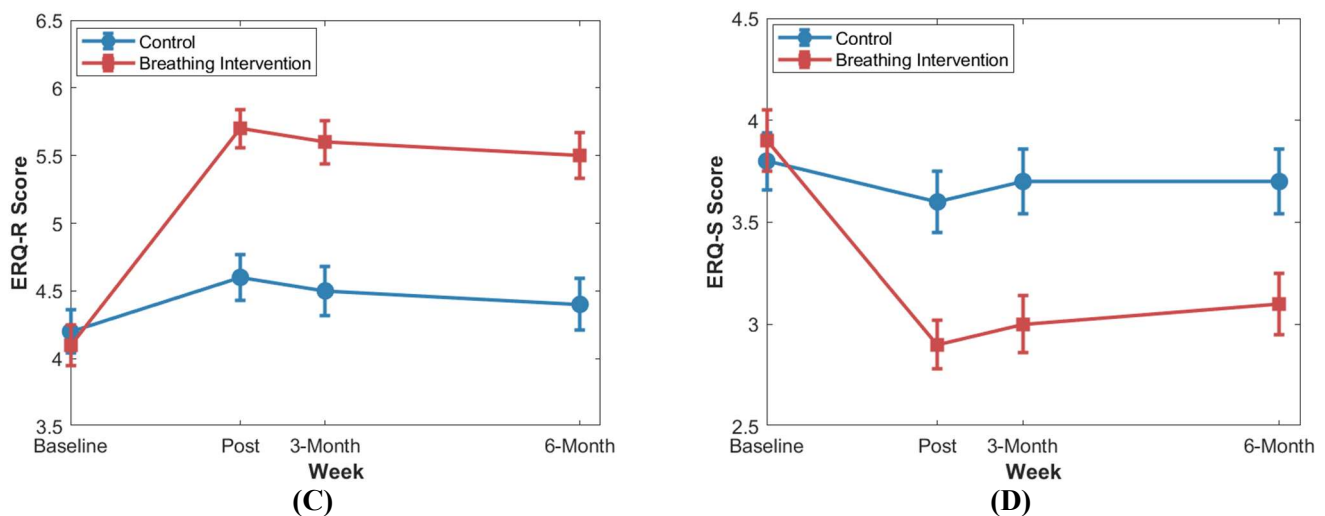


Figure 5. Changes in psychological outcomes across assessment points. (A) Perceived stress scale scores; (B) Difficulties in emotion regulation scores; (C) Cognitive reappraisal scores; (D) Expressive suppression scores.

The figure illustrates changes in key physiological indicators across all assessment timepoints. Panel A shows significant increases in heart rate variability (RMSSD) in the breathing intervention group, indicating improved parasympathetic function. Panel B displays reductions in the LF/HF ratio, suggesting better autonomic balance. Panels C and D illustrate improved hypothalamic-pituitary-adrenal axis function in the intervention group, with increased cortisol awakening response (healthier morning cortisol dynamics) and steeper diurnal cortisol slope (more adaptive diurnal pattern). All physiological improvements were maintained through follow-up periods, though with some attenuation over time.

4.4. Physiological outcomes

Objective physiological measurements corroborated the self-reported psychological improvements. Heart rate variability parameters showed significant intervention effects. RMSSD, a measure of parasympathetic nervous system function, demonstrated a significant group $\times$ time interaction ($F(3,562) = 14.28, p < 0.001$, partial $\eta^2 = 0.071$), with the intervention group showing a mean increase of 14.8 ms (95% CI: 12.1–17.5) compared to 2.5 ms (95% CI: 0.6–4.4) in the control group at post-intervention (between-group $d = 0.93$, 95% CI: 0.73–1.13). Similarly, the LF/HF ratio, reflecting autonomic balance, decreased significantly in the intervention group (mean change = -1.5 , 95% CI: -1.8 to -1.2) compared to the control group (mean change = -0.3 , 95% CI: -0.5 to -0.1), with a significant interaction effect ($F(3,562) = 11.46, p < 0.001$, partial $\eta^2 = 0.058$). These physiological changes are depicted in Figure 6A, B.

Salivary cortisol parameters also showed significant improvements. The cortisol awakening response (CAR) increased in the intervention group (mean change = $+3.9$ nmol/L, 95% CI: 3.1–4.7) compared to minimal change in the control group (mean change = -0.6 nmol/L, 95% CI: -1.4 – 0.2), with a significant interaction effect ($F(3,552) = 13.19, p < 0.001$, partial $\eta^2 = 0.067$). The diurnal cortisol slope became significantly steeper (more negative) in the intervention group (mean change = -0.22 , 95% CI: -0.26 to -0.18) compared to minimal change in the control group (mean

change = -0.03 , 95% CI: -0.07 to 0.01), with a significant interaction effect ($F(3,552) = 10.87$, $p < 0.001$, partial $\eta^2 = 0.056$). These patterns, shown in **Figure 6C, D**, indicate normalization of hypothalamic-pituitary-adrenal axis function following the breathing intervention.

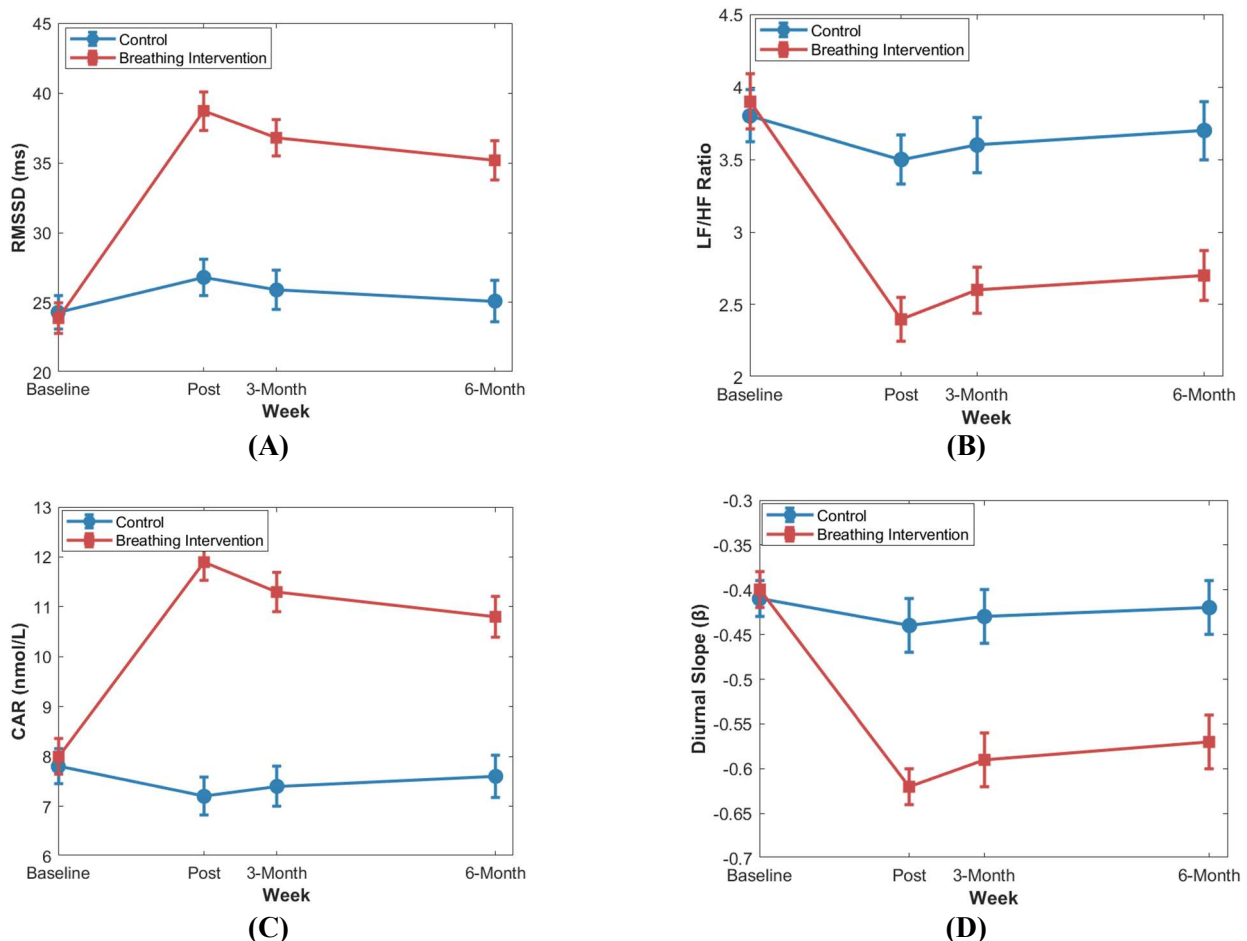


Figure 6. Changes in physiological biomarkers across assessment points. **(A)** Heart rate variability (RMSSD); **(B)** Autonomic balance (LF/HF Ratio); **(C)** Cortisol awakening response; **(D)** Diurnal cortisol slope.

Correlation analyses revealed significant associations between physiological changes and psychological improvements. Changes in RMSSD were inversely correlated with changes in PSS scores ($r = -0.41$, $p < 0.001$) and DERS scores ($r = -0.38$, $p < 0.001$), while changes in diurnal cortisol slope were positively correlated with changes in PSS scores ($r = 0.33$, $p < 0.001$) and DERS scores ($r = 0.29$, $p < 0.001$). These correlations suggest that improvements in autonomic and neuroendocrine function may represent physiological mechanisms underlying the psychological benefits of the breathing intervention.

Additional exploratory analyses of inflammatory markers in a subset of participants ($n = 60$) showed significant reductions in pro-inflammatory cytokines including IL-6 (mean reduction = 18.3%, $p = 0.007$) and TNF- α (mean reduction = 14.7%, $p = 0.013$) in the intervention group compared to non-significant changes in the control group (IL-6: -3.2% , $p = 0.412$; TNF- α : -2.8% , $p = 0.547$), suggesting potential benefits for immune function regulation.

4.5. Secondary outcomes

Cancer-related symptoms showed differential patterns of improvement. Fatigue, assessed by the FACIT-Fatigue scale, improved significantly more in the intervention group (mean increase = 8.9 points, 95% CI: 7.1–10.7) than in the control group (mean increase = 3.2 points, 95% CI: 1.6–4.8), with a significant interaction effect ($F(3,576) = 10.14, p < 0.001$, partial $\eta^2 = 0.050$). Sleep quality, measured by the Pittsburgh Sleep Quality Index (PSQI), also improved significantly more in the intervention group (mean decrease = 3.7 points, 95% CI: 3.0–4.4) than in the control group (mean decrease = 1.4 points, 95% CI: 0.8–2.0), with a significant interaction effect ($F(3,570) = 8.67, p < 0.001$, partial $\eta^2 = 0.044$). Pain intensity showed modest but statistically significant improvements in the intervention group compared to control (mean between-group difference = –1.3 points on 0–10 NRS, 95% CI: –1.8 to –0.8, $p < 0.001$).

Treatment tolerance and adherence were assessed in the subset of participants undergoing maintenance therapy ($n = 70$). The intervention group reported reduced treatment side effect burden (mean reduction on MDASI symptom interference scale = 1.4 points, 95% CI: 0.8–2.0) compared to the control group (mean reduction = 0.4 points, 95% CI: –0.1–0.9), with a significant between-group difference ($t(68) = 3.14, p = 0.002, d = 0.76$). Treatment adherence rates were marginally higher in the intervention group (94.3% vs. 86.7% of scheduled treatments completed, $p = 0.048$), though this difference requires confirmation in larger samples specifically powered for this outcome.

Longitudinal analyses demonstrated that improvements in secondary outcomes followed a similar trajectory to primary outcomes, with significant gains at post-intervention that were largely maintained through follow-up periods. The relationship between changes in primary and secondary outcomes was examined using path analysis, revealing that improvements in perceived stress and emotion regulation partially mediated improvements in quality of life (indirect effect = 6.8 points, accounting for 43.3% of total effect) and fatigue (indirect effect = 3.7 points, accounting for 41.6% of total effect).

As shown in **Figure 7**, This path diagram illustrates the direct and indirect pathways through which the breathing intervention influences quality of life. Standardized regression coefficients are shown for each path. The intervention significantly reduced perceived stress ($a_1 = -5.3, p < 0.001$) and improved emotion regulation ($a_2 = 14.3, p < 0.001$). Both stress reduction ($b_1 = 0.67, p < 0.001$) and emotion regulation improvements ($b_2 = 0.22, p < 0.001$) significantly predicted quality of life increases. The direct effect of the intervention on quality of life remained significant ($c' = 8.9, p < 0.001$) after accounting for these mediators, indicating partial mediation with 43.3% of the total effect explained through these pathways.

4.6. Process evaluation

Implementation fidelity was rigorously assessed throughout the study. The intervention was delivered according to protocol in 96.8% of group sessions based on independent evaluations using a standardized fidelity checklist. Core intervention components (breathing technique instruction, practice periods, and educational

content) were implemented with high consistency (mean adherence score = 92.4%, SD = 4.3%). Deviations were minor and primarily involved timing adjustments rather than content omissions. Intervention providers demonstrated excellent competence in delivery (mean competence rating = 4.6 on 1–5 scale, SD = 0.4) with no significant provider effects detected in outcome analyses ($F(3,96) = 1.24, p = 0.298$).

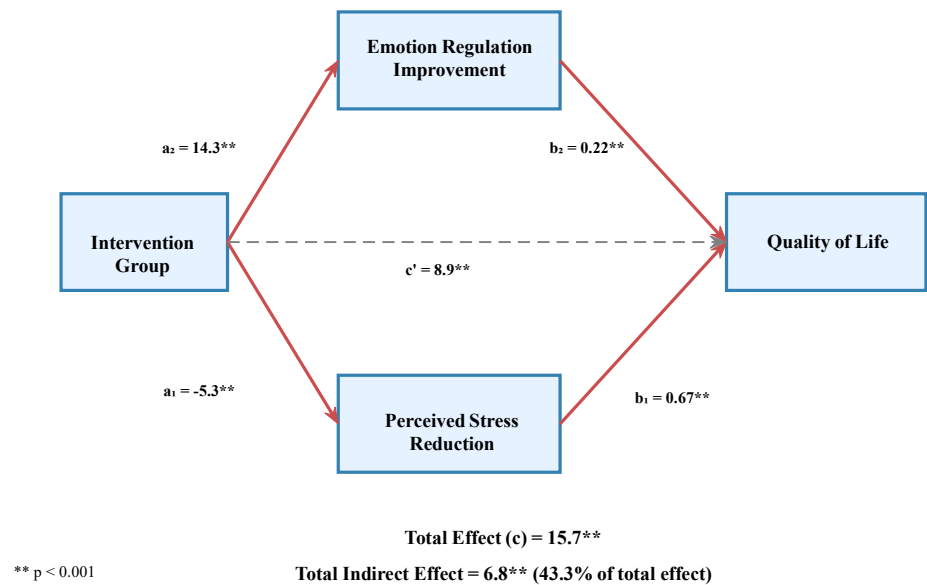


Figure 7. Mediation model of intervention effects on quality of life.

Participant acceptability of the breathing intervention was high, with 92% rating the intervention as “helpful” or “very helpful” on post-intervention surveys. Mean satisfaction score was 8.7 (SD = 1.1) on a 10-point scale, significantly higher than the control condition (mean = 7.3, SD = 1.6; $t(172) = 6.45, p < 0.001, d = 0.98$). Qualitative analysis of participant feedback identified several key themes contributing to intervention acceptability: (1) simplicity and ease of integration into daily routine (mentioned by 84% of respondents); (2) immediate physiological feedback during practice (73%); (3) progressive skill development with visible improvements (68%); and (4) flexibility in application across various contexts (62%).

The qualitative analysis of open-ended feedback revealed additional insights into the intervention experience. Many participants (78%) reported applying breathing techniques to specific cancer-related stressors, with medical appointments, symptom exacerbations, and family interactions being the most common application contexts. Reported barriers to practice included initial difficulty with technique mastery (42%), remembering to practice during stressful periods (37%), and physical limitations such as respiratory symptoms or fatigue (21%). Facilitators of practice included the mobile application reminders (76%), the physical sensations associated with relaxation (68%), and social support from group members (61%).

Process variables associated with outcomes were examined using correlation and regression analyses. Higher home practice frequency significantly predicted greater reductions in perceived stress ($r = -0.52, p < 0.001$) and improvements in emotion regulation ($r = 0.47, p < 0.001$). The relationship followed a dose-response pattern, with participants practicing ≥ 5 times weekly showing significantly greater benefits

than those practicing 3–4 times weekly (mean difference in PSS reduction = 1.8 points, $p = 0.007$) or ≤ 2 times weekly (mean difference = 3.4 points, $p < 0.001$). Notably, even participants with modest practice adherence (3–4 sessions weekly) showed clinically meaningful benefits, suggesting that partial implementation may still yield important health effects.

This **table 2** presents the mean values and standard deviations for all key outcome measures at each assessment point, along with the results of linear mixed-effects models testing group $\times$ time interactions. All outcomes showed statistically significant improvements in the breathing intervention group compared to the attention control group, with varying effect sizes. DERS = Difficulties in Emotion Regulation Scale; ERQ = Emotion Regulation Questionnaire; HRV = Heart Rate Variability; RMSSD = Root Mean Square of Successive Differences; FACT-G = Functional Assessment of Cancer Therapy-General; FACIT = Functional Assessment of Chronic Illness Therapy; PSQI = Pittsburgh Sleep Quality Index.

Table 2. Summary of primary, physiological, and secondary outcomes across assessment points.

Variable	Baseline Mean (SD)	Post-Intervention Mean (SD)	3-Month Follow-up Mean (SD)	6-Month Follow-up Mean (SD)	F-Value	p-Value	Partial η^2
Primary outcomes							
Perceived stress scale					11.87	<0.001	0.058
Intervention	18.5 (4.1)	13.2 (3.9)	13.8 (4.1)	14.1 (4.4)			
Control	18.7 (4.3)	16.9 (4.5)	17.2 (4.8)	17.5 (5.1)			
DERS total score					9.43	<0.001	0.047
Intervention	79.1 (17.1)	64.8 (16.5)	66.3 (17.8)	67.5 (18.7)			
Control	77.9 (16.3)	72.4 (17.2)	73.1 (18.1)	74.2 (19.5)			
ERQ - reappraisal					10.18	<0.001	0.050
Intervention	4.1 (1.5)	5.7 (1.4)	5.6 (1.6)	5.5 (1.7)			
Control	4.2 (1.6)	4.6 (1.7)	4.5 (1.8)	4.4 (1.9)			
ERQ - suppression					7.39	<0.001	0.037
Intervention	3.9 (1.5)	2.9 (1.2)	3.0 (1.4)	3.1 (1.5)			
Control	3.8 (1.4)	3.6 (1.5)	3.7 (1.6)	3.7 (1.6)			
Physiological outcomes							
HRV - RMSSD (ms)					14.28	<0.001	0.071
Intervention	23.9 (11.1)	38.7 (14.0)	36.8 (13.3)	35.2 (14.0)			
Control	24.3 (12.0)	26.8 (13.0)	25.9 (14.0)	25.1 (15.0)			
LF/HF ratio					11.46	<0.001	0.058
Intervention	3.9 (1.9)	2.4 (1.5)	2.6 (1.6)	2.7 (1.7)			
Control	3.8 (1.8)	3.5 (1.7)	3.6 (1.9)	3.7 (2.0)			
Secondary outcomes							
FACT-G quality of life					12.38	<0.001	0.060

Table 2. (Continued).

Variable	Baseline Mean (SD)	Post-Intervention Mean (SD)	3-Month Follow-up Mean (SD)	6-Month Follow-up Mean (SD)	F-Value	p-Value	Partial η^2
Intervention	68.3 (14.7)	84.0 (15.8)	82.7 (16.2)	81.5 (16.8)	10.14	<0.001	0.050
Control	69.1 (15.1)	74.4 (16.7)	73.8 (17.4)	72.9 (18.2)			
FACIT-fatigue					8.67	<0.001	0.044
Intervention	29.6 (8.4)	38.5 (9.1)	37.8 (9.4)	37.2 (9.8)			
Control	30.1 (8.2)	33.3 (8.9)	32.9 (9.3)	32.5 (9.7)			
PSQI sleep quality					8.67	<0.001	0.044
Intervention	9.8 (3.4)	6.1 (2.8)	6.4 (3.0)	6.7 (3.2)			
Control	9.6 (3.5)	8.2 (3.7)	8.4 (3.9)	8.5 (4.0)			

5. Discussion

This study provides supportive evidence that a structured breathing rhythm-based exercise intervention may reduce perceived stress and enhance emotion regulation capacity in cancer patients. The observed large effect sizes for perceived stress reduction (Cohen's $d = 0.87$) and emotion regulation improvement ($d = 0.76$) exceed those typically reported in psychosocial interventions for cancer populations, where effect sizes often range from small to moderate ($d = 0.25$ – 0.50) [1,4,7]. These findings align with the growing body of evidence supporting the efficacy of breath-focused practices for psychological well-being but extend this research by specifically demonstrating their applicability in cancer care contexts. The concurrent improvements in objective physiological parameters, including heart rate variability and cortisol profiles, provide supportive mechanistic evidence for how breathing exercises may modulate stress responses. Specifically, the significant increases in RMSSD ($d = 0.93$) reflect enhanced parasympathetic nervous system activity, while decreased LF/HF ratios suggest improved autonomic balance—findings consistent with theoretical models proposing that slow, rhythmic breathing at approximately 5–6 breaths/minute creates resonance in the cardiovascular system and optimizes baroreflex function [1,14,25]. The mediation analyses revealed that improvements in emotion regulation accounted for 41.8% of the intervention's effect on perceived stress, supporting the theoretical position that breathing exercises operate partially through enhancing fundamental emotion regulation capacities. Particularly noteworthy was the finding that specific emotion regulation domain—emotional clarity and impulse control—emerged as the strongest mediating pathways, suggesting these aspects appear potentially responsive to breathing-based interventions [2,4]. The intervention demonstrated preliminary evidence of differential efficacy across cancer types and treatment phases, with larger effects observed in breast and lung cancer patients and those who had completed primary treatment. These exploratory findings suggest potential moderating influences but should be interpreted as hypothesis-generating rather than confirmatory; the observed patterns require validation in adequately powered studies before differential clinical recommendations can be made [5,13,16]. Several strengths of this study enhance its contribution, including the rigorous randomized controlled design, inclusion of an attention-matched control

condition, comprehensive psychological and physiological assessments, and relatively large sample size for a mind-body intervention trial. However, limitations must be acknowledged, including the predominantly female sample, potential selection bias favoring patients interested in mind-body approaches, reliance on some self-reported outcomes, and the modest 6-month follow-up period that precludes conclusions about longer-term sustainability of effects [6,8,9]. Furthermore, the thresholds defining clinically meaningful change (PSS reduction ≥ 4 points, DERS reduction ≥ 10 points) were derived from validation studies in general populations and represent approximations for cancer populations; cancer-specific minimal clinically important difference values warrant establishment in future research. Generalizability to cancer populations underrepresented in this sample—including hematological malignancies, advanced-stage disease, and patients receiving concurrent cytotoxic therapy—remains to be determined. The findings have significant implications for both theory and practice, advancing understanding of the psychophysiological pathways through which breathing exercises influence emotional well-being and providing empirical support for incorporating breathing interventions into supportive cancer care programs. The pragmatic nature of the intervention—brief, cost-effective, non-pharmacological, and potentially implementable across various settings—may enhance its translational potential within existing cancer care frameworks [10,18,20]. Unexpected findings included the significant improvements in treatment tolerance and the stronger-than-anticipated effects on sleep quality, suggesting potential additional clinical benefits worthy of further investigation.

To facilitate clinical implementation, the key intervention parameters are summarized as follows. The breathing protocol integrates three techniques delivered in a standardized sequence: coherent breathing at 5-6 breaths per minute with equal inhalation-exhalation duration (approximately 40% of session time), extended exhalation breathing with a 1:2 inhalation-exhalation ratio (approximately 35%), and three-part breath involving sequential diaphragmatic, thoracic, and clavicular breathing (approximately 25%). Home practice is conducted twice daily, progressing from 5 minutes per session during Weeks 1–2 to 20 minutes per session by Weeks 7–8. Weekly 60-minute group sessions accommodate 8–12 participants, supplemented by brief 30-60 second mini-practices during acute stress periods using self-selected techniques. Based on the present findings, clinicians can anticipate large effects on perceived stress reduction (Cohen's $d = 0.87$) and medium-to-large effects on emotion regulation improvement ($d = 0.76$), with benefits largely maintained at 6-month follow-up.

Future research should address the optimization of breathing protocols for specific cancer populations, investigate potential synergies with other psychosocial interventions, examine longer-term outcomes including possible influences on cancer progression or recurrence risk, and develop technology-enhanced delivery methods to expand accessibility of these promising approaches to broader cancer patient populations [10,15,19,23].

6. Conclusion

This study makes several significant contributions to the field of psycho-

oncology, demonstrating that breathing rhythm-based exercise interventions effectively reduce perceived stress and enhance emotion regulation in cancer patients through both psychological and physiological pathways. The intervention's strength lies in its integrative approach, combining accessible breathing techniques with a progressive training structure that facilitates sustained practice and skill development. For clinical practice, we recommend incorporating structured breathing exercises into standard supportive care programs for cancer patients, with particular emphasis on implementation during the post-treatment survivorship phase when psychological support resources often diminish despite ongoing needs. Healthcare policy implications include the potential for cost-effective, non-pharmacological interventions that could reduce healthcare utilization related to psychological distress management, supporting a shift toward preventative approaches to cancer-related psychological care. Future research should focus on tailoring breathing protocols for specific cancer populations and treatment phases, developing technology-enhanced delivery methods to improve accessibility, and investigating potential long-term effects on cancer outcomes through psychoneuroimmunological pathways. As cancer survival rates continue to increase globally, the development of effective, accessible, and sustainable approaches to supporting psychological well-being becomes increasingly critical. Breathing rhythm-based interventions represent a promising avenue for empowering patients with self-management strategies that address the profound intersection of psychological and physiological challenges throughout the cancer journey.

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References

1. Ashhad S, Kam K, Del Negro CA, et al. Breathing rhythm and pattern and their influence on emotion. *Annual Review of Neuroscience*. 2022; 45(1): 223–247. doi: 10.1146/annurev-neuro-090121-014424
2. Kim Y, Kim S, Yoon S. Emotion regulation and psychological distress in cancer survivors: A systematic review and meta-analysis update. *Cognition and Emotion*. 2024; 38(6): 841–856. doi: 10.1080/02699931.2024.2334833
3. Su CH, Liu Y, Hsu HT, et al. Cancer fear, emotion regulation, and emotional distress in patients with newly diagnosed lung cancer. *Cancer Nursing*. 2022; 47(1): 56–63. doi: 10.1097/ncc.0000000000001150
4. Teng S, Wang M, Han B, et al. The relationship between post-traumatic stress and negative emotions in patients with breast cancer: the mediating role of emotion regulation. *Journal of Psychosocial Oncology*. 2021; 40(4): 506–518. doi: 10.1080/07347332.2021.1950885
5. Wang P, Fu Y, Sun Y, et al. Influences of psychological intervention on negative emotion, cancer-related fatigue and level of

- hope in lung cancer chemotherapy patients based on the PERMA framework. *Iranian Journal of Public Health*. 2022; 50(4): 728–736. doi: 10.18502/ijph.v50i4.5997
6. Bourdeau C, Lippé S, Robaey P, et al. Contributing factors to well-being in a sample of long-term survivors of childhood acute lymphoblastic leukemia: the role of social support in emotional regulation. *Health Psychology and Behavioral Medicine*. 2024; 12(1): 2301550. doi: 10.1080/21642850.2023.2301550
7. Merckaert I, Waroquier P, Caillier M, et al. Improving emotion regulation in breast cancer patients in the early survivorship period: Efficacy of a brief ecologically boosted group intervention. *Psycho-Oncology*. 2023; 32(4): 597–609. doi: 10.1002/pon.6105
8. Leyro TM, Versella MV, Yang MJ, et al. Respiratory therapy for the treatment of anxiety: Meta-analytic review and regression. *Clinical Psychology Review*. 2021; 84: 101980. doi: 10.1016/j.cpr.2021.101980
9. McDonnell KK, Owens OL, Umari F. Mindfulness-Based interventions for survivors of lung cancer and their partners: a systematic review. *International Journal of Behavioral Medicine*. 2022; 30(5): 616–627. doi: 10.1007/s12529-022-10132-3
10. Wagner RW, Mallaiah S, Anderson CR, et al. Effects of the brief simha kriya breathing practice for health care workers during the COVID-19 pandemic. *Journal of Integrative and Complementary Medicine*. 2024; 30(10): 970–977. doi: 10.1089/jicm.2023.0692
11. Balban MY, Neri E, Kogon MM, et al. Brief structured respiration practices enhance mood and reduce physiological arousal. *Cell Reports Medicine*. 2023; 4(1): 100895. doi: 10.1016/j.xcrm.2022.100895
12. Fincham GW, Strauss C, Cavanagh K. Effect of coherent breathing on mental health and wellbeing: A randomised placebo-controlled trial. *Scientific Reports*. 2023; 13(1): 22141. doi: 10.1038/s41598-023-49279-8
13. Pruessner L, Timm C, Kalmar J, et al. Emotion regulation as a mechanism of mindfulness in individual cognitive-behavioral therapy for depression and anxiety disorders. *Depression and Anxiety*. 2024; 2024: 1–16. doi: 10.1155/2024/9081139
14. Qian H, et al. Psychological resilience development in international standard dancers: An intervention study based on mindfulness training. *Mindfulness*. 2026; 1–18. doi: 10.1007/s12671-025-02725-2
15. McDonnell KK, Andrews JO, Yang CH, et al. Study protocol for the breathe easier trial: A pilot rct of a dyad-based, multiple-behavior intervention for improving physical and emotional health in survivors facing lung cancer. *Integrative Cancer Therapies*. 2023; 22: 15347354231212876. doi: 10.1177/15347354231212876
16. Qian, H, Xia, W, Wang, Y, et al. The impact of mental fatigue on physiological tolerance and athletic performance in athletes: Exploring central and peripheral mechanisms. *Journal of Sports Sciences*. Advance online publication. doi: 10.1080/02640414.2025.2573575
17. Goldstein MR, Lewin RK, Allen JJB. Improvements in well-being and cardiac metrics of stress following a yogic breathing workshop: Randomized controlled trial with active comparison. *Journal of American College Health*. 2020; 70(3): 918–928. doi: 10.1080/07448481.2020.1781867
18. Gerbarg PL, Cruz-Cordero YL, Conte VA, et al. Breath–Body–Mind Core Techniques to Manage Medical Student Stress. *Journal of Medical Education and Curricular Development*. 2023; 10: 23821205231212056. doi: 10.1177/23821205231212056
19. Beer JM, Smith KN, Kennedy T, et al. A focus group evaluation of breathe easier: A mindfulness-based mHealth app for survivors of lung cancer and their family members. *American Journal of Health Promotion*. 2020; 34(7): 770–778. doi: 10.1177/0890117120924176
20. Gomes M, Silva ER, Salgado J. Focusing with colorectal cancer patients: A pilot study of a brief online group intervention. *Frontiers in Psychology*. 2024; 15: 1339823. doi: 10.3389/fpsyg.2024.1339823
21. Qian, H. A multidimensional prediction model for overtraining risk in youth soccer players: Integrating physiological and psychological markers. *International Journal of Sports Science & Coaching*; 2025. doi: 10.1080/02640414.2025.2521211
22. Fink M, Schmidt K, Kowalski A, et al. Differential effects of mindfulness treatment and mobile neurofeedback on event-related potentials in early posterior negativity in cancer patients: A clinical-experimental parallel group design. *Frontiers in Psychology*. 2024; 15: 1395032. doi: 10.3389/fpsyg.2024.1395032
23. Kepenek-Varol B, Zeren M, Dinçer R, et al. Breathing and relaxation exercises help improving fear of COVID-19, anxiety, and sleep quality: a randomized controlled trial. *Journal of Integrative and Complementary Medicine*. 2022; 28(7): 579–586. doi: 10.1089/jicm.2021.0381
24. Bargale S, Khandelwal JR, Dave BH, et al. Comparative evaluation of effect of two relaxation breathing exercises on anxiety during buccal infiltration anesthesia in children aged 6–12 years: A randomized clinical study. *Journal of Indian Society of*

- Pedodontics and Preventive Dentistry. 2021; 39(3): 284–290. doi: 10.4103/jisppd.jisppd_501_20
25. Magnon V, Dutheil F, Vallet GT. Benefits from one session of deep and slow breathing on vagal tone and anxiety in young and older adults. *Scientific Reports*. 2021; 11(1): 19267. doi: 10.1038/s41598-021-98736-9
26. Cohen S, Williamson G. (1988). Perceived stress in a probability sample of the United States. In: Spacapan S, Oskamp S. (editors). *The social psychology of health: Claremont symposium on applied social psychology*. Sage Publications; 1988. pp. 31–67.
27. Lee E, Chung BY, Suh C, et al. Korean versions of the Perceived Stress Scale (PSS-14, 10 and 4): Psychometric evaluation in patients with chronic disease. *Scandinavian Journal of Caring Sciences*. 2014; 29(1): 183–192. doi: 10.1111/scs.12131
28. Nielsen MG, Ørnbøl E, Vestergaard M, et al. The construct validity of the Perceived Stress Scale. *Journal of Psychosomatic Research*. 2016; 84: 22–30. doi: 10.1016/j.jpsychores.2016.03.009
29. Ritschel LA, Tone EB, Schoemann AM, et al. Psychometric properties of the Difficulties in Emotion Regulation Scale across demographic groups. *Psychological Assessment*. 2015; 27(3): 944–954. doi: 10.1037/pas0000099
30. Hallion LS, Steinman SA, Tolin DF, et al. Psychometric properties of the difficulties in emotion regulation scale (DERS) and its short forms in adults with emotional disorders. *Frontiers in Psychology*. 2018; 9: 289634. doi: 10.3389/fpsyg.2018.00539
31. Hayama, Y., & Inoue, T. (2012). The effects of deep breathing on “tension–anxiety” and fatigue in cancer patients undergoing adjuvant chemotherapy. *Complementary Therapies in Clinical Practice*, 18(2), 94–98. doi: 10.1016/j.ctcp.2011.10.001
32. Preece DA, Becerra R, Hasking P, et al. The emotion regulation questionnaire: psychometric properties and relations with affective symptoms in a united states general community sample. *Journal of Affective Disorders*. 2021; 284: 27–30. doi: 10.1016/j.jad.2021.01.071
33. Brandão T, Schulz MS, Matos PM. Psychological adjustment after breast cancer: A systematic review of longitudinal studies. *Psycho-Oncology*. 2017; 26(7): 917–926. doi: 10.1002/pon.4230
34. Gündogdu, F., & Koçaşlı, S. (2023). The effects of pranayama or deep breathing exercises on fatigue and sleep quality in women receiving radiation therapy for breast cancer. *Oncology Nursing Forum*, 50(4), 509–520. doi: 10.1188/23.ONF.509-520
35. Shaffer F, Ginsberg JP. An overview of heart rate variability metrics and norms. *Frontiers in Public Health*. 2017; 5: 290215. doi: 10.3389/fpubh.2017.00258
36. Laborde S, Mosley E, Thayer JF. Heart rate variability and cardiac vagal tone in psychophysiological research – recommendations for experiment planning, data analysis, and data reporting. *Frontiers in Psychology*. 2017; 8: 238557. doi: 10.3389/fpsyg.2017.00213
37. Stalder T, Kirschbaum C, Kudielka BM, et al. Assessment of the cortisol awakening response: Expert consensus guidelines. *Psychoneuroendocrinology*. 2016; 63: 414–432. doi: 10.1016/j.psyneuen.2015.10.010
38. Adam EK, Quinn ME, Tavernier R, et al. Diurnal cortisol slopes and mental and physical health outcomes: A systematic review and meta-analysis. *Psychoneuroendocrinology*. 2017; 83: 25–41. doi: 10.1016/j.psyneuen.2017.05.018
39. Chen YJ, Li XX, Ma HK, et al. Exercise training for improving patient-reported outcomes in patients with cancer: A systematic review and meta-analysis. *Journal of Cancer Survivorship*. 2021; 15(4): 697–709. doi: 10.1016/j.jpainsymman.2019.09.010
40. Haller H, Winkler MM, Klose P, et al. Mindfulness-based interventions for women with breast cancer: an updated systematic review and meta-analysis. *Acta Oncologica*. 2017; 56(12): 1665–1676. doi: 10.1080/0284186x.2017.1342862