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Cardiac Vagal Control and Emotional Awareness Associated With Pain Among Breast Cancer Survivors

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ABSTRACT

Pain is the most common symptom reported by breast cancer survivors (BCS), and it significantly affects their quality of life. Higher vagally mediated heart rate variability (vmHRV) is associated with higher emotional awareness (EA) and lower pain. This study examines the moderating role of vmHRV in the association between EA and pain among BCS, which, to our knowledge, has not previously been explored. The study is a cross-sectional secondary analysis of baseline data from an existing study exploring mental health outcomes after art therapy. Participants were 156 female BCS 14 months after cancer diagnosis. We measured vmHRV indexed by the root mean square of successive differences (RMSSD) at rest via electrocardiogram recordings, levels of EA via a performance measure, and how much pain interferes with daily life activities and the intensity of pain in one's daily activities through questionnaires. A negative association was found between RMSSD and pain intensity but not pain interference or EA. At high but not low RMSSD, EA was negatively associated with pain intensity. High EA supports implicit-to-explicit emotional processing, increased vmHRV supports top–down modulation of the nervous system, and both are relevant to pain. Further research is needed to explore the impacts of EA and vmHRV on pain management and psychotherapy interventions.

1 | Introduction

Pain is a major burden among breast cancer survivors (BCS), with 21%–46% reporting persistent pain following surgery (Wang et al. 2018; Wang et al. 2020). The International Association for the Study of Pain (IASP 2020) defines *pain* as "an unpleasant sensory and emotional experience associated with or resembling that associated with actual or potential tissue damage." Cancer-related pain can arise from the tumors themselves or from cancer metastases that erode bones, viscera, and nerves or cause inflammation. It may also be the result of tissue or nerve damage caused by cancer treatments, such as surgery, chemotherapy, hormone therapy, and radiation (Bennett et al. 2019; Leysen et al. 2017). However, pain is not only a somatic experience. It is also a subjective multidimensional experience, including affective, cognitive, and social components (IASP 2020), and inversely associated with quality of life (Costa et al. 2017; Hamood et al. 2018).

Emotional factors play a role in the experience of cancer-related pain. For example, patients may focus their attention on physical symptoms to override emotional pain (Lane et al. 2018). A recent meta-analysis found that preoperative anxiety, depression, pain catastrophizing, and distress were weak but significant predictors of pain after breast cancer surgery (Moloney et al. 2021). A systematic review of 12 studies found anxiety, low psychological resilience, and especially distress predicted acute pain following surgery (McCowat et al. 2019).

However, low emotional awareness (EA) that may be associated with pain following breast cancer and its various treatments has not been examined to the best of our knowledge. *Emotional awareness* is the ability to differentiate and integrate emotions of the self and others to promote emotional processing and regulate emotions. At lower levels of EA, affective responses tend to be experienced as bodily states (implicit experience of emotion). By contrast, at higher levels of EA, individuals will more likely recognize specific emotions (explicit experience of emotion), including combinations of emotions (e.g., sadness, happiness, and fear), experience many nuances of emotions, make subtle distinctions between nuances of emotion, and differentiate them from bodily sensations (Lane and Schwartz 1987; Lane and Smith 2021). Individuals may be advantaged by their ability to make more nuanced adjustments in their perceptions of and responses to the things happening in their lives if they can distinguish more subtle differences in the emotions generated by their experiences.

In a study among patients with long QT syndrome, a disorder associated with increased risk for sudden cardiac death, participants ($n = 161$) were randomly paged 10 times a day to report their momentary experience of somatic symptoms (e.g., headache, sore throat, tiredness). Differentiation of somatic symptoms was assessed by analyzing the granularity of each experience through the magnitude of intercorrelations among reported experiences. Higher levels of EA were associated with more differentiated reporting of somatic symptoms (Lane et al. 2011). Higher levels of EA were also found to have an automatic inhibitory effect on emotional responses (Lieberman et al. 2007). However, higher EA does not exclusively suppress the emotional response; rather, it fosters the coexistence of multiple emotions in a single situation (e.g., acknowledging feeling both angry and sad in an emotional experience rather than merely a global negative feeling) and the effective use of emotional self-regulation strategies (Lane and Smith 2021).

A recent study examining the direct association between EA, levels of somatization, and pain intensity demonstrated high EA with low levels of somatization and low pain intensity in patients with irritable bowel syndrome but not in the healthy control group (Smith et al. 2020). It may be that participants with high EA are also better at differentiating between bodily feelings and emotions (Lane et al. 2011), thus decreasing the odds of recognizing affective physiological changes in the body as signs of a medical problem. Conversely, individuals with low EA may not differentiate between bodily cues, leading to a more generalized experience of negative affect that may amplify the pain's perceived intensity. Smith et al. (2020) found that lower EA was associated with higher levels of somatization. This aligns with findings from a meta-analysis associating alexithymia, a condition characterized by difficulty identifying and describing one's emotions, with high pain intensity, depression, and anxiety (Aaron et al. 2019). Another possibility for the reversed association between EA and pain is through distress. It has been shown that high distress is associated with high pain levels (McCowat et al. 2019). However, in relatively more differentiated distress, as in high EA (e.g., "I feel angry and frustrated" rather than "I feel bad"), the emotion-processing areas of the brain may downregulate high distress-generating limbic activity more specifically, creating the association between high emotional awareness and low pain intensity.

However, EA as a cognitive developmental construct may also affect participants' attunement to pain, causing them to be more aware of their pain levels. Our previous work (Harel et al. 2025) found a positive association between inflammation and both pain and depression only among individuals with high levels of EA. Although no direct association was found between inflammation and pain, participants with high EA may be more sensitive to the somatic effects of the inflammation–pain association. Further research is needed to elucidate the directional influences within these processes. It seems counterintuitive that low pain levels would develop participants' ability to be aware of emotions and that high pain levels would affect participants' cognitive development to name emotions, differentiate between emotions, and differentiate blends of emotions. Because Smith et al.'s (2020) study found no association between EA and pain among the healthy controls (who showed relatively low pain intensity compared to the irritable bowel syndrome group but no differences in the levels of EA), further research on the subject is needed. The differences between the groups suggest that EA may be associated with pain among individuals with underlying conditions, and a regulatory physiological factor, such as cardiac vagal control, may affect the EA–pain association. Notably, these associations have not been tested among BCS to date. Considering that physical factors may also cause BCS pain (Bennett et al. 2019), EA and pain may differ among BCS patients from those with somatoform and somatic symptom disorders.

The neurophysiological mechanisms that may link pain and EA have not been extensively studied. A possible path is via high *cardiac vagal control*—a physiological mechanism through which differentiated recognition of emotions (Spangler et al. 2024; Verkuil et al. 2016) may stimulate a regulated arousal state (Smith et al. 2017) with lower somatization levels (Broadbent et al. 2021) and, accordingly, decreased perceived pain (Koenig et al. 2016). Kogan et al. (2012) documented the relevance of understanding vagally mediated heart rate variability (vmHRV) in relation to emotions of breast cancer patients. They found that higher baseline vmHRV was associated with a greater decrease in anxiety during the first 2 years after a breast cancer diagnosis.

Cardiac vagal control indexes the vagus nerve activity that affects the heart. The *vagus* is the 10th cranial nerve originating in the brainstem. It is a major component of the parasympathetic nervous system branch and descends through many organs,

including the heart and visceral organs. The vagus nerve plays a complex role in carrying communications within bidirectional parasympathetic efferent and afferent pathways (Shaffer et al. 2014). Vagal nociceptive communication can transmit afferent information regarding actual or potential tissue damage to the brain, as well as efferent information that inhibits or increases nociceptive processing (Koenig et al. 2016). A systematic review and meta-analysis (Broadbent et al. 2021) found lower vmHRV associated with higher attentional bias to somatosensory stimuli (prioritizing attention to pain-related information over other information) among chronic pain patients compared with healthy controls. In support of these findings, a meta-analysis and systematic review showed lower vmHRV among chronic pain patients compared to healthy controls (Koenig et al. 2016).

Heart rate variability measures the beat-to-beat (specifically R–R interbeat intervals) changes in heart rate. Further, vmHRV can easily be indexed by the root mean square of successive differences (RMSSD) between normal heartbeats. The RMSSD is the time domain metric of heart rate variability that most correlates during resting conditions with high-frequency heart rate variability and the 0.12–0.40 Hz frequency-limited measure of respiratory sinus arrhythmia (Allen et al. 2007; Shaffer et al. 2014). It was found almost entirely to be vagally mediated in the high- and low-frequency bands when studied in a seated resting position (Kromenacker et al. 2018). In the current study, we used RMSSD with participants sitting in a resting position to measure vmHRV because RMSSD is easier to measure and less affected by artifacts (e.g., breathing) than other vmHRV measures, provides a metric comparable across labs and recording setups, and has large normative databases to indicate levels associated with physical or mental health issues (Jarczok et al. 2019). Moreover, RMSSD appears to be caused chiefly by respiratory sinus arrhythmia (Quigley et al. 2024). It correlates ($r = 0.91$) during resting conditions with the 0.12–0.40 Hz frequency-limited measure of respiratory sinus arrhythmia (Allen et al. 2007).

A systematic review found that higher vmHRV was associated with better self-regulation abilities and higher pain inhibition capacity (Forte et al. 2022). In one study, it increased recognition of emotions (Quintana et al. 2012). Importantly, two studies positively associated vmHRV at rest (RMSSD and high-frequency heart rate variability) with levels of EA (Spangler et al. 2024; Verkuil et al. 2016).

Increased EA and higher vmHRV were found to be associated with increased medial prefrontal cortex activity (Lane et al. 2001). The neurovisceral integration (NVI) model (Thayer 2009; Thayer and Lane 2000) holds that implicit emotional states arising in subcortical regions transition to explicit EA within the medial prefrontal cortex, leading to top–down modulation of subcortical structures accompanied by autonomic responses mediated through the vagus nerve. Accordingly, high EA in the context of low vmHRV may be associated with greater awareness of negative affect and high distress without a modulatory effect on pain. In contrast, high EA in the context of high vmHRV would be associated with a greater modulatory effect between awareness of negative affect and distress on pain (e.g., self-regulation abilities, higher pain inhibition capacity; Forte et al. 2022), predicting a negative association between EA and pain.

Another theoretical model that explains bottom–up (implicit-to-explicit) processing is the three-process model of implicit and explicit emotions (Smith 2020). Per the three-process model, *conscious access* (the conscious representation of an experience in a given moment) requires that bodily sensations and affective representation be associated with cognitive control processes (bottom–up) and sufficient for the conscious representation to occur. Although emotional awareness is closely related to conscious access, they are not identical. Conscious access does not always include recognition of emotions, as with high EA. An example may be the case of unconsciously represented emotions. One may say, "I don't feel angry about what happened," and be aware of their aggressive behaviors but not their emotions. An emotional experience is more complex than EA. It includes complex interplay between factors such as physiological arousal, cognitive interpretations, and behavioral responses. Higher EA may facilitate the differentiation between bodily sensations (Lane et al. 2011) and emotions conceptualized as such during their processing, thereby decreasing the odds of recognizing affective physiological changes as physical pain.

According to the three-process model, this processing (from implicit-to-explicit emotions) may be reflected as conscious access to the experience; according to the NVI model, top–down modulation may be expressed by higher vmHRV. Therefore, the interaction between high EA and high vmHRV may be vital in these processes. Examining these processes may advance our understanding of the interactions among the autonomic nervous system, EA, and pain. See Figure 1 for a schematic diagram of the main concepts from the NVI and the three-process models with the study variables.

The main objectives of the current study are to examine the associations between EA, pain, and vmHRV, as well as to explore the potential differential effect of vmHRV on the EA–pain relationship in BCS. Based on previous research, we hypothesize the following: (1) A negative association between EA and pain (Smith et al. 2020), (2) A negative association between vmHRV and pain (Koenig et al. 2016; Forte et al. 2022), (3) A positive association between EA and vmHRV (Spangler et al. 2024; Verkuil et al. 2016), and (4) A moderating effect of vmHRV on the EA–pain association. It is expected that high vmHRV will moderate the negative association between EA and pain among BCS and that this moderating effect will be decoupled among individuals with low vmHRV. See Figure 2 for the schematic diagram of the proposed moderation analyses.

2 | Methods

To examine our hypothesis, we conduct a cross-sectional secondary analysis of baseline data from "The Role of Emotional Processing in Art Therapy for Breast Cancer Patients" (REPAT) study (Czamanski-Cohen and Weihs 2023; Czamanski-Cohen et al. 2019). The REPAT examined the effect of emotional processing and cholinergic anti-inflammatory pathways on reducing cancer-related symptoms (depression, fatigue, and pain)

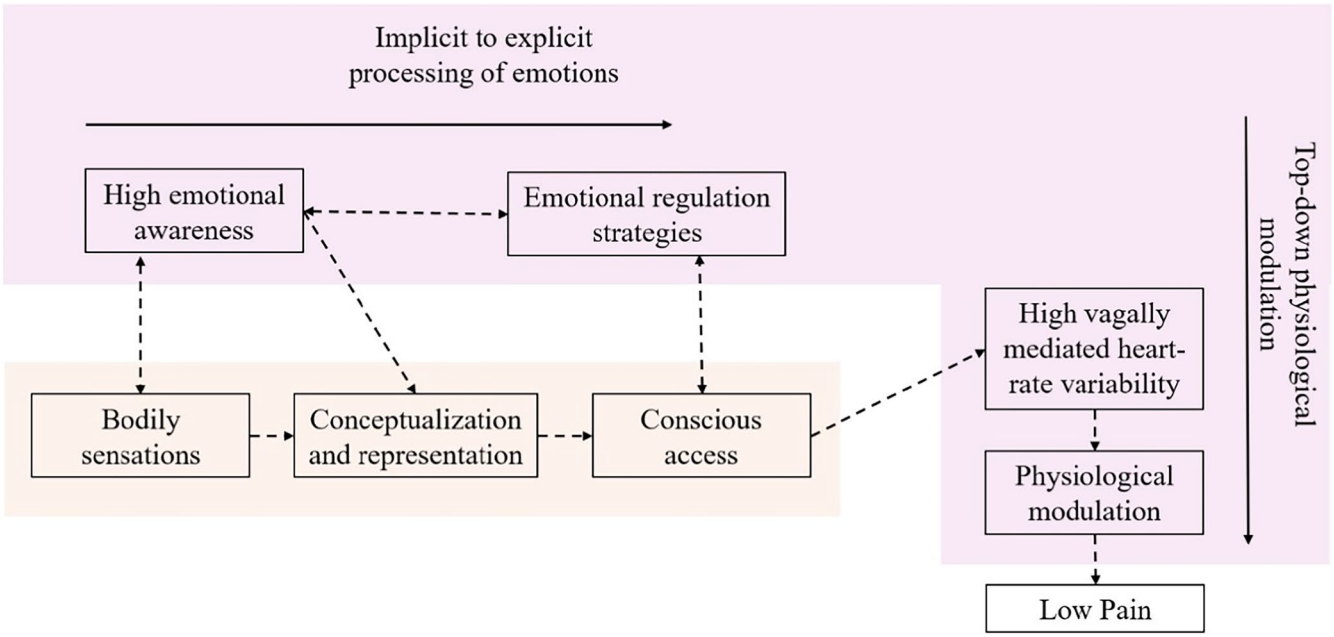

FIGURE 1 | Integration of concepts from the neurovascular integration model, three-process model, and study variables. The dashed arrows indicate information flow that depends on the emotional experience being processed from implicit-to-explicit, leading to a conscious experience and goal-directed decision-making processes. The light orange color reflects concepts from the three-process model, and the light purple color reflects concepts from the NVI model.

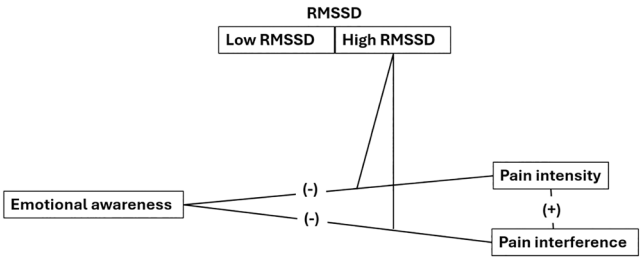

FIGURE 2 | Schematic diagram of the moderation analyses. RMSSD, root mean square of successive differences; (–), negative association; (+), positive association.

through an art therapy intervention among BCS (Czamanski-Cohen et al. 2019).

2.1 | Participants and Procedure

Of the 241 Jewish and Arab participants recruited between May 2019 and March 2022 for the REPAT study, we included only 179 Jewish participants in our analyses due to cultural and value differences (see Hebi et al. 2024, for details regarding these differences). We eliminated 11 participants who did not provide electrocardiograms (ECGs) and eight whose ECG recordings were corrupted. Levels of EA were missing for four participants, resulting in a sample of 156 participants. The 19 participants excluded due to ECG issues were compared for pain (intensity and interference) and EA to the 156 participants included in this analysis. Pain (intensity and interference) did not differ between these groups. However, EA was significantly lower in the excluded group, $F(1, 171) = 5.38$ ($p < 0.05$). An a priori power analysis using G*Power showed that the minimum sample size needed for multiple regression analysis with 11 variables (independent study variables and background variables) at a power of 0.80, $\alpha = 0.05$ (medium effect size) was 123 participants (Cohen 1992).

Inclusion criteria included being (1) an adult (> 18 years) female BCS with an initial diagnosis or first recurrence of breast cancer or second primary breast cancer, (2) at least 3 months since completing chemotherapy or radiation therapy, not less than 1 month after surgery (lumpectomy, mastectomy, or reconstruction) and no more than 19 months after the end of treatment, and (3) able to complete the assessment in Hebrew. Exclusion criteria included a diagnosis of (1) lifelong bipolar disorder, schizophrenia, or schizoaffective disorder, (2) fibromyalgia or chronic fatigue syndrome, (3) anticholinergic medication or major cardiac events, or (4) taking autonomic drugs, or (5) dementia or other disorder that precluded informed consent, or (6) having an active suicidal plan (question during screening). A detailed rationale for the inclusion and exclusion criteria can be found in Czamanski-Cohen et al. (2019). We had planned to include male BCS if a sufficient number to randomize expressed interest in the study; however, none asked to participate.

Participants were recruited from the Davidoff Center for Cancer Treatment at Rabin Medical Center and the community. At study completion, participants received the equivalent of $US200 in new Israeli shekels to cover expenses. All standard, additional, or replacement medical treatments for cancer were allowed. At baseline, participants completed questionnaires through the Research Electronic Data Capture (REDCap; Harris et al. 2019) web-based application system, and ECGs were recorded. Because various activities may influence RMSSD throughout the day, for ECG recordings, participants were required to fast for at least 12 h before

collection and refrain from smoking, exercising, and drinking coffee (the REPAT study also collected blood samples beyond this paper's scope). In addition, to avoid any extraneous influences, the ECG recordings at rest (sitting) were collected between 7:00 a.m. and 11:00 a.m. via 5.5 cm Ag-AgCl disposable electrodes with gel attached to the participant's chest at the breastbone, two fingers below the sternal notch. The electrodes were attached to a portable signal receiver (BioPatch, Zephyr Technology; Annapolis, MD) and communicated with OmniSense software via Bluetooth Low Energy. Participants were asked to sit quietly without talking, moving, reading, using a smartphone, or interacting socially. The ECG recordings lasted 25 min: 5 min to acclimate to a resting heart rate (not included in the analysis) and 20 min recorded for analysis (Allen et al. 2007), as defined by the REPATs protocol (Czamanski-Cohen et al. 2019).

2.2 | Ethical Considerations

The Helsinki Committees of the Davidoff Center for Cancer Treatment at Rabin Medical Center, Israel (0778-17-RMC) and the Ethics Committee of the Faculty of Social Welfare and Health Sciences at the University of Haifa, Israel (234/18) approved the REPAT study. Before participating, all participants signed informed consent forms and were informed they could leave at any time without affecting their treatment. The authors declare that the study was conducted in accordance with the declaration of the World Medical Association (2013).

2.3 | Measures

2.3.1 | Demographic and Medical Information

Questionnaires assessing sociodemographic (e.g., age, marital status, education, household income, and religiosity) and medical information (e.g., cancer diagnosis, cancer stage, cancer treatment, time since diagnosis, and time from the end of cancer treatment) were collected, including lifestyle habits (e.g., smoking, Mediterranean diet, alcohol consumption, and meditation practice). All possible response categories for the demographic, medical, and lifestyle habits are specified in Table 1.

2.3.2 | Emotional Awareness

A short (10-item) validated version (Subic-Wrana et al. 2005) of the Levels of Emotional Awareness Scale was used to assess EA (Lane et al. 1990). Following short, evocative interpersonal scenarios, participants describe their own and others' feelings. Scores are determined by analyzing how differentiated and integrated the emotions are, the number of emotions described, and the sum of emotions attributed to the self and other person scenarios. Responses for EA of self (EA_{self}) and EA of other (EA_{other}) range from 0 to 4 for each of the 10 scenarios (0–40 for all scenarios). The EA total (EA_{total}) scores are calculated based on the EA_{self} and EA_{other} scores and range between 0 and

TABLE 1 | Sociodemographic, lifestyle habits, and medical information of Jewish participants breast cancer survivors.

Categorical variable	*N* (%)
Age (years)	
26–35	5 (3.2)
36–45	32 (20.5)
46–70	107 (68.6)
Older than 70	12 (7.7)
Education	
High school or below	26 (16.7)
Certificate or above	130 (83.3)
Employed	92 (59.0)
Income	
Below average	22 (14.1)
Average	76 (48.7)
Above average	57 (36.5)
Married or long-term relationship	113 (72.4)
Religiosity level	
Secular	87 (55.8)
Traditional	43 (27.6)
Religious	26 (16.7)
Lifestyle and habits	
Nonsmoker (past week)	144 (92.3)
Mediterranean diet (yes or somewhat)	135 (86.6)
Non-alcohol drinker (past week)	128 (82.1)
Nonuser of medicinal or recreational marijuana (past 2 weeks)	115 (73.7)
No meditation or mindfulness practice (past 2 weeks)	96 (61.5)
Cancer stage	
Stage 0–1	52 (33.3)
Stage 2	64 (41.0)
Stage 3	26 (16.7)
Stage 4	8 (5.1)
Treatment[a]	
Chemotherapy	96 (61.5)
Radiotherapy	130 (83.3)
Surgery	144 (92.3)
Hormonal (aromatase inhibitors, Tamoxifen, Letrozole)	120 (76.9)
Biological	31 (19.9)
Numeric variables	***M* (SD)**
Months from the end of treatment to the baseline	6.2 (4.10)
Months from diagnosis to baseline	13.75 (5.95)
Body mass index	26.46 (4.92)

[a]Treatment combinations are possible.

5 for each scenario (0–50 for all 10 scenarios). An EA_{total} score of 5 is obtained for each scenario if the EA_{self} and the EA_{other} feelings are rated 4 and reflect different feelings. Higher scores reflect higher EA and ability to differentiate and integrate complex emotions in oneself and others. The EA_{total} score internal consistency in the present study was Cronbach's alpha of 0.80 and interrater reliability of 0.9 for EA_{total}, EA_{self}, and EA_{other}.

2.3.3 | Vagally Mediated Heart Rate Variability

The ECG recordings were manually analyzed for R–R intervals using the QRSTool software (available at www.psychofizz.org), and vmHRV was extracted using CMetX software (Allen et al. 2007). We calculated the RMSSD as the vmHRV metric. Artifacts and ectopic beats were manually corrected through mid-beat corrections or excluding sections. Mid-beat corrections were applied to 42 ECGs with artifacts or ectopic beats. Additionally, 33 ECGs had sections excluded from analysis due to excessive artifacts or uncorrectable ectopic beats.

2.3.4 | Pain

We assessed pain (interference and intensity) using the validated translation of the Patient-Reported Outcomes Measurement Information System (PROMIS). Pain interference (PIQ-6a) measures how much pain interfered with daily activities during the last week, and pain intensity (Item 3a) measures the intensity of pain in one's daily activities (Cella et al. 2007). Based on a Likert scale, the level of pain interference and intensity ranged from 0 (*not at all interfered with*) to 4 (*very much interfered with*). Questions included, "To what extent did the pain interfere with your daily activities?" and "What was the intensity of your worst pain?" The PROMIS instruments are scored based on item-level calibration. Each question has a response range value between 0 and 5. The sums ranged from 6 to 30 for pain interference and 3 to 15 for pain intensity. Based on each measurement's raw scores, a calibration *t*-score was calculated using REDCap. The *t*-scores ranged from 41 to 78.3 for pain interference and 36.3 to 81.8 for pain intensity (HealthMeasures 2020a, 2020b). The Cronbach's alpha of internal consistency was 0.95 for pain interference and 0.87 for pain intensity.

2.4 | Data Analysis

We performed item mean imputation within each participant's pain intensity and interference scale (mean imputation was not performed within EA and RMSSD) for participants missing 20% or fewer responses (Downey and King 1998). Statistical analyses were conducted in IBM SPSS (Version 27). Descriptive statistics with means and standard deviations were first calculated for all demographic and medical variables. Pearson's correlation analysis was conducted to evaluate whether there was a direct relationship between the study variables, vmHRV (RMSSD), EA (self, other, and total), and pain (intensity and interference).

Additionally, Pearson correlations were used between study variables and sociodemographic and medical characteristics to determine which variables accounted for covariance during the moderation analysis. A PROCESS procedure for SPSS (Model 1) using 95% confidence intervals with 5000 bootstrap samples was used to assess the interaction effect between RMSSD and EA on pain intensity and interference (separate analyses for each aspect of pain) while accounting for covariate sociodemographic and medical variables. The 16th, 50th, and 84th percentiles were used, guaranteeing that the probed points were within the observed data range. The Johnson-Neyman (J-N) technique was used to examine conditional effects at specific RMSSD levels where EA is significantly associated with pain symptoms, including the direction of the association (Hayes 2018).

3 | Results

3.1 | Sample Characteristics

Most participants had more than 12 years of education (83.3%), were from 36 to 70 years old (89.1%), were employed (59%), and had average or above income (85.2%). Half were secular, and approximately 74.3% had been diagnosed with early-stage breast cancer (Stages 0–2). Table 1 presents the sample's sociodemographic, lifestyle, and medical characteristics.

3.2 | Associations Between Study Variables

Pain intensity and interference were correlated ($r = 0.79$, $p < 0.01$), and EA_{self}, EA_{other}, and EA_{total} were strongly intercorrelated ($r = 0.67$–0.91, $p < 0.01$) and not associated with pain interference or intensity. Because the EA variables measuring awareness of self, other, or both (total) were strongly intercorrelated, our analyses focused on EA_{self} and EA_{other} (excluding EA_{total}). The RMSSD was negatively associated with pain intensity ($r = -0.17$, $p < 0.05$) but not with pain interference or EA. See Table 2 for Pearson correlations, means, and standard deviations of study variables.

Sociodemographic and medical variables were not associated with pain intensity or interference. However, age, chemotherapy, and body mass index (BMI) were associated with RMSSD; education level was associated with EA_{self}; and hormonal therapy was associated with EA_{other}. See Table 3 for the Pearson correlations between study variables and sociodemographic and medical variables.

3.3 | The Moderating Role of vmHRV

The moderation analyses accounted for covariance (age, chemotherapy, BMI, and education level). The effect of the independent variable and moderator on the outcomes (pain interference and intensity) was not eliminated (remained significant) when accounting for covariances; therefore, our moderation analyses included the covariance.

The interaction between RMSSD and EA_{self} was significant for pain intensity (B = −0.02, SE = 0.01, 95% CI [−0.03, 0.00]) but not significant for pain interference (B = −0.01, SE = 0.01, 95% CI [−0.02, 0.00]), as shown in Table 4. The EA_{self} variable was

TABLE 2 | Pearson zero-order correlations between study variables, means, and standard deviations.

Variable	*N*	*M*	(SD)	1	2	3	4	5
1. Pain intensity	156	55.85	(12.74)					
2. Pain interference	156	57.39	(9.92)	0.79**				
3. LEAS-self	156	24.85	(6.50)	−0.10	−0.10			
4. LEAS-other	156	23.21	(7.07)	−0.01	0.07	0.67**		
5. LEAS-total	156	28.88	(6.51)	−0.12	−0.09	0.91**	0.80**	
6. RMSSD	156	33.13	(21.00)	−0.17*	−0.08	0.06	−0.01	0.05

Abbreviations: LEAS, Levels of Emotional Awareness Scale; RMSSD, root mean square of successive differences.
*$p < 0.05$, **$p < 0.01$.

TABLE 3 | Pearson correlations between study variables and sociodemographic and medical variables.

Sociodemographic and medical variables	Pain intensity	Pain interference	LEAS-self	LEAS-other	LEAS-total	RMSSD
Age	−0.06	−0.05	−0.03	−0.15	−0.05	−0.17*
Education level	−0.12	−0.06	0.19*	0.12	0.22**	0.11
Income level	−0.14	−0.07	−0.1	−0.12	−0.13	0.03
Cancer stage	0.01	0.80	−0.01	−0.11	−0.05	−0.07
Cancer treatment						
Chemotherapy	0.12	0.12	0.09	−0.01	0.06	0.18*
Radiotherapy	0.01	−0.01	−0.05	−0.05	−0.08	0.01
Surgery	−0.01	−0.01	0.04	0.02	0.05	0.02
Hormonal	−0.07	−0.05	0.11	0.18*	0.12	−0.03
Biological	0.08	0.03	0.06	0.11	0.05	−0.06
Body mass index	0.06	0.09	0.03	0.12	0.06	−0.22**
Months from end of treatment to baseline	−0.03	−0.09	−0.04	−0.05	−0.03	0.00
Months from diagnosis to baseline	−0.04	−0.07	0.15	0.09	0.16	0.05

Abbreviations: LEAS, Levels of Emotional Awareness Scale; RMSSD, root mean square of successive differences.
*$p < 0.05$, **$p < 0.01$.

negatively associated with pain intensity in participants with high RMSSD. The interaction between RMSSD and EA_{self} explained 2% of the variance in pain intensity.

The J-N technique revealed that EA_{self} was significantly associated with pain intensity at levels of RMSSD above the 50th percentile, specifically, above 46.39 RMSSD. Figure 3 visually represents the interaction effects at different levels of RMSSD. Participants with high RMSSD and high EA_{self} present significantly lower pain intensity while accounting for covariance. However, this effect was not significant in participants with average or low levels of RMSSD.

The interaction between RMSSD and EA_{other} was not significantly associated with pain intensity ($B = 0.00$, SE = 0.01, 95% CI [−0.02, 0.01]) or pain interference ($B = -0.01$, SE = 0.01, 95% CI [−0.02, 0.01]).

4 | Discussion

To the best of our knowledge, this is the first study to examine the relationships between EA, vmHRV, and pain symptoms among BCS. The key finding is that EA was negatively associated with pain intensity among BCS with high RMSSD. This association was not significant for patients with low or average RMSSD or for pain interference. We suggest through this discussion that one's high level of EA and high vmHRV as a physiological regulatory modality are important in the experience of pain, especially among BCS. We begin our discussion by interpreting the moderating role of high RMSSD on the association between high EA and low pain symptoms.

The framework of the three-process model (Smith 2020) and the NVI model (Thayer 2009; Thayer and Lane 2000) may explain the potential mechanisms underlying the interaction between EA and

TABLE 4 | Moderated effects of root mean square of successive differences (RMSSD) on the Relationship Between Levels of Emotional Awareness Scale (LEAS)-self and pain intensity (simple slopes).

			95% CI	
Variable	***B***	**SE**	**LL**	**UL**
LEAS-self	0.36	0.30	−0.24	0.96
RMSSD	0.30	0.22	−0.13	0.74
Age	−1.59	1.70	−4.95	1.76
Education level	−3.07	2.81	−8.61	2.48
Chemotherapy	3.69	2.15	−0.56	7.94
BMI	0.02	0.21	−0.40	0.45
RMSSD: Conditional effects at 16th, *M*, 84th percent				
15.76	0.10	0.20	−0.30	0.51
30.9	−0.15	0.16	−0.46	0.17
46.94	−0.41	0.21	−0.82	0.00
Johnson-Neyman: Significance region				
RMSSD	% below		% above	
46.39	83.66		16.34	
F	2.37 (7, 145)*			
R^2	0.10			

Abbreviations: *B*, unstandardized coefficient; BMI, body mass index; SE, standard error.
*$p < 0.05$.

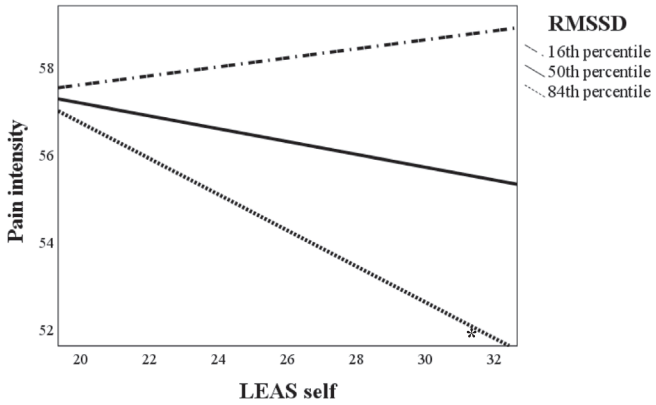

FIGURE 3 | Moderated effects of root mean square of successive differences (RMSSD) on the Relationship Between Levels of Emotional Awareness Scale (LEAS)-self and pain intensity. *$p < 0.05$.

vmHRV in association with pain. The three-process model coordinates the interactions between three processes that influence variations in EA: (1) the activation of bodily sensations associated with affect, (2) an affective response representation, and (3) conscious access to emotions (such as attention) triggering goal-directed processes. In brief, the NVI model holds that implicit emotional states arising in subcortical regions transition to explicit EA within the cortex accompanied by top–down modulation of subcortical structures and autonomic responses mediated through the vagus nerve. Therefore, differentiation and complexity of the emotional experience (as in high EA) are reflected in more varied and intricate patterns of physiological responses, such as higher vmHRV (Spangler et al. 2024; Verkuil et al. 2016).

In the prototypical case, higher EA reflects the bottom–up transformation of implicit (unconscious) bodily responses into explicit (conscious) emotional processing (Lane 2006; Lane et al. 2001). Bodily responses are transmitted to the medial prefrontal cortex for conceptualization (Lane and Garfield 2005; Lane et al. 2001), and conscious awareness occurs. According to the NVI model, the complexity of the emotional experience is then reflected in higher vmHRV. However, according to the three-process model, emotional experiences must be associated with bodily awareness—interoception and with affect representation for conscious awareness to occur (Smith 2020).

Interoception, often referred to as *interoceptive awareness*, refers to the internal representation of all bodily sensations and how the brain processes these sensations (Pinna and Edwards 2020). A systematic review found both high vmHRV and interoceptive awareness to be positively associated with adaptive emotional regulation strategies, such as reappraisal and acceptance of emotions (Pinna and Edwards 2020). Although not previously examined directly, theory suggests that interoception and EA facilitate each other (Herbert et al. 2011; Simmons et al. 2013). This enhanced interoception may assist in better differentiation between various somatic pain sensations. Consequently, participants with the ability to recognize and name their somatic experience with high levels of granularity and differentiation, likely corresponding to high levels of EA and high vmHRV (Spangler et al. 2024; Verkuil et al. 2016), may be less prone to misinterpreting bodily distress and negatively valenced affect as pain (Lane et al. 2011). However, because no association was found in our study between EA and RMSSD, the differences among participants with high EA relative to interoception remain an open question requiring further investigation. Nevertheless, participants with high RMSSD and high EA reported lower levels of pain. Further research is necessary to understand the underlying mechanisms of this process fully.

Notably, our findings also show low EA associated with high pain symptoms when RMSSD is high, which may be explained by Damasio and Damasio's (2006) proposed "as if body loop" concept. This concept suggests that cognitive representations can be elaborated as if occurring in the body without access to bodily sensations. In the context of low EA, the "as if body loop" might represent negative emotions reinterpreted as somatic distress (pain) in addition to the physical body-based pain BCS may experience (Bennett et al. 2019). Although low EA reflects an absence of processing implicit emotions into explicit emotions (Smith 2020), it does not preclude the possibility of top–down modulation reflected by the high vmHRV. Cardiac vagal control, measured by vmHRV, reflects autonomic nervous system activity and is influenced by multiple factors, including physical health, beyond emotional processing. Therefore, we cannot rule out the possibility that participants with high vmHRV, low EA, and high pain symptoms were in good physical health with strong cardiac vagal control despite reporting high pain levels. Further research could examine whether individuals with low EA and high vmHRV may be more prone to the intensity of pain symptoms. The association between low EA and high pain symptoms at high RMSSD challenges the assumption that high

vmHRV under all circumstances is a protective physiological factor and that high vmHRV alone can reduce pain among BCS. Further research is needed to explore this possibility.

Our study also found a weak but significant negative correlation between pain intensity and RMSSD. In their systematic review, Forte et al. (2022) found mixed results for vagal withdrawal during experimentally induced pain among healthy adults. They reported significant changes in both the sympathetic and parasympathetic autonomic nervous systems during painful stimulations and several factors affecting these changes, including affective states. Moreover, they reported higher vmHRV associated with better self-regulation and pain inhibition. We provide additional information to these findings by demonstrating the importance of high EA in conjunction with high vmHRV.

Prior research examining the relationship between EA and pain has focused primarily on patients with functional somatic syndromes (fibromyalgia, irritable bowel syndrome), where the source of the nociceptive pain signal was often unclear (Carlson et al. 2019; Smith et al. 2020). To the best of our knowledge, ours is the first study to examine these associations among BCS whose pain may be due to tissue damage, bone erosion, nerve damage, or other physical factors (Bennett et al. 2019). This distinction of pain etiology—between functional somatic syndromes and BCS pain—may explain the weaker associations between EA and pain we observed among BCS. Additionally, modulations of pain due to somatic injury may require both higher EA and vmHRV rather than high EA alone.

Our study did not reveal a significant positive correlation between RMSSD and EA, as found in Verkuil et al.'s (2016) and Spangler et al.'s (2024) findings among healthy students and patients with long QT syndrome. This discrepancy may be due to differences in the sample's characteristics. The BCS in our study's sample were older than those in past studies (Spangler et al. 2024; Verkuil et al. 2016) and, as expected, had lower RMSSD (Jandackova et al. 2016). Additionally, our sample demonstrated significantly lower EA ($M=28.88$, $SD=6.51$, our study sample, $M=32.38$, $SD=1.18$, $t=2.94$, $p<0.001$; Verkuil et al. 2016, and $M=34$, $SD=4.7$, $t=7.97$, $p<0.001$; Spangler et al. 2024). Lower levels of EA and RMSSD, as in our study, may decrease the likelihood of the implicit-to-explicit transition of EA, perhaps limiting the opportunity for top–down vmHRV to be activated. Additionally, breast cancer and its treatments may contribute to lower vmHRV in BCS compared to matched healthy controls, though this subject remains unclear (Arab et al. 2016).

The lack of a significant association between EA and pain interference and the absence of the moderating effect of RMSSD on this relationship may be attributable to the relatively low EA and RMSSD observed in our sample. However, it could also be that EA as an emotional resource for pain management and the physiological regulatory modality of vmHRV are less relevant than the intensity of pain for the interference of pain in daily life activities.

Similar to Smith et al.'s (2020) study, we found no associations between EA_{other} and pain. In addition, EA_{other} was not associated with pain during high RMSSD. Although, intuitively, emotional empathy would not be related to one's pain, Smith et al. found higher somatization associated with low EA_{other}. They argued that low EA_{other} may be associated with a worsening in interpersonal relationships and a reduction in the social support associated with both negative emotions and amplified pain distress (e.g., Roberts et al. 2015). Awareness of one's emotions may contribute to pain management through effectively recognizing bodily discomfort and differentiating between somatic illness and psychological distress or being able to mentalize those bodily discomforts with life events and regulate them. The lack of association between EA_{other} and pain may highlight that pain is a more intrapersonally focused coping problem than a socially focused coping problem.

As we hypothesized based on Smith et al.'s (2020) findings of a negative association between EA and pain, the EA–pain association was decoupled among participants with low and average RMSSD. However, the EA–pain association was not found in our sample. It is reasonable to speculate that low RMSSD decreases the odds of finding this association because the top–down modulatory effect on pain may be absent (Thayer and Lane 2000). At low RMSSD and low EA, we may expect to find high pain symptoms. However, some participants with low RMSSD and low EA may just have low pain symptoms due to their physical health conditions, whereas others may have high pain symptoms due to low EA or physical health conditions. Despite the absence of a significant correlation between RMSSD and EA (possibly due to sample characteristics), we suggest that the interaction between high vmHRV and high EA is important for the experience of pain among BCS.

4.1 | Translational Implications and Future Research

Our findings may contribute to the design of psychotherapeutic interventions for BCS and future research directions. In randomized controlled trials, EA and expression therapy have been shown to reduce pain and somatic symptoms among patients with somatoform disorders (Farnam et al. 2014; Lumley et al. 2017; Maroti et al. 2021; Thakur et al. 2017). If our results are replicated, these interventions hold promise for reducing pain for breast cancer patients, especially those with low EA and high vmHRV. Measuring vmHRV might help identify patients who could benefit from interventions to improve EA and reduce pain.

Interventions promoting self-compassion—treating oneself with kindness and accepting positive and negative emotions—have been shown to reduce pain (Luo et al. 2020; Tian et al. 2020). In these studies, high vmHRV with self-compassion showed greater bodily control over pain arousal and a less distressing experience of pain. Emotional awareness may be a prerequisite for developing compassion for one's emotions.

Psychotherapies that integrate holistic body–mind perceptions (e.g., dance movement therapy) with the aim to enhance bodily interoceptive awareness and foster EA, facilitating the interpretation of bodily sensations associated with complex emotions, may be beneficial in reducing pain symptoms (Ashar et al. 2022; Calsius et al. 2016; Majore-Dusele et al. 2021; Payne and Brooks 2019). In these experiential therapies, the body is

integrally involved in the therapy process, thus promoting embodied experiences and explicit processing.

Future research may investigate our hypothesis that low physical fitness contributed to the lack of association between EA and RMSSD in this study. One could add measures of RMSSD to physical fitness interventions to test hypothesized increased RMSSD, EA, and decreased pain intensity as benefits in addition to their already recognized salutary effects on cancer patients' wellbeing. Studies of awareness and accuracy of interoception as means through which EA and RMSSD may reduce pain intensity in breast cancer patients could set the stage for its use as another point of intervention in this patient population.

A final important avenue for future research is to more comprehensively understand the circumstances in which EA and vmHRV can be dissociated. As noted above, under non-stressful conditions, higher emotional awareness is associated with better reflective capacity and better capacity for emotion regulation. However, under conditions of stress, such as breast cancer diagnosis, emotion regulation may be impaired, potentially making emotional awareness a double-edged sword. To illustrate, in a previous study of BCS, higher emotional awareness was associated with above-average depression in women with low social support, whereas EA was associated with below-average depression in women with high levels of social support (Goldman et al. 2024). Emotional awareness can facilitate emotion regulation when reflective capacity is intact, but under conditions of stress, reflective capacity may be compromised. It is possible that women in this sample with higher emotional awareness were heterogeneous with regard to whether awareness of distress or capacity for emotion regulation predominated. Future research should address whether this difference, due either to social support or changes in reflective capacity due to stress, corresponds to lower versus higher vmHRV, which in turn could affect pain experience.

4.2 | Limitations

This study has several limitations that require caution in interpreting the results. The cross-sectional study design limited our ability to conclude about the direction of associations and causality. We did not control all potentially confounding variables that may affect vmHRV, such as physical fitness and training levels. In addition, we did not assess factors such as interoception, which may also influence the relationship between EA and pain. These limitations further restrict our ability to draw definitive conclusions about causality. This study was performed within a Jewish Israeli community of highly educated BCS with average and above incomes. As such, the findings may not apply to other populations, particularly ethnic minorities, such as Arab Israelis. Although all Israeli citizens are entitled to all necessary cancer treatments according to the equality law of public health, there may be differences. Ethnic minorities might encounter additional challenges related to discrimination and healthcare access that may affect pain. Additionally, cultural factors, including religiosity (as among orthodox Jews), may influence attitudes toward pain and potentially restrict the generalizability of our results.

Our results must be examined in other populations, with other pain syndromes, and in a longitudinal study design to determine the directionality of the findings. The lower levels of both EA and RMSSD in our study sample of BCS compared to previous research (Spangler et al. 2024; Verkuil et al. 2016) that demonstrated a positive association between EA and RMSSD may weaken the magnitude of the EA–pain association. However, our sample reflects the limited ability of this population to downregulate through emotional processing.

In addition, our study's cross-sectional design, examining resting vmHRV at a single time point, limited our ability to identify within-person changes in vmHRV. To capture such changes, longitudinal or experimental designs involving stimulus-induced vmHRV fluctuations would be necessary (Laborde et al. 2018). The study was also limited by how the vmHRV data were collected. Sitting for more than 20 min to measure ECG without social interaction or movement may be difficult for some participants and lead to distress-induced vmHRV reduction. A potential drawback of RMSSD is that it may also capture some lower frequency heart rate variability (Allen et al. 2007, Figure 3) that may have sympathetic influences. However, as Kromenacker et al. (2018) demonstrated, such sympathetic influences are negligible during seated resting conditions, and RMSSD is abolished by pharmacological vagal blockage (Penttilä et al. 2001).

5 | Conclusions

To the best of our knowledge, this is the first study to examine vmHRV as a moderator of the association between EA and pain in BCS. We found that EA is negatively associated with pain intensity in BCS with high vmHRV but not low or average vmHRV. This result is consistent with the NVI model of higher vmHRV, reflecting greater complexity of the emotional experience emanating from the complex sensory and autonomic foundation upon which it is based.

The study's results are initial evidence that both vmHRV and EA are relevant to the multifaceted nature of pain and highlight the need for interdisciplinary approaches to study and treat pain in the context of somatic injury. If these results are replicated and extended, they could inform interventions to increase EA and the authentic processing of bodily responses in real-time to derive emotional meaning from physical information in the person's context (i.e., awareness as an expression of the process coordination suggested in the three-process model). Therefore, this study emphasizes the synergistic role of EA and vmHRV in modulating pain perception in BCS.

Author Contributions

Keren Harel: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, validation, visualization, writing – original draft, writing – review and editing. **Johanna Czamanski-Cohen:** conceptualization, data curation, funding acquisition, investigation, methodology, project administration, resources, supervision, writing – review and editing. **Miri Cohen:** conceptualization, investigation, methodology, supervision, writing – review and editing. **Richard D. Lane:** conceptualization, methodology, writing – review and editing. **John J. B. Allen:** conceptualization,

investigation, methodology, project administration, resources, software, writing – review and editing. **Opher Caspi:** conceptualization, data curation, investigation. **Karen L. Weihs:** conceptualization, funding acquisition, investigation, methodology, project administration, resources, supervision, writing – review and editing.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the REPAT study's PI upon request.

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