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Interoceptive awareness mediated the effects of a 15-minute diaphragmatic breathing on empathy for pain: A randomized controlled trial

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Abstract

Although empathy for pain plays an important role in positive interpersonal relationships and encourages engagement in prosocial behavior, it remains largely unknown whether empathy for pain could be effectively altered by psychophysiological techniques. This study aimed to investigate the impact of a single session of diaphragmatic breathing practice on empathy for pain and examine the potential mechanism involving interoceptive awareness. A total of 66 healthy participants were randomly assigned to the intervention group or the control group. The intervention group received a 15-minute diaphragmatic breathing (DB) practice with real-time biofeedback, while the control group was to gaze at a black screen at rest and not engaged in any other activities. Before and after the invention, all participants were instructed to evaluate the intensity and unpleasantness of empathy for pain while watching different pictures with pain or non-pain conditions. The Multidimensional Assessment of Interoceptive Awareness (MAIA) was then administered to measure interoceptive awareness. The results indicated a significant interaction between group and time with regard to empathy for pain and MAIA. The DB group showed a statistically significant decrease in both pain intensity and unpleasantness during the pain picture condition, as well as a noteworthy increase in MAIA scores. The control group did not demonstrate any substantial changes. More importantly, the regulation of attention, a dimension of MAIA, had a significant mediating effect on the impact of diaphragmatic breathing on reported unpleasantness. Diaphragmatic breathing could serve as a simple, convenient, and practical strategy to optimize human empathy for pain that warrants further investigation, which has important implications not only for individuals with impaired empathy for pain but also for the improvement of interoceptive awareness.

KEYWORDS

diaphragmatic breathing, empathy for pain, interoceptive awareness, unpleasantness

1 | INTRODUCTION

The ability to perceive, judge, and emotionally respond to the pain of others is known as empathy for pain (Decety & Jackson, 2004). Compared to other forms of empathy, empathy for pain has a stronger connection to emotional contagion (Tait, 2008). It emerged earlier in the course of evolution, making it a more primitive and universal empathy type (Fitzgibbon et al., 2010). This form of empathy operates in a distinctly empathic manner, drawing on neural representations that are associated with personal experiences of pain (Roche & Harmon, 2017). Empathy for pain response is conceptualized into two distinct but independent components, cognitive empathy for pain and affective empathy for pain. The former refers to the capacity to identify others' emotions while the latter is the ability to share and match others' emotions (de Waal & Preston, 2017). Empathy for pain is a multifaceted social-psychological phenomenon, which aids individuals in establishing positive interpersonal relationships and encourages engagement in prosocial behavior (Decety, 2009; Jackson et al., 2006). However, some researchers believe that a reduction of empathy in healthcare professionals might enhance the precision of clinical tasks (Cheng et al., 2007; Decety et al., 2010). In specific medical situations, such as surgery, oncology, or psychological counseling, maintaining an emotional distance from patients is beneficial for preserving clinical objectivity (Düşünceli et al., 2021; Halpern, 2003; Levinson et al., 1997). Meanwhile, being empathic could potentially alleviate healthcare professionals' stress and "compassion fatigue" (Cavanagh et al., 2020).

Diaphragmatic breathing, also known as belly breathing or abdominal breathing, emphasizes the focus on the abdomen, using the diaphragm muscle to regulate the flow of air in and out of the lungs (Petri et al., 2020; Yamaguti et al., 2012). This type of breathing is often recommended as a regimen in emotional health for its benefits of decreasing anxiety (Chen et al., 2017) and alleviating depression. Not only that, but it is regarded as an effective complementary therapy for reducing pain in patients with low back pain or fibromyalgia (Carson et al., 2010; Gard et al., 2014; Mehling et al., 2005). Although few studies have addressed the effect of breathing practice on empathy for pain, a large body of research investigated the effect of breathing-related techniques, such as meditation, yoga, and relaxation techniques on decreasing pain intensity. For instance, a 15-minute meditation training significantly improved the participants' pain tolerance and reduced their distress in a cold-pressor test (Liu et al., 2013). Another intervention study with only three days of meditation training observed that the brief training for 20 min/day significantly reduced the ratings of pain intensity in an electrical stimulation test (Zeidan et al., 2010). In addition, some clinical studies have shown that breathing-based treatments were effective in reducing symptoms of chronic pain (Chiesa & Serretti, 2011; Harrison et al., 2017). Given these evidences, we assumed that diaphragmatic breathing might have a positive effect on empathy for pain.

Notably, one requirement of breathing-based training is to focus on inner sensations, with an emphasis on bodily perception and interoception induced by diaphragmatic breathing. Interoception is the ability to perceive internal bodily states (Cameron, 2001), which constitutes an essential component of cerebral processes for maintaining bodily homeostasis (Harrison et al., 2021). Interoceptive awareness could be measured by self-report instrument with multiple dimensions of interoception (Garfinkel et al., 2016). It is not only closely related to empathy (Bird et al., 2010), but also influences emotional contagion (Lischke et al., 2020). Several studies have shown that breathing-based training increased interoceptive awareness in healthy individuals (Chen, Dai, et al., 2021; D'Antoni et al., 2021), which greatly contributed to decreased anxiety and depression (Britton, 2019; Hölzel et al., 2011; Murphy et al., 2017). Therefore, it is hypothesized that interoceptive awareness might play a mediating role in empathy for pain induced by diaphragmatic breathing practice.

This study aimed to examine if diaphragmatic breathing could change empathy for pain via interoceptive awareness. The measurement of empathy for pain encompasses self-report questionnaires, behavioral tasks, and neuroimaging techniques (Giummarra et al., 2015; Lamm et al., 2011). In behavioral measures, empathy for pain is often assessed by rating the perceived intensity and unpleasantness when they witness somatic pain or observe images of body parts in painful conditions (Meng et al., 2012; Preis & Kroener-Herwig, 2012). Based on the good validity of the wearable real-time breathing feedback technique, a short-term diaphragmatic breathing practice was employed as an intervention in this study. Before and after the intervention, both a behavioral rating task of empathy for pain and interoceptive awareness were measured. We first hypothesize that empathy for pain could be modified following a 15-minute diaphragmatic breathing intervention. Secondly, interoceptive awareness was predicted to play a mediating role in the improvement of empathy for pain through diaphragmatic breathing.

2 | METHODS

2.1 | Participants

We conducted a power analysis using G*Power 3.1.9.7 (Faul et al., 2007) to determine the sample size in the means of two groups using a two-tailed t test with a level of significance of $\alpha = .05$, a medium effect size (Cohen's $d = 0.50$), and a power of 0.80, a total sample size of 66 participants (33 in each group) would be required. A total of 66 healthy college students (mean age = 19.61 ± 1.28) from local universities were recruited by posters. Exclusion criteria included pain-related diseases, neurological diseases, psychiatric disorders, physical health problems, and drug or alcohol abuse. These participants were told to go to bed early the night before the experiment and not to drink caffeinated beverages on the day of the experiment. We used semi-structured interviews to determine whether the participants met the criteria. In addition, participants were randomly assigned to the diaphragmatic breathing group ($n = 33$) or the control group ($n = 33$) based on computer-generated random numbers. The study procedure was fully explained to the participants, and all participants provided their written informed consent and received monetary compensation. No participants and data were excluded from the analysis. This experiment was approved by the Ethics Committee of the Chinese Academy of Sciences (Research Ethical Review Number: H20053) and was performed in line with the 2013 Declaration of Helsinki.

2.2 | Measurements

2.2.1 | Empathy for pain task

This study employed a behavioral research paradigm to assess empathy for pain (Lang, 2005; Meng et al., 2013; Ren et al., 2020). The pictures used in the task are sourced from the International Affective Picture System (IAPS), which depicts a model's hand, forearm, or foot in painful or non-painful situations in daily life (e.g., hand-cut by a knife or hand using a knife to sharpen a pencil). Each picture had dimensions of 9 × 6.76 cm (width × height) and 100 pixels per inch. Arousal level [negative: 4.725 ± 0.39, neutral: 4.726 ± 0.35, positive: 4.717 ± 0.36; $F(2, 57) = 0.004$, $p = .997$], luminance, contrast, and color were matched between painful and non-painful pictures (Meng et al., 2012), as illustrated in Figure 1. Stimuli were presented and responses were collected with E-prime Software 3.0. The task consisted of one practice block with two trials and three test blocks with 40 trials (20 pictures for painful and 20 pictures for non-painful conditions, respectively, randomly presented) with a 30-s interval of break. As shown in Figure 1, each trial began with a fixation cross presented for 500 ms. Next, there was a painful or non-painful picture presented for 3000 ms. Subsequently, participants were required to successively rate pain intensity (What level of pain intensity do you perceive if you were the person in the picture? from 1 = no pain to 9 = unbearable pain) and unpleasantness (What level of unpleasantness do you perceive if you were the person in the picture? from 1 = no unpleasantness to 9 = extremely unpleasantness). The scale remained on the screen until a response was completed or for a 4000 ms maximum. Afterward, a black screen was presented for 1000 ms.

2.2.2 | Interoceptive bodily awareness

The Multidimensional Assessment of Interoceptive Awareness (MAIA) was administered to evaluate interoceptive bodily awareness. The MAIA consists of 32 items. All participants were required to rate on a 6-point scale from Never to Always. The MAIA includes eight subdimensions of interoceptive body awareness: (1) awareness of body sensations (noticing); (2) the propensity to dismiss or divert oneself from pain or suffering (not-distracting); (3) emotional distress or worries with sensations of pain or suffering (not-worrying); (4) capacity to regulate attention (attention regulation); (5) awareness of the connection between body sensations and emotional states (emotional awareness); (6) ability to regulate psychological distress by attention to body sensations (self-regulation); (7) actively listens to the body for insight (body listening); and (8) experiences one's body as safe and trustworthy (body trusting). A higher total score represents a higher level of interoceptive body awareness. The Cronbach's alphas for the subscales ranged from 0.66 to 0.87 (Lin et al., 2017; Mehling et al., 2012).

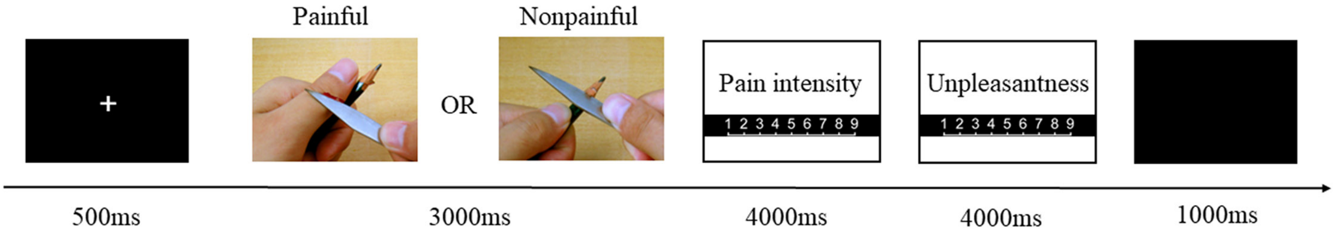

FIGURE 1 Empathy for pain task design.

2.2.3 | Breathing recording

To monitor the respiratory process, respiration frequency, phase, and respiratory volume were derived from a digital breathing APP. Breathing monitors (Dongtuo Science and Technology Ltd., Beijing, China) recorded synchronized breathing signals as well as participants' respiration parameters with high temporal resolution. An inductive sensor (JD/PW-5; Boda Electron Co., Beijing, China) was used to collect all data for the experiment, which was placed against the abdomen of participants during abdominal breathing or resting conditions. Data were transferred to the host App (Relax Master) via Bluetooth and expressed onscreen as a continuous visual waveform. Each crest represents a corresponding breath amplitude, while the wavelength indicates the duration (Ma et al., 2017).

2.3 | Procedure

Participants were randomly assigned by a computer program to an intervention group or a control group before the experiment (see Figure 2). All tasks and interventions were performed in a quiet laboratory. Before the intervention, a demographic questionnaire, and MAIA were administered to each participant. Then participants were seated in a comfortable chair in front of a computer at a viewing distance of 90 cm. E-Prime 2.0 program (Psychology Software Tools Inc., Sharpsburg, PA, USA) was used to display the stimuli on the 27-inch computer screen, with a visual horizontal angle of 4° and a vertical angle of 6°. They were instructed to respond as fast and accurately as possible to complete the empathy for pain task.

Two groups completed the pre- and post-measurements interleaved by 15-min intervention or 15-min rest. Participants in the intervention group wore the breathing sensor on their abdomen and were instructed to breathe deeply and slowly by contracting the diaphragm, a horizontal muscle between the chest and stomach cavities. They were instructed as follows: "First, inhale slowly, let air enter the lungs and expand the belly; then exhale slowly, allowing the air to drain all out of the lungs and shrink the abdomen. The target (the beginning point or the ending point) is your abdomen, but during the breathing you could focus on the part of your body related to breathing. It could be your nose, chest, or your stomach. Choose any part of your body and feel the change of this body part when you take the abdomen breathing. Try to observe your feelings when you are breathing." Once participants could perform the breathing correctly, they were further instructed to breathe abdominally by an audio instruction: an animated fish swimming in the water. When the fish inhales the abdomen will become larger, and the subject should follow along with the inhale abdomen expansion; when the fish exhales the abdomen will become smaller, and the subject should follow along with the exhale abdomen shrink. The animated fish completes a full breath in 12 s (Wei et al., 2016). The diaphragmatic breathing practice lasted for 15 min at a frequency of around 5 times per minute (IG = 5.06 ± 0.43). The sensor signals were recorded by an APP named Relax Master so that the experimenter could monitor the process of practice in real time to ensure that participants followed the video completely. The participants in the control group sat quietly to monitor their natural breathing for 15 min followed by wearing a breathing sensor. The instructions for the control group were to watch a black screen at rest during the experiment, and not engaged in any other activities, for a duration of 15 min. The breathing rate of the control group was 10–15 times per minute (CG = 13.72 ± 1.10). After 15-min rest, they were required to complete MAIA, and the empathy for pain task again.

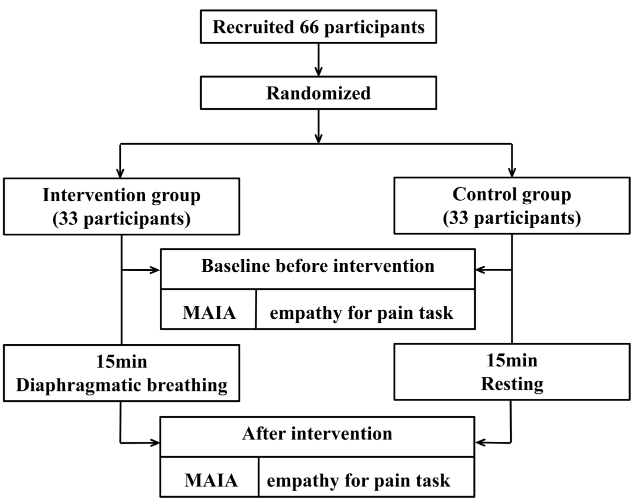

FIGURE 2 Experimental procedure of intervention.

2.4 | Statistical analysis

Statistical analyses used SPSS 23.0 (IBM Corp., Armonk, NY, USA). Independent sample t-tests (two-tailed) were conducted to compare group differences in age, MAIA, pain intensity, and unpleasantness scores. Group differences of gender were performed using the chi-square test. The effect of diaphragmatic breathing intervention on outcome measurements was analyzed using repeated measures analysis of variance (ANOVA), in which time (pre-intervention and post-intervention) was considered to be the within-subject factor, group (intervention and control groups) was the between-subject factor, and controlling for baseline levels. The Benjamini–Hochberg false discovery rate (FDR) adjustment was implemented to address the issue of multiple comparisons. Pearson correlation was performed to analyze the relationship among the intervention, empathy for pain, and interoceptive awareness. The significant level was set at .05.

We then used the PROCESS Macro (Model 4) in IBM SPSS to examine the mediating role of MAIA between diaphragmatic breathing intervention and empathy for pain (Hayes, 2012). In this model, the condition (1=intervention; 0=control) was the independent variable, the change of MAIA and subscales of MAIA were the mediators, and the change of unpleasantness of empathy for pain was the dependent variable. This method produces the 95% bias-corrected and accelerated confidence intervals (95% BCa CIs) for the indirect effects. Significance is indicated if the lower and upper CIs do not include zero.

3 | RESULTS

3.1 | Demographic characteristics

The demographic characteristics are depicted in Table 1. There were no significant baseline differences between the intervention group and the control group in demographic characteristics or study variables ($p > .05$).

3.2 | Intervention effect of Diaphragmatic breathing

As shown in Figure 3, we observed a marginally significant interaction effect in time * group in pain intensity of empathy for pain ($F_{(1,64)} = 3.99$, $p = .050$, $\eta_p^2 = .06$). The main effect of time analysis showed that the intervention group exhibited a significantly decreased score in pain intensity at T2 (after 15-min diaphragmatic breathing) compared to T1 (baseline before intervention) ($F = 15.92$, $p < .001$, $\eta_p^2 = .20$) while no significant change was detected between T1 and T2 in the control group ($F = 1.10$, $p = .30$, $\eta_p^2 = .02$). Regarding the affective response of empathy for pain, we also observed a significant interaction effect in time * group in unpleasantness level ($F_{(1,64)} = 11.05$, $p = .001$, $\eta_p^2 = .15$). The main effect of time analysis revealed that the intervention group exhibited significantly reduced unpleasantness at T2 compared to T1 ($F = 31.54$, $p < .001$, $\eta_p^2 = .33$) while the control group did not show any significant change at T2 compared to T1 ($F = .48$, $p = .49$, $\eta_p^2 = .01$).

There were also significant effects of time * group on MAIA scores ($F_{(1,64)} = 15.02$, $p < .001$, $\eta_p^2 = .19$) (see Figure 4). In the intervention group, MAIA scores were significantly higher at T2 compared to T1 ($F = 54.72$, $p < .001$, $\eta_p^2 = .47$) while no significant change was detected between T1 and T2 in the control group ($F = 2.48$, $p = .11$, $\eta_p^2 = .04$). The interaction of time * group was significant for four out of eight scales, including Noticing ($F_{(1,64)} = 4.58$, $p = .036$, $\eta_p^2 = .07$), Attention regulation ($F_{(1,64)} = 11.76$, $p = .001$, $\eta_p^2 = .16$), Emotional awareness ($F_{(1,64)} = 8.86$, $p = .004$, $\eta_p^2 = .12$), Self-regulation ($F_{(1,64)} = 13.44$, $p < .001$, $\eta_p^2 = .18$), Body listening ($F_{(1,64)} = 4.50$, $p = .038$, $\eta_p^2 = .07$), and Body trusting ($F_{(1,64)} = 4.48$, $p = .038$, $\eta_p^2 = .07$). It was not significant for Not-Worrying, Not-Distracting (Supplementary Table S1).

TABLE 1 Demographic characteristics and baseline measurements.

	IG ($n = 33$)	CG ($n = 33$)		
	M (*SD*)	*M* (*SD*)	t/χ^2	*p*
Gender (M/F)[a]	6/27	6/27	<0.001	1.000
Age	19.33 (1.36)	19.88 (1.14)	−1.78	.082
MAIA	18.97 (4.62)	19.89 (4.91)	−0.78	.437
Noticing	2.39 (1.02)	2.70 (0.92)	−1.30	.198
Not-distracting	2.28 (0.82)	2.21 (0.79)	0.36	.721
Not-worrying	2.13 (1.05)	2.11 (0.93)	0.08	.934
Attention regulation	2.23 (0.88)	2.21 (0.97)	0.10	.925
Emotional awareness	2.61 (0.88)	2.99 (0.96)	−1.68	.097
Self-regulation	2.05 (0.97)	2.45 (1.10)	−1.61	.113
Body listening	2.23 (1.25)	2.25 (1.24)	−0.07	.948
Body trusting	3.05 (1.29)	2.96 (1.09)	0.31	.758
Empathy for pain				
Pain intensity ratings	4.96 (1.30)	4.76 (1.75)	0.53	.600
Unpleasantness ratings	5.61 (1.36)	5.23 (1.74)	0.99	.325

Abbreviations: CG, control group; IG, intervention group.

[a]Group differences in gender were performed using the chi-square test.

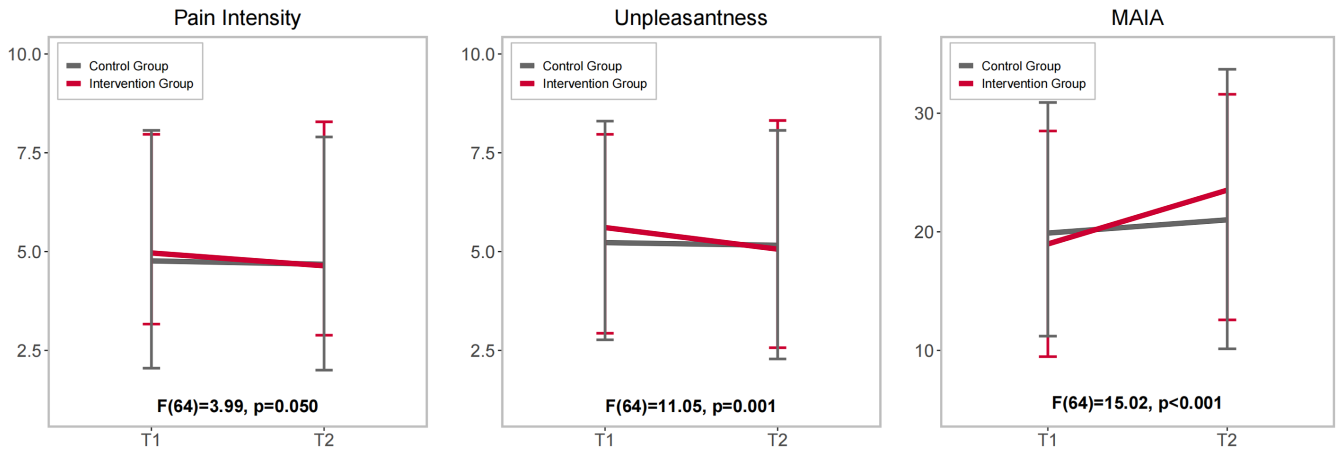

FIGURE 3 Effect of DB on pain intensity, unpleasantness, and MAIA. T1 = Baseline before intervention; T2 = After 15-min diaphragmatic breathing.

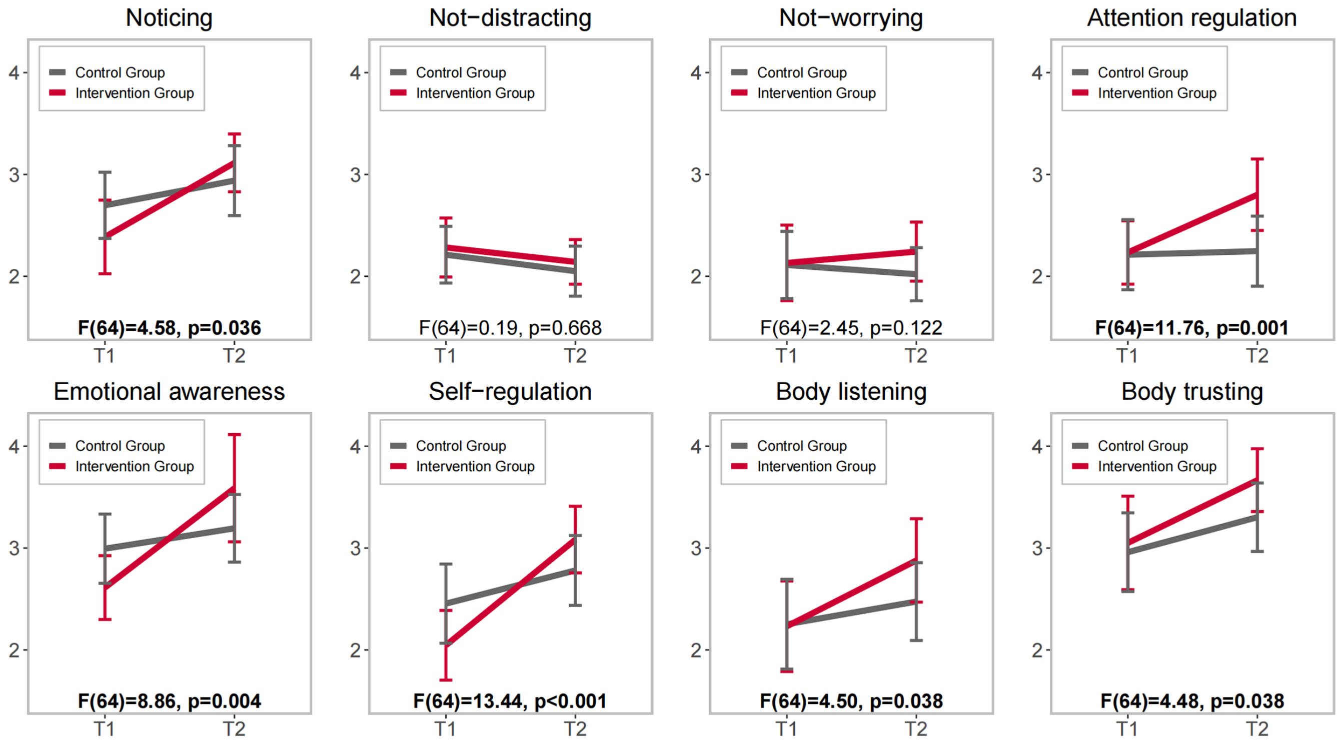

FIGURE 4 Changes through intervention on the eight MAIA scales. T1 = Baseline before intervention; T2 = After 15-min diaphragmatic breathing.

3.3 | Correlation analysis

To examine the relationship among condition, empathy for pain, and interoception, a correlation analysis was conducted (Table 2). There were significant negative correlations between the condition and the changed pain intensity ($r_{66} = -0.25$, $p = .04$) and unpleasantness ($r_{66} = -0.40$, $p = .001$), and significant positive correlations between the condition and the changed total score of MAIA ($r_{66} = .44$, $p < .001$). Regarding the scores of MAIA subscales, significant positive correlations were observed between the condition and the changed scores of noticing ($r_{66} = .30$, $p = .013$), attention regulation ($r_{66} = .38$, $p = .002$), emotional awareness ($r_{66} = .38$, $p = .002$), self-regulation ($r_{66} = .46$, $p < .001$), respectively. As Table 2 shows there was no correlation between the changed total score of MAIA and the changed empathy for pain (pain intensity and unpleasantness). However, we observed that the changed score of unpleasantness in empathy for pain task was negatively correlated with the changed score of attention regulation ($r_{66} = -0.38$, $p = .002$).

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3.4 | Mediation analysis

To further investigate the role of interoceptive awareness in a breathing-induced change of empathy for pain, we conducted a mediation analysis based on the significant correlation between attention regulation and unpleasantness. As Figure 5 shows the total and direct effects of the intervention on unpleasantness were significant (total effect: $B=-0.48$, $SE=0.14$, 95%CI = [−0.75, −0.20]; direct effect: $B=-0.36$, $SE=0.14$, 95%CI = [−0.65, −0.07]). Diaphragmatic breathing intervention was found to have an indirect effect on the unpleasantness through attention regulation (indirect effect: $B=-0.23$, $SE=0.10$, 95%CI = [−0.44, −0.02]).

4 | DISCUSSION

To our knowledge, this is the first study to explore the strategy to alter empathy for pain from the approach of behavioral intervention. The results indicated that a 15-minute intervention of diaphragmatic breathing reduced both the intensity and unpleasantness of empathy for pain tasks. The findings of this study supported the hypothesis that empathy for pain could be modified by a 15-minute diaphragmatic breathing training, highlighting its practical implications for individual practice and group training as a simple and feasible intervention. Moreover, this acute breathing exercise also enhanced interoceptive awareness. Intriguingly, attention regulation, a subscale of interoceptive awareness mediated the effect of diaphragmatic breathing on the unpleasantness of empathy for pain.

The most important finding is that diaphragmatic breathing is effective in decreasing pain intensity and unpleasantness of empathy for pain. Currently, there has been only one intervention study investigating the influence of integrating mindfulness and breathing practice on empathy for pain, which utilized social pain pictures to induce empathy for pain (Laneri et al., 2017). In neuroscience, numerous brain imaging studies have shown that the brain regions involved in first-hand pain are also active in response to others' pain, indicating a significant overlap in neural correlates between pain and empathy for pain (Singer et al., 2004), and pain-alleviating treatments could potentially be effective in reducing empathy for pain (Cankaya et al., 2020). Although there was few direct evidence to demonstrate the effect of similar breathing interventions on empathy for pain, many studies have supported the effectiveness of breathing practice to relieve somatic pain. For instance, a study based on heat-pain stimulation found that slow and deep breathing reduced ratings of

TABLE 2 Means, standard deviations, and bivariate correlations of the study variables.

	M (SD)	1	2	3	4	5	6	7	8	9	10	11	12
1.Condition	0.5 (0.50)	1											
2.ΔPain intensity	−0.21 (0.48)	−.25*	1										
3.ΔUnpleasantness	−0.31 (0.60)	−.40**	.80**	1									
4.ΔMAIA	2.83 (3.90)	.44**	−.06	−.23	1								
5.ΔNoticing	0.48 (0.81)	.30*	.00	−0.24	0.72**	1							
6.ΔNot-distracting	−0.15 (0.60)	.02	−.03	.12	.17	−.02	1						
7.ΔNot-worrying	0.01 (0.70)	.15	−.15	−.16	.49**	.30*	.35**	1					
8.ΔAttention regulation	0.30 (0.70)	.38**	−.23	−.38**	.78**	.53**	.05	.38**	1				
9.ΔEmotional awareness	0.59 (1.03)	.38**	−.10	−.16	.70**	.40**	.02	.25*	.54**	1			
10.ΔSelf-regulation	0.68 (0.79)	.46**	.01	−.22	.79**	.47**	−.04	.19	.60**	.47**	1		
11.ΔBody listening	0.43 (0.93)	.23	−.18	−.15	.69**	.48**	−.13	.19	.47**	.29*	.56**	1	
12.ΔBody trusting	0.48 (0.78)	.17	.19	.11	.45**	.16	−.09	−.12	.20	.22	.44**	.27*	1

Note: $N=66$. Condition coded as 0 = control group; 1 = intervention group. Δ = T2–T1.

$^{*}p<.05$; $^{**}p<.01$.

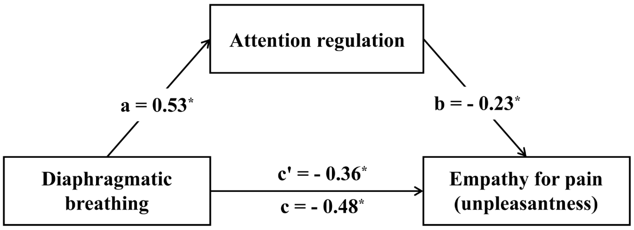

FIGURE 5 Mediation model testing indirect effects leading from diaphragmatic breathing intervention to unpleasantness via attention regulation. *$p < .05$.

pain intensity and unpleasantness compared to normal breathing (Zautra et al., 2010). Another study has also shown that slow deep breathing at a 50% normal rate reduced the pain intensity induced by electrical stimulation relative to normal breathing (Martin et al., 2012). Pain and empathy for pain are closely related since the activation of the mirror neuron system during empathy for pain amplifies one's pain perception and duration. A typical example is that analgesics could not only relieve pain but also significantly reduce the level of empathy for pain (Mischkowski et al., 2016). Some cross-sectional studies have shown that individuals who experience chronic pain may have altered empathy for pain responses (Lamm et al., 2011). Notably, accumulative evidence demonstrated that there are overlapped neural correlates between empathy for pain and somatic pain (Gu et al., 2010; Osborn & Derbyshire, 2010; Valentini, 2010; Zhao et al., 2020). Therefore, diaphragmatic breathing might potentially regulate affective response and decrease pain intensity partly via neural circuits related to pain.

Some relaxation training similar to diaphragmatic breathing has been widely used in the field of alleviating unpleasant emotions. Previous studies have demonstrated that relaxation training could help the individual to better cope with the negative emotional experience (Ooi et al., 2017; Zaccaro et al., 2018). Brain imaging studies suggest that engaging in mindful breathing could promote the changes in the corticolimbic circuits that are responsible for regulating emotions (Way et al., 2010). In addition, several studies with longitudinal design suggested that mindful breathing practice could enhance the function of brain regions related to emotion regulation. For instance, an 8-week breathing-based course increased functional connectivity between the amygdala and the ventromedial prefrontal cortex (VMPFC), which was associated with enhanced emotion regulation (Kral et al., 2018). Another intervention study found that only 2-week of training integrating mindfulness and breathing practice was effective in regulating aversive emotions via increasing amygdala–prefrontal integration (Doll et al., 2016). It is suggested that amygdala–dorsal prefrontal cortex integration is a crucial neural pathway of emotion regulation induced by mindful breathing practice (Doll et al., 2016). Therefore, the diaphragmatic breathing practice might exert its influence on the affective response via altering neural circuits related to negative affect and further contribute to the decreased unpleasant experience while observing painful conditions.

We also observed that interoceptive awareness was increased after a 15-minute breathing training. As mentioned above, interoception is the sense of the internal functioning of the body (Murphy et al., 2017). It encompasses the brain's process of integrating signals relayed from the body into specific subregions. This is of great significance for maintaining homeostatic conditions in the body (Khalsa et al., 2018). Previous studies have shown that slow breathing is a practical way to improve interoception (Paulus, 2013). In this study, we also found that attention regulation mediated the effect of diaphragmatic breathing on the unpleasantness of empathy for pain. Attention regulation is the ability to maintain one's focus on internal sensory stimuli (Chen, Liu, et al., 2021). Bowling and colleagues found that directing one's attention to internal physiological changes could consciously replace the pain sensation (Bowling et al., 2019). A recent study further observed that manipulating interoceptive attention reduced the corresponding brain activation elicited by witnessing another's pain, leading to alleviated negative emotional experiences (Balconi & Angioletti, 2022). Thus, it is plausible that diaphragmatic breathing might alter the individuals' emotional responses to the pain of others by regulating their attention to their own inner body. The finding might be of implication for altering excessive empathy for pain in healthcare workers. A recent review study has demonstrated that breathing and mindfulness training reduced negative effects associated with empathy for pain, thereby reducing the risk of psychotherapists' burnout and enhancing their ability to care for themselves (Bibeau et al., 2016). Our study confirmed that 15-minute diaphragmatic breathing significantly reduced the negative effects of empathy for pain. This finding might provide an alternative strategy to promote mental health for medical workers (Boellinghaus et al., 2013), which warranted a further investigation.

Although this study has potential implications, its main limitations should be acknowledged. Firstly, the sample size is relatively small. Thus, caution should be taken when drawing any conclusions about the mediating role of interoceptive awareness. Especially, only healthy adults aged 18–21 were recruited, which might limit the generalizability of the results. It is still unknown whether acute diaphragmatic breathing is effective for patients or health care workers with impaired empathy for pain. Further studies should expand to more heterogeneous populations. Secondly, we need to add more physiological indicators (including respiration volume) to evaluate the manipulation of diaphragmatic breathing to assess differences in respiration parameters between groups. It would be helpful to have these markers as well to test to confirm the experimental manipulation and to test as mediators in mediation models. Thirdly, our intervention might consist of diaphragmatic breathing and interoceptive awareness. In future studies, researchers could utilize more elaborate experimental designs to disassociate these components in order to explore the effect of a solo breathing technique on our mind. Lastly, improved instruments for measuring empathy for pain and internal feelings should also be considered. The use of images with social context (e.g., social exclusion and social embarrassment) or specific emotions (e.g., fear, sadness, anger, and happiness) to examine more nuances of empathy for pain. Interoceptive awareness also needs to be measured in ways other than self-reporting (Garfinkel et al., 2016).

To summarize, our study is the first randomized controlled trial to examine the effect of diaphragmatic breathing on empathy for pain by using a 15-minute intervention. The most intriguing finding was that diaphragmatic breathing significantly enhanced the response to empathy for pain, indicating that empathy for pain exhibits behavioral plasticity. Moreover, the whole intervention process was based on real-time biofeedback of breathing parameters, which validated the effect of diaphragmatic breathing on the outcomes.

AUTHOR CONTRIBUTIONS

YaPing He: Conceptualization; data curation; formal analysis; investigation; methodology; writing – original draft. **LiKun Ge:** Formal analysis; writing – review and editing. **Jiajin Yuan:** Conceptualization; writing – review and editing. **Yingying Wang:** Methodology. **Danni Zheng:** Methodology. **An Rui:** Methodology. **Jun Song:** Writing – review and editing. **Li Hu:** Writing – review and editing. **Gao-Xia Wei:** Conceptualization; funding acquisition; supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

All authors declared no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available. If you have any specific requests or need further information, please feel free to contact the corresponding author.

ETHICS STATEMENT

This study was approved by the Ethics Committee of the Chinese Academy of Sciences (Research Ethical Review Number: H20053) and was performed in line with the 2013 Declaration of Helsinki.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

TABLE S1. Dependent variable comparison: pre versus post in IG and CG.

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