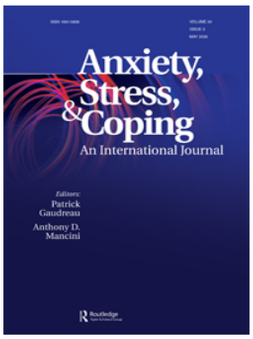

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Simply breathing anxiety away? A pilot, just-in-time ecological momentary intervention study of one-minute cyclic sighing versus box breathing as tools for acute anxiety reduction and attention promotion in real life

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ABSTRACT

Background and objectives: In this preregistered pilot study, we conducted a just-in-time ecological momentary intervention to examine the real-life effects of two different one-minute breathing exercises on state anxiety and attention in acute threat situations among university students, with trait anxiety serving as a moderator.

Methods: During acute threat situations, 47 participants completed a short questionnaire assessing state anxiety. They were subsequently assigned to one of three conditions: box breathing, cyclic sighing or a passive control condition. Five minutes later, state anxiety and attention were measured.

Results: Compared with the control condition, both box breathing and cyclic sighing were associated with greater reductions in state anxiety. Interestingly, the students made fewer inhibition errors in the attention test after the box breathing condition. This effect was more pronounced for individuals with high levels of trait anxiety. Unexpectedly, box breathing and cyclic sighing were negatively related to attention efficiency: there were longer reaction times after the breathing exercises than after the control condition.

Conclusions: This study suggests that box breathing and cyclic sighing may be effective methods for reducing anxiety in everyday life.

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Breathing exercises; state anxiety; trait anxiety; cognitive performance; just-in-time ecological momentary intervention

Stress and anxiety

Many people suffer from anxiety. In a recent study conducted in the general U.S. adult population, more than 80% of respondents reported symptoms of anxiety in the past two weeks (Momin et al., 2023). State anxiety can be defined as a transitory emotional state consisting of feelings of apprehension, nervousness, and physiological sequelae such as an increased heart rate or respiration (Spielberger, 1979). State anxiety is differentiated from trait anxiety, which refers to an individual's predisposition to experience anxious states (Laux et al., 1981). According to the multidimensional

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interaction model of stress, anxiety and coping (Endler, 1997), state anxiety results from an interaction of situational stressors and individual characteristics such as trait anxiety that induces a perception of threat. Because anxious states are unpleasant, people react to increases in state anxiety through various types of coping, which differ in their effectiveness (Endler, 1997). Real-world threat situations are highly diverse; thus, having a flexible coping method depending on the type of situation is crucial (Leslie-Miller et al., 2025). In the coping circumplex model, emotion regulation constitutes one of the two core dimensions of coping; therefore, it is essential across different coping responses (Stanisławski, 2019). Deficits in emotion regulation skills may be related to the development of various mental disorders; therefore, in recent years, there has been an increasing research focus on teaching emotion regulation strategies (Castilla et al., 2022).

Ecological momentary interventions

As a result of technological advances, ecological momentary interventions, which refer to "treatments delivered to people during their everyday lives (i.e., in real time) and in natural environments (i.e., the real world) (via a mobile, electronic device)" (Heron & Smyth, 2010, p. 1), are becoming increasingly common (Balaskas et al., 2021). In the context of emotion regulation, ecological momentary interventions offer important advantages because they teach skills in "real time" and in the "real world." Whereas programs delivered outside everyday life – such as mindfulness-based stress management training – require individuals to transfer the learned techniques to daily situations, ecological momentary interventions develop these skills directly within real-life contexts, eliminating the need for later transfer. Initial ecological momentary interventions conducted among mostly clinical samples have investigated different intervention techniques, such as cognitive behavioral therapy, reappraisal, acceptance and commitment therapy, and mindfulness (see Balaskas et al., 2021, for a review). An earlier meta-analysis reported a pre–post effect size of $g = .47$ for ecological momentary interventions in reducing anxiety (Versluis et al., 2016). However, particularly with respect to emotion regulation, a new class of ecological momentary interventions called just-in-time interventions, which aim to provide support "at the right time," appears to be particularly promising (Balaskas et al., 2021). Regarding anxiety states, just-in-time interventions address the management of acute increases in state anxiety. By applying a pre–post design, Pham et al. (2016) investigated the feasibility and efficacy of the "Flowy" breathing app for acute anxiety reduction.

Breathing exercises and their psychological and physiological effects

Breathing exercises "involve voluntarily changing the rate, pattern, and depth of respiration, affecting both cardiac and cortical activity" (Banushi et al., 2023, p. 2). Several recent reviews have supported the beneficial effects of breathing exercises on subjective and physiological parameters (Banushi et al., 2023; Bentley et al., 2023; Zaccaro et al., 2018). In their meta-analysis, Fincham et al. (2023) reported small to moderate effects of breathing exercises on stress, anxiety, and depression.

A large variety of breathing exercises exist. Physiologically, anxiety is associated with increased heart rate (Noteboom et al., 2001) and increased respiratory rate (Homma & Masaoka, 2008). Thus, slow breathing exercises, which reduce the average adult breathing rate from 12 to 20 breaths per minute (Chourpiliadis & Bhardwaj, 2022) to less than 10 breaths per minute (Zaccaro et al., 2018), may be particularly beneficial in reducing anxiety through the activation of the relaxation response. Zaccaro et al. (2018) concluded from their systematic review that slow breathing is associated with changes in parasympathetic activity (reflected by higher HRV) and central nervous system activity (increased EEG alpha power and decreased EEG theta power). Given that slow breathing effectively regulates internal bodily states and that nasal mechanoreceptors modulate olfactory bulb activity, which in turn modulates cortical activity, both mechanisms may contribute to emotion regulation (Zaccaro et al., 2018). In addition to physiological mechanisms, psychological aspects may be important for the effectiveness of breathing exercises. Anxiety is often associated with a sense of loss of control (Brown et al., 2004), and successful breath control may counteract

this feeling (Balban et al., 2023). Another psychological mechanism is the ability for breathing exercises to distract from negative thoughts by focusing on the breath (Röttger et al., 2021).

Cyclic sighing and box breathing

Two slow breathing techniques whose mechanisms have been investigated to reduce anxiety are cyclic sighing and box breathing. Balban et al. (2023) recently examined the effects of five minutes of daily breathing exercises in the field, including these two exercises. Cyclic sighing is a breathing technique in which a deep inhalation phase (e.g., three seconds) is followed by a second short inhalation phase (e.g., one second) before the exhalation phase lasts twice as long (e.g., eight seconds). In box breathing, which has long been used in a military context during threat situations (Grossman & Christensen, 2008), breathing occurs in four equal parts: inhale deeply into the abdomen for four seconds, hold breath for four seconds, exhale for four seconds, and keep the lungs empty for four seconds. When participants performed these breathing exercises daily at a self-selected time, both techniques were associated with a reduction in state anxiety, decreased negative affectivity, and increased positive affectivity from before to after the breathing exercises (Balban et al., 2023).

Anxiety, breathing, and performance

State anxiety can be cognitively costly because task-related processes are disrupted by anxiety-related processes, such as task-irrelevant worried thoughts or high arousal (Moran, 2016). According to attentional control theory, anxiety impairs central executive functioning (Eysenck et al., 2007), with inhibition and shifting being particularly negatively affected (Eysenck & Derakshan, 2011). Inhibition encompasses two aspects: dominant response inhibition and resistance to distraction (Friedman & Miyake, 2004). Attentional control theory distinguishes two aspects of performance (Eysenck et al., 2007): *effectiveness*, which refers to the quality of performance, and *efficiency*, which additionally considers the resources used to accomplish the task. Because of compensatory effort, which is generally measured as time invested, anxiety may not affect response accuracy (effectiveness); however, differences may appear when reaction times are considered (Eysenck et al., 2007). Consistent with attentional control theory, a meta-analysis revealed that state and trait anxiety were negatively associated with performance on a variety of tasks (Moran, 2016).

Breathing exercises are thought to improve attention in the face of threats (Grossman & Christensen, 2008). Röttger et al. (2021) compared box breathing with prolonged exhalation during a Stroop task under time pressure and noise distraction in the laboratory. While prolonged exhalation was superior to box breathing in terms of performance, physiological arousal was lower in the box breathing condition. The authors concluded that box breathing may be too cognitively demanding during task performance because of the need to monitor the four phases of breathing. Therefore, it is important to distinguish whether the breathing exercise is performed during task performance or shortly before. De Couck et al. (2019) reported that participants who performed a two-minute prolonged exhalation breathing exercise performed better on a subsequent challenging decision task than did individuals in the waiting condition. Furthermore, studies on test anxiety have shown that breathing exercises can improve test performance. In a pre-test/post-test intervention study, Khng (2017) found that primary school children who practiced deep breathing before a timed mathematics test reported lower state anxiety and achieved higher test scores than their peers in the control group.

Trait anxiety as a moderator of the benefits of breathing exercises

According to attentional control theory (Eysenck et al., 2007) both state and trait anxiety impair performance. Trait anxiety is positively associated with maladaptive coping strategies such as escape, self-blame, and resignation and negatively associated with adaptive strategies such as positive

self-instruction and situation and response control (Englert et al., 2011). Since individuals with trait anxiety exhibit an unfavorable coping pattern in stressful situations, they may benefit more from coping interventions than would less anxious individuals who naturally cope in more positive ways. Matko et al. (2022) recently examined those who benefited most from four different mind–body medicine treatments (mantra meditation alone, meditation plus physical yoga, meditation plus ethical education and meditation plus yoga and ethical education) and reported that those who were more vulnerable improved their emotional regulation skills more than those with a more adaptive personality structure did. Clinton and Meester (2019) reported that a breathing exercise or expressive writing before an exam was associated with lower anxiety states and improved performance among students with high levels of test anxiety, whereas students with low anxiety did not benefit from the exercises.

The aim and hypotheses of the present study

By applying a just-in-time ecological momentary intervention design, this study aims to investigate whether two different one-minute breathing exercises in real threatening situations in the field are associated with a greater reduction in state anxiety five minutes later compared with a passive control condition in the same individuals. In most previous studies (see, for example, Clinton & Meester, 2019, for an exception) that have examined the effects of breathing exercises in actual stressful situations, the stressful situation was either experimentally created (e.g., Khng, 2017; Röttger et al., 2021) or represented a specific stressful situation far outside the person's normal life circumstances (e.g., breathing exercises before surgery; Bidgoli et al., 2016). Thus, the present study contributes to research by focusing on real-world threat situations and natural increases in state anxiety in the normal lives of students.

In police and military contexts, breathing exercises are used to maintain performance in high-stress situations (Grossman & Christensen, 2008). However, the question of whether breathing exercises can improve performance has been investigated mainly in laboratory studies. Using the innovative method of ambulatory attention measurements (Perzl et al., 2024), this pilot study contributes to current knowledge by investigating this relationship in real-life, field settings. As a further contribution to the literature, we consider trait anxiety as a potential moderator of the effectiveness of breathing exercises in threatening situations, as learning how to reduce state anxiety should be particularly important for those who frequently experience state anxiety and who habitually have less effective coping skills (Englert et al., 2011). On the basis of the theoretical arguments presented above, we propose the following hypotheses:

H1: Compared with the control condition, cyclic sighing (H1a) / box breathing (H1b) is associated with a greater reduction in state anxiety.

H2: Compared with the control condition, cyclic sighing (H2a) / box breathing (H2b) is associated with increased performance effectiveness.

H3: Compared with the control condition, cyclic sighing (H3a) / box breathing (H3b) is associated with increased performance efficiency.

H4: Compared with the control condition, individuals with greater trait anxiety show a greater reduction in state anxiety after cyclic sighing (H4a) / box breathing (H4b) than do less anxious individuals.

H5: Compared with the control condition, cyclic sighing (H5a) / box breathing (H5b) has a stronger positive effect on performance effectiveness among individuals with greater trait anxiety than among less anxious individuals.

H6: Compared with the control condition, cyclic sighing (H6a) / box breathing (H6b) has a stronger positive effect on performance efficiency among individuals with greater trait anxiety than among less anxious individuals.

Methods

Procedure

This preregistered study (https://osf.io/64u9x/overview) combined a just-in-time ecological momentary intervention with an event-contingent ecological momentary assessment. Our within-person field experiment included a within-subject experimental condition (cyclic sighing, box breathing, and control condition) and a between-subject moderator (trait anxiety). Ethical approval for the study was granted by the researcher's university ethics committee (no. 168–2023). Recruitment took place through advertisements in campus newsletters, short presentations at the beginning or end of courses, and a university-internal online registration tool for psychological experiments. Interested students registered by email. Afterward, they received an email with information about participation and a consent form. If they wished to participate, the students returned the signed consent form and scheduled an initial appointment in groups via Zoom. The initial appointments were conducted by a master's-level psychology student who had been personally trained by a yoga instructor to lead the breathing exercises. During the initial appointment, the participants were informed about the structure, organization, and technology of the study and were instructed on how to perform the breathing exercises. Additionally, the initial questionnaire was completed.

This study was conducted throughout the students' normal daily routine using the smartphone app movisensXS, which is a technical tool for the implementation of experience or event sampling studies (movisens GmbH, Karlsruhe, Germany). The study procedure is illustrated in Figure 1. After a practice phase in which the students tried the breathing exercises six times at self-selected times in their daily routine, the actual data collection phase began. The participants were instructed to access the movisensXS app whenever they felt tense, nervous, anxious, worried, or distressed. The questionnaire was blocked for two hours after the participant reported an anxiety state. State anxiety (T0) was assessed using the five items of the STAI-SKD (Englert et al., 2011). The students subsequently performed a one-minute cyclic sighing (70 s) or box breathing (69 s) exercise or continued as usual (control condition; in this condition, the app simply displayed the message "There is nothing for you to do here at the moment"). The three conditions, cyclic sighing, box breathing, and control condition, were presented in two blocks, each consisting of nine randomly ordered, stratified trials. Each block contained three trials of cyclic sighing, box breathing, and control condition. Within each

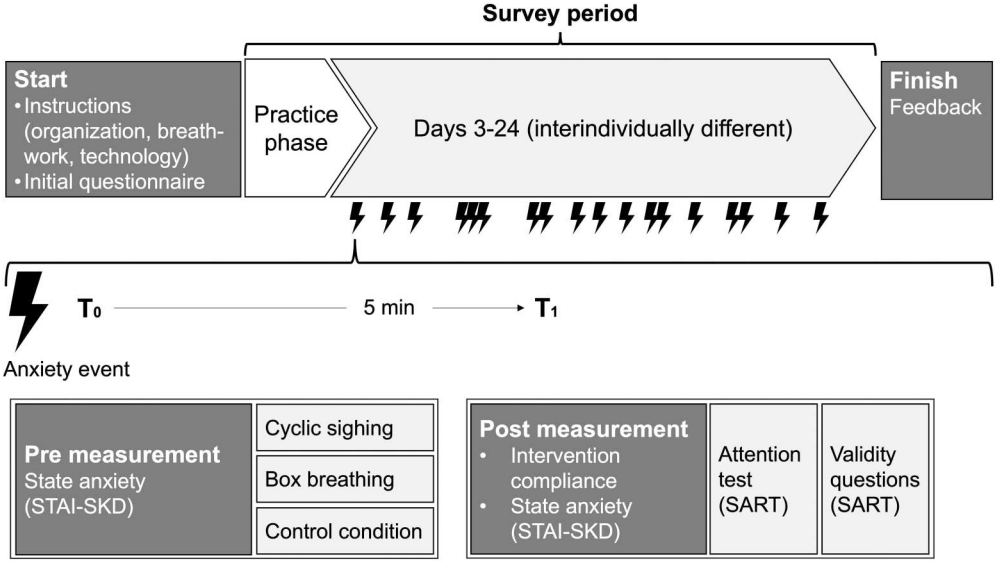

Figure 1. Study procedure.

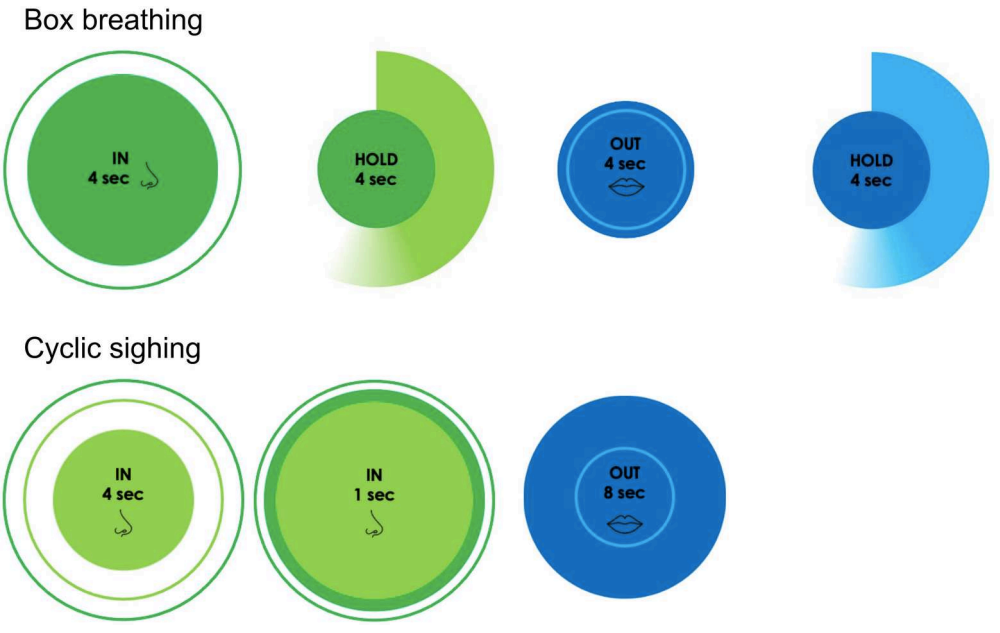

Figure 2. Illustration of the breathing exercises.

block, the order of the three conditions was randomly assigned for each participant. Thus, each person experienced each condition six times (three times per block).

The breathing exercises were supported by video instructions (see Figure 2 and the Supplementary Material for the video files in English), which were developed in collaboration with a yoga teacher on the basis of the descriptions of Grossman and Christensen (2008), Balban et al. (2023), and Röttger et al. (2021). In the initial appointment, the participants were informed how to perform the breathing exercises (breathing deeply into the belly through the nose as if smelling a flower, breathing out evenly through the mouth as if blowing out candles; see Obradović et al., 2021). In the videos, cyclic sighing and box breathing were both represented by circles. Inhalation was represented by an ascending circle in green, and exhalation was represented by a descending circle in blue. Breath holding was represented by a clockwise filling wheel. Nasal and oral breathing were represented symbolically and verbally. Circular lines were used to facilitate estimation of the phase length. The end of the breathing exercises was indicated acoustically by a gong and visually by a smiley face.

Five minutes after the start of the state anxiety questionnaire, a postmeasure of state anxiety and an attention test were triggered by an alarm. After the smartphone alarm, the T1 questionnaire was accessible for five minutes. The participants received a smartphone alarm as a study reminder at two random times each day between 9 am and 7 pm. After 18 T0 and T1 measurements were collected (missing T1 measurements were made by collecting data from another state anxiety event), the study ended with a feedback survey.

Sample and data cleaning

The study ran from 12 April 2024 to 31 July 2024. Given that the main focus of the study was within-subject associations, we aimed for a minimum sample size of 40 people, which should be sufficient to show medium–strong level 1 effects with high probability (Arend & Schäfer, 2019). The participants in the study were undergraduate students 18 years of age or older. Given the hypothesized physiological mechanisms, only students up to 30 years of age without cardiovascular/neurological/

endocrinological or respiratory diseases and who were not pregnant were included in the study. The students received course credits or compensation of up to 50 euros for their participation in the study.

Fifty students began the study by participating in the first session. However, three participants dropped out directly after the first session; for these individuals, no data was available. Three other individuals dropped out later during the study, but they had already provided data that were included in the analyses. Thus, data from 47 participants were available for the anxiety analyses. These 47 participants provided 960 measurements for T0 and 808 measurements for T1 (T1 compliance = 84%). T0 anxiety was not significantly associated with T1 compliance ($r = 0.01$, $p = .77$). Four T1 measurements were excluded because of noncompliance with the breathing exercises, 13 because the T1–T0 interval exceeded 15 min (technical errors), and nine because the T0 questionnaire and video were completed within one minute, suggesting skipped exercise time. These cleaning steps were preregistered. Thus, 782 pre–post measurements for assessing anxiety reduction remained (cluster sizes: 4–20; two subjects had > 18 measurements due to technical problems).

Regarding the dependent variable attention, two of the 47 participants were excluded entirely because of general technical problems with the attention test. For one additional participant, no valid attention data remained after data cleaning. In 18 cases, the participants stopped taking the test. After the attention test, the participants were asked three yes or no questions: "When working on the task, I made an effort/I was disturbed/there were technical problems." Invalid measures were excluded (low effort: $N = 8$; distraction: $N = 85$; technical problems: $N = 2$). The preregistered criterion of excluding cases with omission errors > 1.5*interquartile range was reconsidered. Given that such cases (10.9%) showed higher commission errors than the other cases did ($b = 5.18$ vs. 3.80), indicating inattention rather than low effort, we retained these cases to avoid bias. A total of 633 attention measures from 44 participants were analyzed (cluster sizes: 3–18).

Measures

State anxiety. At T0 and T1, state anxiety was measured using the five items of the STAI-SKD (Englert et al., 2011). To capture even small changes in state anxiety within the short time frame, all five items were scored on a 10-point scale with anchors ranging from "not at all" to "very" instead of the original four-point scale. High values represent high levels of state anxiety.

Attention. At T1, momentary attention performance was measured using the 90-second ambulatory SART (Perzl et al., 2024). In this attention test, which has been validated for repeated measures in the field (Perzl et al., 2024), the participants are instructed to respond to each number from one to nine, except for the number three, as quickly as possible, by touching the smartphone screen. Two outcome measures were considered: (1) The number of commission errors (touching number three on the screen), with a high number of commission errors indicating low effectiveness, and (2) performance efficiency, which is the number of hits (total go-trials minus omission errors, in which omission errors are nonreactions to all the digits except three) divided by the average reaction time on correct responses (Chan et al., 2009). Thus, performance efficiency suffers from high omission errors and/or high reaction times. There is empirical evidence that the SART is suitable as an anxiety-sensitive objective performance measure, as, in field studies, SART performance is positively correlated with calmness (Perzl et al., 2024).

Trait anxiety. Trait anxiety was measured using the German version of the State-Trait Anxiety Inventory, which consists of 20 items answered on a four-point Likert scale (Laux et al., 1981).

Data analysis

Analyses were conducted using Mplus version 8.1.6. For each dependent variable, multilevel models were built stepwise, starting with null models. In the next step, the two predictor variables, cyclic sighing and box breathing, were added. The random effect variances for cyclic sighing and box

breathing were successively removed if $p > .10$. By setting model constraints, we investigated whether one breathing technique was superior to the other. In the third step, the grand-mean centered between-level moderator trait anxiety was added. The difference in state anxiety (T0/T1) was modeled as the difference between T1 and T0, which was based on models 12 and 13 of Lischetzke et al. (2015). Please see the preregistration for the model equations.

The performance data (omission errors and performance efficiency) were analyzed using models 6 and 7 described by Lischetzke et al. (2015). For both dependent performance variables, possible practice effects were controlled by adding the number of measurements as a predictor variable. All preregistered hypotheses were tested with a significance level of $p < .05$ (one-tailed).

Results

Descriptive information

Among the 47 participants, 43 were female, two were male, and two were of non-binary sex. The mean age was 21.09 years ($SD = 2.70$, range = 18–30). Trait anxiety ranged from 34 to 68, with a mean of $M = 47.4$ ($SD = 9.00$). Using a cutoff score of 44 or higher (Ercan et al., 2015), approximately 60% of the sample was classified as highly anxious. The null model for the dependent variable difference in state anxiety showed an intercept of 5.80, which indicates state anxiety at T0 (see Table 1). At T1, state anxiety was reduced by $b = -0.80$ ($SE = 0.08$, $p < .001$) across conditions.

Associations of cyclic sighing and box breathing with anxiety reduction compared with the control condition and the role of trait anxiety as a moderator

Consistent with hypotheses H1a and H1b, compared with the control condition, cyclic sighing ($b = -0.73$, $SE = 0.10$, $p < .001$) and box breathing ($b = -0.80$, $SE = 0.09$, $p < .001$) were associated with greater reductions in state anxiety. The partially standardized effects in the metric of standard deviations of the difference in state anxiety indicate very strong effects (cyclic sighing: beta = −0.98, box breathing: beta = −1.07). There was no difference in the effectiveness of the two breathing exercises ($b = -0.07$, $SE = 0.05$, $p = .19$).

Trait anxiety was not associated with state anxiety levels at T0 ($b = -0.07$, $SE = 0.38$, $p = .85$). However, trait anxiety was significantly associated with the change in state anxiety from T0 to T1 ($b = 0.39$, $SE = 0.13$, $p = .002$), indicating that individuals with higher trait anxiety experienced smaller decreases – or even increases – in state anxiety over time.

Table 1. Multilevel modeling results for changes in state anxiety.

		Step 1 *b* (*SE*)	Step 2 *b* (*SE*)	Step 3 *b* (*SE*)
	Intercept T0	5.80 (0.19)		
	Intercept T0–T1	−0.80 (0.08)**	−0.30 (0.07)**	
Within-subject	CS		−0.73 (0.10)**	
	BB		−0.80 (0.09)**	
Between-subject	T0 on trait anxiety			−0.07 (0.38)
	T0–T1 on trait anxiety			0.39 (0.13)**
Cross-level	CS × Trait Anxiety			0.06 (0.16)
	BB × Trait Anxiety			0.24 (0.20)
Random effects	Var T0 (within)	1.86 (0.19)	1.86 (0.19)	1.86 (0.19)
	Var T0–T1 (within)	0.74 (0.08)	0.60 (0.05)	0.60 (0.05)
	Var T0 (between)	1.56 (0.35)	1.56 (0.35)	1.56 (0.35)
	Var T0–T1 (between)	0.23 (0.05)	0.23 (0.05)	0.18 (0.04)

Notes: N_2 (persons) = 47, N_1 (measurements) = 782 (box breathing: $N_1 = 256$, cyclic sighing: $N_1 = 260$, control condition: $N_1 = 266$). T0 = indication of a state anxiety event, T1 = five minutes after the indication of a state anxiety event, CS = cyclic sighing, BB = box breathing. *b* = unstandardized coefficients. SE = standard error.

**$p < .01$.

For individuals with average trait anxiety, state anxiety decreased by $b = -0.30$ ($SE = 0.06$, $p < .001$) from T0 to T1 in the control condition. However, for each one-unit increase in trait anxiety, the predicted change in state anxiety increased by $b = 0.39$. Thus, for individuals with a trait anxiety score one unit above the mean, the model predicts a net increase in state anxiety from T0 to T1 (i.e., $-0.30 + 0.39 = +0.09$), suggesting that higher trait anxiety is linked to a failure to reduce state anxiety – or even a worsening of state anxiety – over time. The effectiveness of both breathing exercises was not moderated by trait anxiety (cyclic sighing: $b = 0.06$, $SE = 0.16$, $p = .71$; box breathing: $b = 0.24$, $SE = 0.20$, $p = .22$). Thus, hypotheses H4a and H4b were not supported: people with higher trait anxiety did not benefit more or less from the exercises.[1]

Associations of cyclic sighing and box breathing with attention performance compared with the control condition and the role of trait anxiety as a moderator

The number of measurements was associated with an increase in commission errors ($b = 0.09$, $SE = 0.02$, $p < .001$; see Table 2). Contrary to hypothesis H2a, cyclic sighing was not associated with fewer commission errors ($b = -0.10$, $SE = 0.17$, $p = .27$). However, in support of hypothesis H2b, box breathing was significantly negatively associated with commission errors ($b = -0.29$, $SE = 0.17$, $p = .04$). The main effect of trait anxiety on commission errors was not significant ($b = -0.23$, $SE = 0.54$, $p = .67$). However, consistent with hypothesis H5b, trait anxiety significantly moderated the relationship between box breathing and commission errors ($b = -0.64$, $SE = 0.34$, $p = .03$), with individuals with high trait anxiety showing a greater reduction in commission errors following the box breathing than did individuals with low trait anxiety (see Figure 3). Contrary to hypothesis H5a, there was no such cross-level interaction for cyclic sighing ($b = 0.16$, $SE = 0.32$, $p > .62$).

The control variable number of measurements was associated with an increase in efficiency ($b = 2.35$, $SE = 0.57$, $p < .001$). Contrary to hypotheses H3a and H3b, both cyclic sighing ($b = -6.33$, $SE = 2.83$, $p = .03$) and box breathing ($b = -9.31$, $SE = 3.37$, $p = .01$) were associated with lower efficiency scores but not with higher scores. Contrary to hypotheses H6a and H6b, trait anxiety did not moderate these associations (cyclic sighing: $b = -3.42$, $SE = 5.58$, $p = .54$; box breathing: $b = -7.02$, $SE = 6.36$, $p = .27$).[2] To examine these unexpected results in more detail, the models were

Table 2. Multilevel modeling results for commission errors and efficiency.

		Step 1 *b* (*SE*)	Step 2 *b* (*SE*)	Step 3 *b* (*SE*)
Commission errors	Intercept	3.95 (0.22)		
Within-subject	Measurement		0.09 (0.02)*	
	CS		−0.10 (0.17)	
	BB		−0.29 (0.17)*	
Between-subject	Trait anxiety			−0.23 (0.54)
Cross-level	CS × Trait Anxiety			0.16 (0.32)
	BB × Trait Anxiety			−0.64 (0.34)*
Random effects	Var (within)	2.46 (0.19)	2.25 (0.19)	2.22 (0.18)
	Var (between)	1.99 (0.38)	1.96 (0.38)	1.91 (0.38)
Efficiency	Intercept	240.45 (5.08)		
Within-subject	Measurement		2.35 (0.57)**	
	CS		−6.33 (2.83)*	
	BB		−9.31 (3.37)**	
Between-subject	Trait anxiety			−3.22 (11.83)
Cross-level	CS × Trait Anxiety			−3.42 (5.58)
	BB × Trait Anxiety			−7.02 (6.36)
Random effects	Var (within)	1073.14 (211.38)	931.72 (168.04)	929.77 (168.29)
	Var (between)	1078.09 (454.30)	1057.70 (429.16)	1048.93 (435.79)

Notes: N_2 (persons) = 44, N_1 (measurements) = 633. CS = cyclic sighing, BB = box breathing. *b* = unstandardized coefficients. *SE* = standard error.
*$p < .05$.
**$p < .01$.

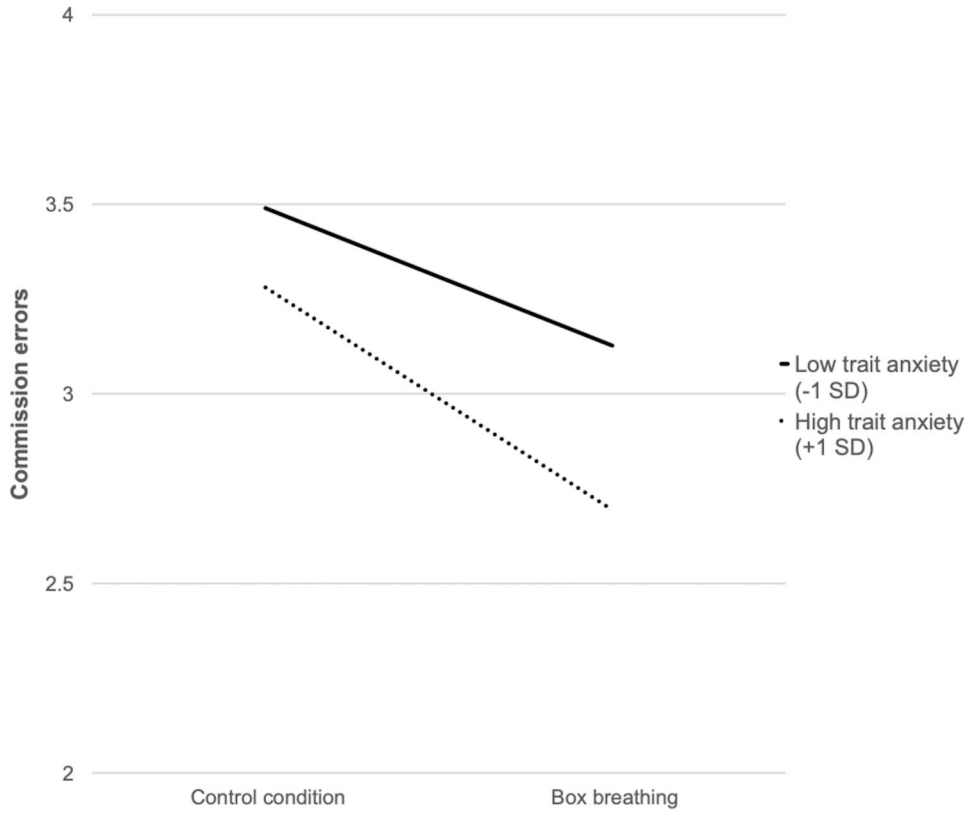

Figure 3. Moderating role of trait anxiety in the relationship between box breathing and commission errors.

run separately for the two components of variable performance, omission errors and reaction times (note that these exploratory analyses were not preregistered and that the two-tailed significance level is reported): box breathing was significantly negatively associated with omission errors ($b = -0.22$, $SE = 0.10$, $p = .03$), whereas cyclic sighing had a negative but not significant association ($b = -0.06$, $SE = 0.11$, $p = .59$). Both cyclic sighing and box breathing predicted slower reaction times (cyclic sighing: $b = 6.85$, $SE = 3.30$, $p = .04$; box breathing: $b = 9.47$, $SE = 3.84$, $p = .01$).

Participant feedback

In the feedback questionnaire, the participants were asked whether they found the breathing exercises easy to use, helpful, pleasant, or annoying. The participants were also asked whether they had performed the exercises outside of stressful events, whether they planned to do them in the future, and whether they would recommend the exercises to others. The questions were asked separately for cyclic sighing and box breathing. All the questions were answered on a five-point Likert scale.

Forty people responded to the feedback survey. While box breathing was found to be easier than cyclic sighing ($M_{BB}/SD_{BB} = 4.60/0.63$, $M_{CS}/SD_{CS} = 3.78/0.89$, $t(39) = 5.78$, $p < .001$), both exercises were found to be equally helpful ($M_{BB}/SD_{BB} = 3.75/0.93$, $M_{CS}/SD_{CS} = 3.60/1.03$, $t(39) = 0.78$, $p = .44$) and were equally likely to be recommended ($M_{BB}/SD_{BB} = 3.30/1.14$, $M_{CS}/SD_{CS} = 2.95/1.22$, $t(39) = 1.83$, $p = .08$). Annoyance ratings were medium for cyclic sighing and low for box breathing ($M_{BB}/SD_{BB} = 1.73/0.70$, $M_{CS}/SD_{CS} = 2.38/1.08$, $t(39) = -3.46$, $p = .001$). Both exercises were rarely used outside of stressful situations ($M_{BB}/SD_{BB} = 2.15/1.17$, $M_{CS}/SD_{CS} = 1.90/1.26$, $t(39) = 1.57$, $p = .12$). In terms of the intention to continue using the exercises, box breathing outperformed cyclic sighing ($M_{BB}/SD_{BB} =$

3.28/1.13, M_{CS}/SD_{CS} = 2.60/1.22, $t(39) = 2.68$, $p = .01$). Thus, evaluations of both exercises were positive on average but tended to be more positive for box breathing. The effect sizes of the three significant mean differences were medium to high (easy: Hedges $d = .90$; annoying: Hedges $d = -.54$; future use: Hedges $d = .42$).

Discussion

Results and interpretations

This pilot study examined the associations between cyclic sighing and box breathing in real-life threatening situations in the daily lives of college students. Although acute help with everyday emotional regulation is essential, studies that aim to directly intervene in the experience of everyday emotions are rare (Feneberg & Nater, 2022). As hypothesized, both breathing exercises reduced the subjective experience of state anxiety more effectively than the neutral control condition did. Despite the short duration of only one minute, the effect sizes were large. However, it is essential to note that these effect sizes are based on a short time frame, as the postmeasurements took place only five minutes after the exercise. Thus, although this pilot study indicates that both cyclic sighing and box breathing are effective methods for short-term relief from acute anxiety among young and healthy college students, it remains unclear how long these effects last and whether the results of this study can be generalized to other populations, such as professionals who are exposed to threatening situations.

Another important contribution of this study is the consideration of attention performance. Interestingly, box breathing was negatively associated with commission errors. These findings suggest that box breathing may indeed improve inhibitory control. However, in contrast to the hypotheses, performance efficiency decreased after both breathing exercises, which was due to longer reaction times. In their within-subject laboratory experiment, Hallion et al. (2020) reported that, compared with the neutral control condition, worry led to faster but less accurate SART performance. The results of this study for box breathing are consistent with these findings, as box breathing was associated with a more accurate but less rapid response style than was the neutral control condition. There are many situations in which a faster but less accurate work style is undesirable. In these situations, box breathing may be helpful. In contrast, cyclic sighing was not associated with commission errors. Compared with cyclic sighing, box breathing may save cognitive resources because of its simple and consistent rhythm. In line with this reasoning, the participants found box breathing to be easier than cyclic sighing in the feedback survey.

We hypothesized that individuals with trait anxiety would particularly benefit from breathing exercises, as trait anxiety is associated with less effective coping in stressful situations (Englert et al., 2011). Consistent with the notion that anxious individuals often rely on less adaptive coping mechanisms, we found that higher trait anxiety was associated with a reduced capacity to naturally reduce state anxiety over time in the neutral control condition. Specifically, compared with individuals with lower trait anxiety, individuals with higher trait anxiety experienced a smaller decrease in state anxiety, suggesting that they had a more limited ability to regulate their anxiety levels without intervention. In contrast, individuals with low anxiety were able to reduce their state anxiety more effectively by simply proceeding as usual. However, we did not find significant Breathing Exercise × Trait Anxiety interactions regarding subjective anxiety. Thus, the breathing exercises were equally effective at reducing subjective state anxiety among individuals with both high and low levels of trait anxiety. Therefore, breathing exercises are a recommended strategy for reducing subjective state anxiety, particularly for individuals with high levels of trait anxiety who may have difficulty managing their anxiety levels without intervention. With respect to the objective outcome measure of attention, trait anxiety was not related to commission errors or efficiency. However, consistent with the hypotheses, there was a significant cross-level interaction of box breathing and trait anxiety on commission errors, indicating that, compared with the control

condition, box breathing increased accuracy more for individuals with trait anxiety than for individuals with low anxiety.

Limitations and future directions

This study indicates that one-minute breathing exercises may serve as accessible, effective tools for acute anxiety relief, even in unstructured, real-life environments. However, several limitations should be noted. Importantly, expectation can play important roles in the associations found. Compliance with the breathing exercises was only assessed by means of control questions and was not objectively verified. Furthermore, the T1 compliance rate was 84%, indicating that the students did not complete the T1 questionnaire for 16% of the reported anxiety events. Research suggests that stress and negative affect are associated with nonresponse in young adult EMA studies (Murray et al., 2023). In this study, reported anxiety levels at T0 were unrelated to T1 compliance, but it is unclear whether the threat events with missing T1 questionnaires share characteristics beyond anxiety levels. Regarding the T0 questionnaire, the event sampling approach used in this study does not permit evaluating whether participants initiated the smartphone questionnaire during each episode of elevated state anxiety. Thus, students may have refrained from reporting some types of situations, such as threat perceptions in the presence of others.

Another limitation of this study relates to the unequal sex ratio, with a predominantly female sample. Given the sex differences in coping strategies used (O'Rourke et al., 2022), the results of this study cannot be readily transferred to male or diverse individuals. Furthermore, as the sample consisted exclusively of young and healthy college students, the findings cannot be generalized to older adults or individuals with different health profiles. Another weakness of this study relates to the lack of physiological parameters as objective outcome variables. Interestingly, recent developments in sensor trigger algorithms provide the opportunity to use heart rate variability to identify stress events on an objective basis (Rominger & Schwerdtfeger, 2022). Follow-up studies should exploit these innovative opportunities.

Potential avenues for future research include exploring the effectiveness of breathwork in regulating other mood states, such as anger or fatigue. Balban et al. (2023) reported associations of breathwork not only with state anxiety but also with positive and negative affect, as measured by the PANAS (Watson et al., 1988), which includes items for attention and alertness and irritability and hostility. Interestingly, compared with mindful meditation, cyclic sighing was more effective at increasing positive affect, which may be related to the intense inhalation involved. Investigating which specific techniques are effective in regulating these mood states in everyday situations could be a future research direction.

Conclusion

This pilot study indicates the potential of two brief breathing techniques as effective tools for reducing anxiety immediately in everyday life, using an innovative just-in-time ecological momentary intervention. The observed reduction in commission errors following box breathing, particularly in individuals with greater trait anxiety, suggests a promising application for enhancing inhibitory control in high-arousal contexts. However, the performance efficiency after box breathing decreased, which was driven by slower reaction times. From a practical perspective, this shift toward a more accurate response style may be beneficial in settings in which precision and considered action are essential.

Notes

1. The results regarding H1a, H1b, H4a and H4b did not change when only female participants were considered.

2. The results regarding H2a, H2b, H3a, H3b, H5a, H5b, H6a and H6b did not change when only female participants were considered.

Author contributions

All the authors contributed to the conception and design of the study. The first author analyzed the data and drafted the manuscript. Under the supervision of the first and third authors, the second author contacted the participants and prepared the materials. The third author acted as an expert in the field of breathing exercises, the fourth author as an expert in the field of ambulatory attention measurement, and the fifth author as an expert in the field of physiology. The second and seventh authors provided scientific advice. All the authors discussed the results and contributed to the final manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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