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BRIEF REPORT

Taking a few deep breaths significantly reduces children's physiological arousal in everyday settings: Results of a preregistered video intervention

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Abstract

This preregistered, randomized field experiment tested the effectiveness of a brief deep breathing intervention on children's concurrent physiological arousal in naturalistic settings ($N = 342$; $M_{age} = 7.48$ years; 46% female; 53% Asian, 26% White; 21% other race/ethnicity). The treatment consisted of an animated video that introduced deep breathing as a self-regulation strategy and scaffolded the child in taking a few slow-paced breaths, while the control group watched an informational video featuring similar animated images. Respiratory sinus arrhythmia (RSA) and heart rate (HR) were measured while children were sitting still (baseline) and subsequently while watching 1-min videos. Relative to baseline arousal, RSA increased and HR decreased only in response to the deep-breathing treatment video. Effects were larger in the second 30-s epoch of the video, which included most of the deep breathing practice. RSA fully mediated the intervention's effects on HR. By analyzing all children exposed to intervention video regardless of their engagement in the deep breathing practice (intention-to-treat design) and by using easily scalable treatment videos, the study identifies an effective and pragmatic approach to reducing children's physiological arousal in everyday, group settings. Implications for advancing applied developmental psychophysiological research are discussed.

KEYWORDS
breathing exercises, heart rate, parasympathetic nervous system, respiratory sinus arrhythmia, school-age population

1 | INTRODUCTION

"Take a deep breath" is often the first guidance offered by parents and teachers to an upset child, as a way to calm the child before addressing any emotion-relevant causes, consequences, or solutions. Teachers also regularly use breathing techniques (e.g., belly breathing) during classroom activities and transition periods when students become restless, unfocused, or emotionally dysregulated (Education's Voice, 2016). Slow-paced breathing is at the core of many school-based mindfulness and meditation programs designed to promote focused attention and self-regulation skills in students (Bakosh et al., 2016; Black & Fernando, 2014; Sibinga et al., 2016; van de Weijer-Bergsma et al., 2014; Zelazo et al., 2018). Yet it is unclear whether deep breathing can significantly alter a young child's physiological response. What is the impact of taking only a few slow-paced breaths on the activity of a child's autonomic nervous system in everyday settings without any individual supervision or feedback? To understand the effects of deep breathing on elementary school-aged children's physiology, we created a short, animated video that introduces the benefits of breathing in the context of learning challenges and visually scaffolds children while they take four slow-paced breaths. In this brief report, we discuss the effectiveness of this scalable video intervention in altering elementary school students' physiological arousal in everyday settings.

Respiratory sinus arrhythmia (RSA) is an index of parasympathetic nervous system (PNS) activity that plays an important role in influencing heart rate (HR) (Beauchaine & Thayer, 2015) and has been linked to children's emotion regulation, focused attention, and task engagement (Beauchaine et al., 2007; Graziano & Derefinko, 2013; Holzman & Bridgett, 2017; Patriquin et al., 2013). Because RSA represents naturally occurring HR variability synchronized with one's respiration rate, it is an ideal biomarker to use when testing the effects of deep breathing on physiological arousal. In small samples of adults, slow-paced breathing (5–6 breaths per minute) has been shown to increase concurrent HR variability (De Couck et al., 2019; Ring et al., 1999) and RSA levels (Ritz et al., 2001; Szulczewski & Rynkiewicz, 2018).

We were unable to identify any studies investigating the association between deep breathing and RSA in children or adolescents. One study of 40 adolescents showed that 3 min of paced—but not deep—breathing had no effect on RSA levels when compared with their baseline RSA values (Balle et al., 2013). In that study, the respiration rate of 15 breaths per minute (0.25 Hz) may not have affected RSA because it does not represent a meaningful slowdown relative to typical respiration rates (0.15–0.40 Hz). Given lack of relevant research with children, there is a great need to systematically investigate the effect of deep breathing on RSA response in elementary school students and expand our understanding of this widespread self-regulation strategy in children.

Prior research on experimentally induced slow-paced breathing in adults has been conducted in university laboratories. This highly controlled context does not approximate the settings in which elementary school students may be asked to engage in deep breathing. In schools, deep breathing exercises may be administered to groups of students with no individual supervision or feedback about their compliance or the quality of their engagement. Thus, intervention work that employs an intention-to-treat study design (which analyzes data for all participants, regardless of whether they actually engaged with the intervention) in everyday settings may provide better insight than laboratory studies. Another limitation in prior research is that adult studies have used extended periods of slow-paced breathing, with intervention practices lasting for at least 3 min. However, interventions that depend on young children voluntarily taking more than a few slow-paced breaths may not be feasible, pragmatic, or sustainable.

2 | PRESENT INVESTIGATION

We examined the effect of an animated video that scaffolds the child in taking four slow-paced breaths on RSA in relation to the child's baseline (pre-video) RSA level and in comparison with a control group that watched a brief animated informational video that contained similar images. We hypothesized that: (1) the deep breathing intervention would have a positive effect on RSA in the 0.12–0.80 Hz frequency band during the intervention video; and (2) the effect of treatment would be larger during the second half of the video (composed entirely of slow breathing exercise) versus the first half (composed of instructions and one slow breath).

Additionally, we addressed measurement questions that can advance the field of research on children's physiology in the context of deep breathing. First, given the considerable variability in frequency bands used to calculate RSA in elementary school-aged children (e.g., Dollar et al., 2020; Feurer et al., 2020; Quiñones-Camacho & Davis, 2018; Ward et al., 2015) and the need to account for lower respiration rate induced by slow-paced breathing (Shader et al., 2018), we tested whether our results were robust across three different lower frequency bounds used to calculate RSA (i.e., 0.12, 0.15 and 0.20 Hz). In the study preregistration, we observed that the deep breathing intervention could reduce respiration rates to approximately 0.12 Hz. Consequently, we expected the deep breathing intervention to have the largest effects on RSA in the 0.12–0.80 Hz band.

Second, we examined whether the effect of slow-paced breathing can also be detected on children's HR, a global biomarker influenced by joint contributions of both the sympathetic nervous system and PNS (Berntson et al., 1997) that is easier to collect in naturalistic settings and faster to score than RSA.

3 | METHOD

3.1 | Procedures

All procedures were approved by the Stanford University IRB and data are available upon request from the authors. Participants were recruited at a children's museum, a public playground, and three full-day summer camps in the San Francisco Bay Area. At the museum and playground, participants were recruited by approaching parents, who provided written consent for their children's participation. At summer camps, parents were informed about the study using email and paper waiver of consent forms, and children were invited to participate in the study unless a parent asked to be excluded. These participants were assessed in small groups (museum/playground range: 1–3 children; camp range: 1–9 children) seated at a table that was set up to the side of the main space where other children were engaged in play or exploration (i.e., exhibition room, playground set, recess yard) or in a separate classroom at one camp site. Since the level of background distractions varied across settings, we controlled for each location in our analyses. All children provided verbal assent. To record participants' continuous electrocardiogram (EKG), three pregelled disposable electrodes were attached to each child's forearms and to a small wireless transmitter that was positioned next to each child to transmit the EKG data to a nearby wireless logger.

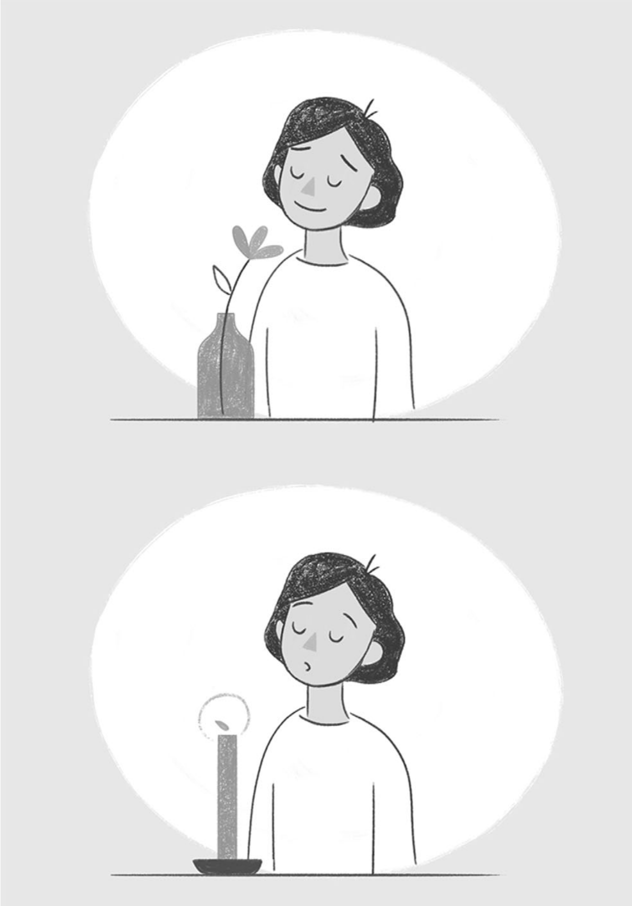

FIGURE 1 Grayscale images from a color breathing intervention video depicting demonstration of paced inhalation and exhalation

First, participants sat quietly for a 1-min baseline period. Next, they were randomly assigned to view either the intervention or control video using an iPad with child-size headphones. These developmentally appropriate videos featured an animated child character of ambiguous gender and race (see Figure 1). In the experimental *deep breathing* video, the female narrator first explains that taking deep, slow breaths can help children manage upset feelings, calm down, and deal with challenges. Then, the narrator guides the participant through deep breathing exercises. The control video features similar animated images, but the narrator makes general statements about things that children do throughout their day. The deep breathing video can be viewed at https://vimeo.com/442138273/f64bd4b5d2 and the control video can be viewed at https://vimeo.com/442138465/7491702efc. The videos were followed by other procedures that are not the focus of this paper; see preregistration for more details. At all locations, the research assistant remained nearby throughout the session to manage transitions and help with any technological issues.

Demographic data (including age, gender, and race/ethnicity) were collected from administrative records for the summer camps or from parent surveys at the children's museum and the playground.

3.2 | Participants

We randomly assigned 386 children to view the control video ($N = 189$) or the deep breathing ($N = 197$) video. One participant declined to have EKG recorded and 41 had completely missing RSA data due to artifacts in the EKG recording. We were not able to monitor the quality of the EKG signal in the field, which resulted in a high rate of missing data (e.g., wireless signal was lost; electrodes failed to make good contact; movement or other artifacts). Intervention condition was unrelated to missing physiological data ($\chi^2 = 0.021$, $p = 1.000$). We restricted our analysis sample to the 342 children for whom RSA data were available. In the analysis sample, 167 children (49%) viewed the control video and 175 (51%) viewed the deep breathing video. Demographic information for the sample is presented in Table 1.

3.3 | Measures

Physiological response was indexed by PNS activity, as measured by RSA. RSA response was measured continuously using a BIOPAC BioNomadix wireless EKG transmitter and logger. We calculated RSA scores for all participants using three frequency bands: 0.12–0.80 Hz (the focal frequency band used in this study), 0.15–0.80 Hz, and 0.20–0.80 Hz. The lower bounds represent three frequencies that have been used in studies of children aged 5 and older (Boyce et al., 2001; Dollar et al., 2020; Gatzke-Kopp & Ram, 2018; Gentzler et al., 2012; Quiñones-Camacho & Davis, 2018; Santucci et al., 2008). Visual inspection of the spectral decomposition of 20 EKG files from 20 participants indicated that there was little to no variability in heart period above 0.80 Hz, an upper bound used by Quiñones-Camacho and Davis (2018) with similarly aged participants. Prior to analyses, each waveform was verified, inter-beat intervals were checked visually, and artifacts were removed. Using Mindware software, RSA values were calculated in 30-s epochs during the baseline and video episodes (Mindware Technologies, 2020).

3.4 | Analysis plan

The analyses reported in this paper were preregistered (see https://osf.io/ywq96). We used multilevel modeling with RSA as the dependent variable: data were nested within individuals, and each participant had four RSA scores: baseline epoch 1, baseline epoch 2, video epoch 1, and video epoch 2. Descriptive statistics for RSA and HR are presented in Table 1. Analyses controlled for assessment site, gender, age, and race/ethnicity. Analyses were run in each data set with lmer 1.1-27 and estimates were pooled with mitml 0.4-1. In order for all participants to be included in the analyses, we used multiple imputation with chained equations (MICE; van Buuren, 2012) to impute 20 data sets using R 4.1.0 with mice 3.13.0.

TABLE 1 Descriptive statistics

	Full Sample (N = 342)			Treatment group (N = 175)		Control group (N = 167)	
	Mean or %	SD	% Missing	Mean or %	SD	Mean or %	SD
Site			0%				
Summer camps	76%			74%		77%	
Children's museum	16%			17%		16%	
Public playground	8%			9%		7%	
Race/ethnicity			34%				
AAPI	53%			51%		54%	
White	26%			25%		26%	
Black	1%			2%		1%	
Hispanic/Latinx	2%			0%		4%	
Other/Multi-racial	18%			22%		14%	
Female	46%		17%	46%		46%	
Age (years)	7.48	1.58	18%	7.50	1.56	7.45	1.62
RSA 0.12–0.80 Hz							
Baseline Epoch 1	6.79	1.25	2%	6.80	1.18	6.77	1.31
Baseline Epoch 2	6.65	1.15	1%	6.68	1.17	6.62	1.14
Video Epoch 1	6.84	1.18	4%	7.03	1.17	6.64	1.15
Video Epoch 2	7.02	1.15	4%	7.38	1.04	6.65	1.14
RSA 0.15–0.80 Hz							
Baseline Epoch 1	6.61	1.25	2%	6.61	1.19	6.61	1.32
Baseline Epoch 2	6.44	1.16	1%	6.45	1.18	6.43	1.15
Video Epoch 1	6.66	1.19	4%	6.83	1.18	6.48	1.19
Video Epoch 2	6.69	1.13	4%	6.90	1.05	6.46	1.16
RSA 0.20–0.80 Hz							
Baseline Epoch 1	6.23	1.28	2%	6.21	1.23	6.26	1.34
Baseline Epoch 2	6.07	1.21	1%	6.04	1.23	6.10	1.20
Video Epoch 1	6.29	1.22	4%	6.41	1.19	6.16	1.23
Video Epoch 2	6.22	1.16	4%	6.23	1.12	6.22	1.20
HR							
Baseline Epoch 1	94.68	11.90	2%	94.74	11.22	94.62	12.61
Baseline Epoch 2	95.05	11.73	1%	94.89	11.01	95.21	12.47
Video Epoch 1	92.58	11.37	4%	92.09	11.02	93.12	11.76
Video Epoch 2	91.95	11.45	4%	90.14	10.88	93.86	11.75

Notes: AAPI, Asian American or Pacific Islander; RSA, respiratory sinus arrhythmia; HR, heart rate.

The predictors included treatment (control vs. deep breathing), task (baseline vs. video), epoch (0–30 vs. 30–60 s), and the two- and three-way interactions among these variables. We report simple effects to probe significant interactions. As a sensitivity analysis, we examined whether results differed depending on the frequency band used to calculate RSA (0.12–0.80, 0.15–0.80, and 0.20–0.80 Hz). We applied the same modeling approach to test the effects of deep breathing on HR. For epochs in which deep breathing had a significant effect on HR, we tested RSA as a mediator to determine the extent to which treatment effects on HR could be attributed to concurrently measured PNS activity, as opposed to SNS activity. The mediation analyses were conducted using Mplus 7.4 with the robust maximum likelihood estimator.

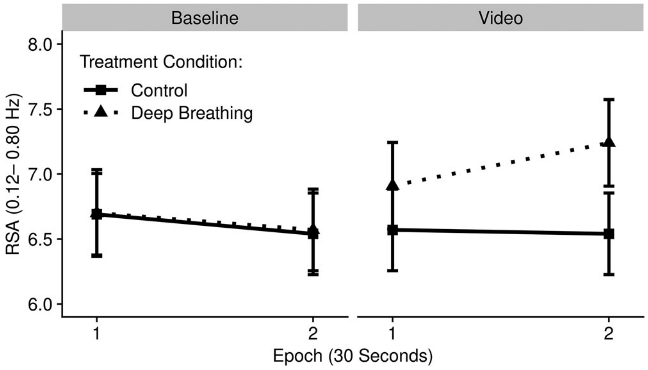

FIGURE 2 Effects of deep breathing on RSA in the 0.12–0.80 Hz frequency band. Error bars represent 95% confidence intervals

4 | RESULTS

4.1 | Intervention effects

4.1.1 | RSA

For the baseline, there was no effect of treatment ($b = 0.03$, $t = 0.11$, $p = .776$), confirming that there were no preintervention differences in RSA between the groups. For the video, there was a positive overall effect of treatment ($b = 0.54$, $t = 4.80$, $p < .001$). Further, we found a significant treatment × epoch interaction ($b = 0.36$, $t = 3.63$, $p < .001$). As hypothesized, the effect of treatment on RSA increased between the first ($b = 0.36$, $t = 2.95$, $p = .003$) and second ($b = 0.72$, $t = 5.83$, $p < .001$) epoch of the video (see Figure 2). During the video, treatment explained additional 2.3% of variance in the first epoch and additional 9.7% of variance in the second epoch relative to a baseline model with covariates (i.e., assessment site, gender, age, race/ethnicity).

As a robustness check, we tested whether frequency band moderated the effects of treatment. RSA corresponds to HR variability at the frequency of respiration. In light of the absence of treatment effects during the baseline, we restricted these analyses to the video task. There was a significant difference in the treatment effect between the 0.12–0.80 and 0.15–0.80 Hz frequency bands ($b = -0.16$, $t = -2.91$, $p = .004$) and between the 0.12–0.80 and 0.20–0.80 Hz frequency bands ($b = -0.42$, $t = -7.42$, $p < .001$). Treatment had the largest positive effect on RSA during the video in the 0.12–0.80 Hz band ($b = 0.54$, $t = 4.71$, $p < .001$), a smaller positive effect on RSA in the 0.15–0.80 Hz band ($b = 0.38$, $t = 3.29$, $p = .001$), and no effect on RSA in the 0.20–0.80 Hz band ($b = 0.12$, $t = 1.05$, $p = .295$).

4.1.2 | HR follow-up analyses

For the baseline, there was no effect of treatment on HR ($b = -0.06$, $t = -0.05$, $p = .960$). For the video, there was a negative effect of deep breathing on HR ($b = -2.32$, $t = -2.00$, $p = .047$). Further, we found a significant treatment × epoch interaction ($b = -2.94$, $t = -5.62$, $p < .001$). As hypothesized, the effect of treatment on HR increased between the first ($b = -0.85$, $t = .1.19$, $p = .477$) and second ($b = -3.79$, $t = -3.18$, $p = .002$) epoch of the video. During the video, treatment explained no additional variance in the first epoch and an additional 2.7% of variance in the second epoch relative to a baseline model with covariates (i.e., assessment site, gender, age, race/ethnicity).

We tested whether the significant effect of treatment on HR during the second video epoch was mediated by RSA. There was a significant indirect effect of treatment via RSA in the 0.12–0.80 Hz frequency band ($\beta = -0.22$, SE = 0.04, $p < .001$) and RSA in this band fully mediated the link between the treatment and HR, with the direct effect becoming non-significant ($\beta = 0.06$, SE = 0.04, $p = .163$). The indirect effect via RSA in the 0.15–0.80 Hz frequency band was also significant ($\beta = -0.13$, SE = 0.04, $p < .001$) and RSA in this band also fully mediated the link between the treatment and HR, with the direct effect becoming non-significant ($\beta = -0.83$, SE = 0.94, $p = .375$).

5 | DISCUSSION

Taking a deep breath is a simple self-regulation strategy that should help lower one's momentary physiological arousal. However, paced inhalation and exhalation are not intuitive to younger children, and many visual, narrative, and tactile supports have been developed to scaffold children through deep breathing exercises. The current study is the first to show that taking a few deep breaths in naturalistic contexts can significantly increase PNS activity in children aged 5–12. The findings extend laboratory studies that show similar results in much smaller samples of adult participants that used longer periods of deep breathing (De Couck et al., 2019; Ring et al., 1999, 2001; Szulczewski & Rynkiewicz, 2018).

Across everyday settings that included an educational summer camp, a children's museum, and a playground, we demonstrated that a brief animated video is effective in inducing significant momentary change in children's RSA and HR using an intention-to-treat study design. Guiding a group of children through 1 min of a slow-paced breathing exercise in classroom or playground settings can significantly lower the average arousal level, even if some children do not comply with the exercise. We hope this study and the freely available intervention video stimulate new research into the effects of deep breathing on children's physiology, emotions, and behavior in elementary school students. Future research should include more socioeconomically diverse populations, as our study was primarily conducted with children whose families have the means to send them to educational summer camps and visit children's museums.

To advance the replication and extension of this work in naturalistic settings with elementary school children, our study illuminates three important methodological issues. First, it is important to account for intervention-related changes in respiration rates when calculating RSA. However, there is considerable variability in the frequency bands used to calculate RSA in school-aged children (Dollar et al., 2020; Feurer et al., 2020; Quiñones-Camacho & Davis, 2018; Ward et al., 2015). Setting an accurate lower bound of the high frequency band is critical to capturing RSA change in response to slow-paced breathing, which reduces the respiration rate. To guide future efforts, we showed that the effect of video intervention was largest when using the 0.12–0.80 Hz frequency band; the effect was significant but smaller when using the 0.15–0.80 Hz frequency band, and not significant with the 0.20–0.80 Hz frequency band. Second, we recognize that maintaining young children's focus and engagement with slow-paced breathing exercises amid natural distractions can be challenging. This raises the question of how many slow-paced breaths are enough to significantly reduce physiological arousal. We found that even a single deep breath (during the first 30 s of the video) significantly affected RSA levels, and that the effect of deep breathing increased substantially with subsequent breaths. Finally, while RSA represents an ideal biomarker to detect the effect of deep breathing on physiological arousal, it is challenging to collect high-quality EKG data outside the laboratory context and time consuming to clean and score EKG signal. Our study show that the momentary effect of deep breathing can be detected using a measure of children's HR, but the effect on HR is fully mediated by changes in RSA. This means that changes in HR in response to taking a few deep breaths were solely controlled by the PNS input to heart. Measuring HR may be more pragmatic and scalable alternative to RSA in large samples that have high statistical power. In this study, the effect size was more than three times greater for RSA than for HR in the second epoch of the video.

Future research should extend the current study by examining the effect of deep breathing following a stressful or challenging experience that elicits increased physiological arousal or negative emotions. Developmental psychophysiology researchers have emphasized the importance of studying physiological recovery and identifying factors that explain different recovery trajectories in children (Burt & Obradović, 2013; Kahle et al., 2018; Obradović, 2012, 2016). Descriptive developmental research has shown that children's cognitive, behavioral, and emotional self-regulation skills are significantly linked to their physiological recovery following a laboratory task (Armstrong-Carter et al., 2020; Finch & Obradović, 2017; Santucci et al., 2008). Determining whether experimentally induced regulation of breathing has a causal effect on children's physiological recovery following a cognitively or emotionally challenging task is a critical next step in translating this work into caregiving and educational practices that can promote children's well-being.

While our study showed that engaging in deep breathing has an immediate impact on RSA levels, it is important to further study whether and how experimentally induced changes in RSA impact other cooccurring aspects of self-regulation. Specifically, studies that measure momentary changes in breathing, arousal, emotional states, attention, and behavior can elucidate directionality and reciprocity of these related self-regulation processes. In addition, previous studies of adults have indicated that deep breathing does not affect PNS activity during the period that follows the end of a short breathing exercise (Hoffmann et al., 2019; Meier & Welch, 2016). More research is needed to identify ways to make the effects of physiological interventions such as deep breathing persist beyond the moment in which they are deployed.

Developmental studies have linked higher baseline RSA levels to processes that support adaptation and learning, including focused attention, on-task behavior, and self-regulation (Blair & Peters, 2003; Holzman & Bridgett, 2017; Marcovitch et al., 2010; Staton et al., 2009; Sulik et al., 2015). Further, higher baseline RSA levels have been identified as a protective factor against developing behavioral problems in the context of environmental adversity (El-Sheikh & Whitson, 2006; Perry et al., 2012; Philbrook et al., 2018). Although baseline RSA has been implicated in developmental outcomes related to children's allostatic load (Hinnant et al., 2013), it is unclear whether interventions could alter baseline RSA in children. Recent evaluations of breathing interventions revealed that 4 or 6 weeks of brief weekly breathing exercises can yield significant increases in baseline RSA levels in small adult samples (Lin, 2018; Sürücü et al., 2021) and decreases in HR in adolescents (Gregoski et al., 2011). Future research should extend this work to children and examine whether regular deep breathing practice can have a sustained effect on baseline RSA levels.

This study highlights the malleability of physiological arousal, which correlates with cognitive, emotional, and behavioral self-regulation (Beauchaine & Thayer, 2015; Holzman & Bridgett, 2017; Obradović, 2012, 2016). Although children's agency in regulating their own arousal is important, it may not be effective to simply ask a young child to take a deep breath. Children's efforts need to be scaffolded, at least initially, as they learn to slow and pace their inhalation and exhalation. To support dissemination of this brief intervention, the animated video used in this study and a shorter (30 s) version that includes only the paced breathing exercise can be viewed and downloaded at https://vimeo.com/442138273/f64bd4b5d2 and https://vimeo.com/442138393/d8f6c46d13. This effective video tool can be easily employed in home, school, or online settings to introduce children to deep breathing as a self-regulation technique. We hope this work is just the beginning of a new wave of psychophysiological research that goes beyond understanding how experiences "get under the skin" (Lupien et al., 2001) and has clear, practical implication for supporting child development (Gunnar, 2020; Obradović & Armstrong-Carter, 2020).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are available from the authors upon request.

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