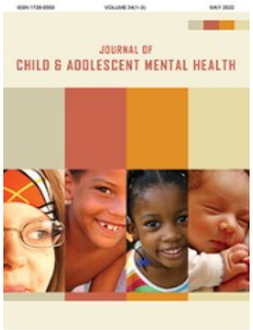

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Experimental evaluation of a neurophysiological intervention designed to increase student resilience: a pilot study

Alex Kresovich[1], Kai MacLean[1], Caroline M. Lancaster[1], Elizabeth D. Torres[2], Jeff R. Temple[2] & Elizabeth A. Mumford[1]*

[1]Public Health Department, NORC at the University of Chicago, Chicago, USA
[2]Center for Violence Prevention, University of Texas Medical Branch, Galveston, USA
**Correspondence: mumford-elizabeth@norc.org*

Social and emotional learning (SEL) interventions have shown promise for building resilience and protecting youth from adverse outcomes. This study reports on an experimental pilot evaluation of the Smart Brain Wise Heart SEL intervention during the 2021–2022 school year. Smart Brain Wise Heart (SBWH) uses a neurophysiological approach among ninth-grade students to evaluate the intervention's impact on youth resiliency, self-compassion, peer violence exposure, internalising disorders, and hyperactivity. Results did not indicate any significant universal changes in target outcomes. These null findings regarding universal impact may be explained by the unprecedented difficulty of implementing a school-based intervention amid ongoing COVID-19 restrictions and administrative issues. Despite these obstacles, students with lower academic achievement in the intervention condition scored significantly higher for resilience and self-compassion and lower on depressive symptoms than their peers in the comparison condition, even when controlling for baseline scores, sex, attachment (father, mother, peer), and exposure to adverse childhood experiences. Our findings suggest SBWH programming may have important implications for the trajectories of students exhibiting lower academic achievement, at a minimum, by significantly improving their emotional resilience, self-compassion, and depressive symptoms during a vital developmental stage. More research is urgently needed under optimal conditions to assess the universal implementation of the program.

Keywords: mental health, school settings, self-compassion, social and emotional learning, youth

Introduction

In December 2021, the United States Surgeon General issued a public health advisory calling for the protection of youth mental health. The report cites increasing rates of psychological distress among adolescents (Office of the Surgeon General, 2021). The report specifically highlighted recent research findings suggesting a two-fold increase in youth depression and anxiety during the COVID-19 pandemic; approximately 25% of young individuals were reported to exhibit depressive symptoms, while 20% experienced symptoms of anxiety (Racine et al., 2021). Further, even before the COVID-19 pandemic, the 2019 Youth Risk Behaviour Survey data indicated that nearly one out of every five adolescents (19.5%) reported exposure to violence in the past twelve months (Underwood et al., 2020). Violence exposure in youth is commonly measured as one of many possible adverse childhood experience (ACEs), which in turn are associated with increased developmental trajectories of depression and anxiety (Blum et al., 2019; Lewis et al., 2010). Thus, reducing exposure to violence and building youth resiliency to the range of stressors they face, requires community-wide efforts.

Social and emotional learning (SEL) interventions have shown promise for building resilience (Cramer & Castro-Olivo, 2016; Green et al., 2021) and improving adolescent outcomes related to hostility (Schonert-Reichl et al., 2012), peer violence (Schonert-Reichl et al., 2012), hyperactivity

(Low et al., 2015), and internalising behaviours (e.g., anxiety, depression, stress) (Dowling et al., 2019). SEL education is designed to build a child's ability to learn about and manage their own emotions and interactions in ways that benefit themselves and others in their school, workplace, relationships, and community (Humphrey et al., 2011).

Resilience – defined as an individual's ability to moderate the negative effects of stress (Wagnild & Young, 1993) – is a core outcome of SEL interventions and has been found to mitigate the effects of violence (Resnick et al., 2004; Salami 2010), hostility and aggression (C. A. Anderson & Bushman, 2002; Ng et al., 2012), depression (J. R. Anderson et al., 2022; Ng et al., 2012), anxiety (J. R. Anderson et al., 2022; Ng et al., 2012), and suicidal ideation (Hirschtritt et al., 2015; Kim, 2021). A systematic review found that universal school-based resilience interventions were promising for youth in reducing short-term depression, anxiety (defined by follow-up 12 months or less after intervention), internalising problems, externalising problems, and general psychological distress (Dray et al., 2017).

Smart Brain Wise Heart (SBWH) is a broad-based SEL resilience-building program utilising a neurophysiological approach from the HeartMath Institute. SBWH takes a novel approach to empowering adolescents through neurophysiological education and techniques to build emotional resilience and self-compassion, as well as to strengthen approaches to conflicts to reduce exposure to violence (HeartMath Institute, 2023). SBWH teaches resilience-building and self-regulation skills to adolescents aged 9 to 16 years through concepts of psychophysiological coherence (McCraty et al., 2009). Psychophysiological coherence is attained when a physiological function is driven by positive emotion. This state of coherence is associated with a sine wave-like pattern in heart rhythms, increased heart-brain synchronisation, and synergy between various physiological systems (McCraty, 2000a).

What differentiates the SWBH program from other SEL interventions is its neurophysiological approach. The SBWH program is built on Heart Based Resonant Frequencies theory, which posits that the heartbeat serves as a centring point for physiological function (Alabdulgader, 2021). This neurophysiological approach is designed to help empower adolescents with greater emotional resilience and self-compassion for dealing with the symptoms of internalising problems (e.g., depression, anxiety) and greater self-control over their externalising behaviours (e.g., hostility, peer violence, hyperactivity). Research examining the potential of neurophysiological SEL interventions on adolescents' issues is limited, and HeartMath-specific intervention research has historically focused on implementation with specific (non-universal) subgroups of youth (Kemeny et al., 2022; Lutz, 2014), often for test-taking anxiety (Bradley et al., 2007, 2010). Emotional resilience plays a role in protecting against internalising problems (Dray et al., 2017) and emotional self-regulation plays a role in externalising behaviour (Stieben et al., 2007). The SBWH programming may help bridge the gap by building youth resiliency both to protect them from internalising behaviours and symptoms (e.g., depression, anxiety, suicidal ideation) and to reduce their violence-related behaviour (e.g., reducing their hostility and peer violence perpetration/victimisation).

While youth resilience interventions expanded in recent years, few explored the importance of building self-compassion, which appears to protect adolescents against aggression (Barry et al., 2015), depression (Marsh et al., 2018; Neff & McGehee, 2010), anxiety (Marsh et al., 2018; Neff & McGehee, 2010), and suicidal ideation (Per et al., 2022). Further, it has become increasingly important to account for factors that may help explain observed intervention effects. For example, attachment (peer attachment, mother attachment, and father attachment) may play a central role in youth's experiences related to resilience, self-compassion, internalising behaviours (e.g., anxiety, depression, suicidal ideation) (Breinholst et al., 2015; Gorrese, 2016), hostility (Muris et al., 2004), and peer violence exposure (Kim et al., 2023). Other factors worth examining are youths' exposure to adverse childhood experiences (ACEs) (Elmore & Crouch, 2020; Morgan et al., 2022) (e.g., emotional abuse, physical abuse, unstable home situation, neglect) and sex differences (Swahn et al., 2008).

Goal of the study

We report on an experimental pilot evaluation of the SBWH intervention among public school students in ninth grade in southeast Texas to evaluate the intervention's impact on youth resiliency,

self-compassion, peer violence exposure (perpetration and victimisation), internalising behaviours (depression, anxiety, suicidal ideation), and hyperactivity. Specifically, our hypothesis was that — controlling for baseline (T1) outcome scores, attachment (peer, mother, father), and ACEs exposure — intervention participants would experience significant improvements on selected study outcomes at follow-up (T2) compared to participants in the comparison condition.

Method

Design

Working in close collaboration with the HeartMath Institute (HMI) and the University of Texas Medical Branch at Galveston (UTMB), we used a quasi-experimental design to investigate the efficacy of a universal resilience intervention for promoting youth resiliency and violence prevention among youth. HeartMath Institute staff trained school district educators to teach the SBWH curriculum to students.

The participating Texas public school district has a predominantly Hispanic (74%) student population. Total enrolment in the 2021–2022 school year exceeded 60 000 students, of whom 89.9% were economically disadvantaged. In participating schools, the ninth grade class is closer to 72% Hispanic or Latino of any race and about 74% of ninth grade students reported receiving free or reduced lunch.

While the initial design of the study called for randomisation of the intervention at the school level, the obstacles presented by COVID-19 pandemic conditions restricted the study to a smaller district and thus fewer schools. The SEL director, working with school principals, determined that purposeful selection of teachers for the SBWH condition was the feasible approach given the stressors at that time. The principals of each of the nine schools identified the teachers to be trained to deliver the SBWH intervention or to serve as comparison teachers. All teacher participation in the SBWH training to deliver the curriculum to SBWH intervention classrooms was voluntary. Intervention teachers predominantly taught health or physical education. Comparison teachers were typically from another core discipline; thus, the comparison condition was not an active control condition, but rather a no-intervention condition. There were also two instances in which an intervention teacher opted not to implement the intervention; as those teachers' students had completed the baseline survey, we moved those responses to the comparison condition. We employed propensity score matching (elaborated on later) to reduce the impact of this limitation.

In total, 14 teachers (42 classrooms) taught the SBWH intervention, and 16 teachers (37 classrooms) served as the comparison settings. For protection of human participants, if any respondents indicated potential for self-harm or alleged, probable, or known abuse, the data collection staff were instructed to notify the project lead to contact the appropriate authorities. Student identity was kept confidential using student identifiers and following the protocol of the approved certificate of confidentiality. The research organisation's institutional review board approved all study procedures (Protocol #21-04-240).

Intervention

The HeartMath Institute conducted hybrid (in-person and virtual instruction) professional development trainings in July and August 2021 for teachers slated to deliver the SBWH curriculum. Given different school and classroom schedules, teacher illnesses, and staff turnover at the beginning of the year, participating teachers began implementing the SBWH curriculum at various points in September and October 2021.

The field research team collaborated closely with teachers to obtain parental consent and student assent for study participation and to conduct the baseline student survey before SBWH implementation. Following the initial SBWH training, HeartMath Institute instructors provided additional training and coaching for teachers throughout the semester via virtual meetings and two in-person site visits to the school district. Program implementation varied significantly across schools due to the complications of returning to in-person settings after COVID-19 school closures, technology difficulties, and different classroom sizes and settings. Some teachers taught the SBWH

curriculum in a combined health and physical education class in the gymnasium (i.e., with over 75 students simultaneously), while others leveraged traditional classroom settings. Implementation fidelity during the study period varied across classrooms. However, the curriculum was designed to convey the same basic content through different approaches, such that all learners have multiple opportunities to absorb the content. Thus, while a quarter of the instructors did not directly deliver the units as directed, three-quarters of the instructors engaged the students in at least some of the SBWH content.

All instructors were themselves trained in the content and supported through practice sessions and ongoing coaching from a HeartMath Institute master teacher. Teachers were provided with curriculum maps with instructions for weekly units as well as weekly suggestions for discussion prompts to deepen learning and connection to content. Educators were encouraged to attend their individual coaching sessions and access on-demand support with the HeartMath Institute master teacher. A culminating two-week "Coherence Challenge" provided all treatment teachers and students the opportunity to engage daily at various time options with synchronous instruction and HM techniques led by the HeartMath Institute master teacher.

The SBWH program implementation was designed to be delivered weekly for a single class period lasting approximately 45 to 55 minutes. The program follows a structured four-step delivery process (HeartMath Institute, 2021). First, it begins with a Video Introduction and Presentation, where students are provided with a brief overview of the unit's content and introduced to key vocabulary. The students then watch a unit-specific video produced by the HeartMath Institute. After viewing the video, instructors guide students through various support activities, including group discussions, individual or collaborative exercises, review questions, vocabulary discussions, and participation in movement-based or game-based activities. Second, the Review, Discuss, and Practice step allows students to consolidate their understanding through review sessions facilitated by instructors. These sessions encourage active engagement, group discussions, pair-shares, and individual activities aimed at deepening comprehension and skill acquisition. Third, students are given Action Assignments designed to reinforce the unit's concepts and practices through practical application. These assignments may involve conducting interviews, creating narratives, skits, multimedia storyboards, conducting internet research, or creating music. Lastly, the program includes Learning-Based Scenarios available on the SBWH website for units 2 through 8. These animated scenarios simulate everyday situations, allowing students to apply and reinforce key concepts introduced in the units (HeartMath Institute, 2021). The eight units of SBWH are described in Table 1.

Table 1: Smart Brain Wise Heart program overview

Unit	Description
1. Let's Get Started	This unit orients participants to the main goals, as well as familiarizing them with the concepts of feeling "in sync" vs. "out of sync."
2. In Sync/Out of Sync	This unit introduces youth to the differences between the 'reactive' brain (cortical inhibition) and the 'thinking brain' (cortical facilitation) and why staying calm helps them work better.
3. Inner Weather	This unit explains the functions of the amygdala and helps youth identify how emotions affect behaviour and decision-making.
4. Two Tools	This unit introduces two techniques, heart-focused breathing and quick coherence, used to engage psychophysiological coherence.
5. Prep and Reset	This unit teaches youth how to effectively use quick coherence to prep for future stressful events and heart-focused breathing to reset after a stress reaction.
6. People Relationships	This unit explains the benefits of developing people and communication skills.
7. Decision-Making	This unit helps participants identify how being 'in sync' can improve decision-making.
8. Heart-Brain Fitness for Learning	This unit explains the thalamus's functioning and helps youth understand why focusing skills are important.

Procedures

Intervention participants were assessed at baseline (T1) from 20 September to 15October, 2021, before delivering the SBWH curriculum. Comparison participants were assessed at baseline from 3 November to 13 December, 2021. The time difference in baseline collection was due to scheduling limitations given school district management of COVID-19 challenges. Follow-up assessments for both intervention and comparison participants were conducted late March through June 2022. Baseline (T1) and follow-up (T2) surveys were taken via computer or tablet during regular school hours. The UTMB research team invigilated and supervised survey taking, including addressing any student or staff questions. The research team selected study measures based on prior research experience and the literature examining these outcomes among adolescents.

Participants

Study participants were ninth grade students in health classes who provided personal assent and received active parental permission. Parents and youth were informed that the project aimed to evaluate a classroom program called HeartMath, designed to build resiliency. During the 2021 Fall semester (August to December), there were 1 231 students in intervention classrooms. Of these intervention classroom students, 520 students (42.2%) provided parental consent and child assent at baseline to participate in the evaluation of the intervention.

With a group of 403 students drawn from comparison classrooms, there were 918 student participants enrolled in the study during the Fall 2021 semester. After data cleaning — removing surveys without enough data to be salvageable, participants with suspicious answer patterns, or participants who completed the entire survey in less than eight minutes (more than 20 items per minute average) — the final Fall 2021 sample included 859 participants (intervention $n = 520$; comparison $n = 339$). Missing data analyses for the Fall 2021 sample indicated slightly more male participants (53.4%; $n = 31$) were dropped than female students (41.3%; $n = 25$) or students of another gender identity (1.7%; $n = 1$), and more of the Fall 2021 participants who were removed from the sample had self-reported higher grades (A or B grades) (71.9%; $n = 41$) than lower grades (C, D, or F grades) (28.1%; $n = 16$). Three dropped participants did not report gender nor self-reported academic grades in the Fall 2021 survey.

At follow-up, 734 student participants initiated the survey (486 intervention, 248 comparison). After following the same data cleaning protocol implemented with the Fall 2021 sample, the final Spring 2022 sample included 673 participants (intervention $n = 411$; comparison $n = 262$). Missing data analyses for the Spring 2022 sample indicated most dropped participants in the Spring 2022 sample identified as female (70.5%; $n = 43$) compared to male (23.0%; $n = 14$), or other gender identity (6.6%; $n = 4$); and more follow-up participants dropped reported higher grades (As and Bs) (86.9%; $n = 53$) than lower grades (Cs, Ds, or Fs) (13.1%; $n = 8$).

Measures

Outcome Variables

Resilience

We measured resilience via the 14-item Resilience Scale (RS-14: Wagnild, 2009). The RS-14 is a set of 14 questions on a five-point scale ranging from 1 = strongly disagree, to 5 = strongly agree. The items asked students about their perceived ability to manage hard times, persevere through challenges, and find enjoyment in life despite difficulties ($\alpha = 0.89$).

Self-compassion

We used 17 items from the Self-Compassion Scale-Long form (SSCS-L: Neff et al., 2021), which were measured on a five-point scale ranging from 1 = almost never, to 5 = almost always. This scale gauged students' reports of being kind to themselves when they are having a hard time and whether they keep the perspective that all people make mistakes ($\alpha = 0.83$).

Hostility

We used six items from the Brief Symptom Inventory (BSI: Derogatis & Melisaratos, 1983) to measure hostility and asked students to report on a four-point scale ranging from 1 = never, to 4 = most of the time. Items enquired about how often they feel annoyed or irritated, have temper outbursts, have urges to harm someone, have urges to break things, get into arguments, and shout or throw things ($\alpha = 0.85$).

Suicidal ideation

We measured suicidality with two items adapted from the Youth Risk Behaviour Surveillance (YRBS: Kann et al., 2018) and asked students whether they have ever seriously thought about suicide in the past six months and whether they have ever planned to attempt suicide in the past six months (yes/no). We averaged the two items ($\alpha = 0.70$) to scores ranging from 0 to 1, with "0" representing no suicidal ideation experiences, "0.5" representing either experiencing suicidal ideation or planning, and "1" representing both experiencing ideation and making a plan.

Peer violence victimisation and perpetration

We used 16 items from the Olweus Bully/Victim Questionnaire (Solberg & Olweus, 2003) to examine peer violence victimisation (8 items) and perpetration (8 items). Specifically, students responded on a five-point scale ranging from 1 = never, to 5 = often. Items asked whether they had ever been involved in different acts of physical violence, bullying, or harassment with a peer. Coefficient alphas were 0.84 and 0.87 for victimisation and perpetration, respectively.

Depression

We measured depression with 10 items from the Center of Epidemiological Studies Depression Scale 10-item scale (CESD-10: Andresen et al., 1994), in which participants are asked how often they experienced depressive symptoms over the past seven days (with 1 = less than one day, to 4 = 5-7 days; $\alpha = 0.77$).

Anxiety

We used the Screen for Anxiety Related Disorders (SCARED) scale (Birmaher et al., 1997). The scale is a set of nine items on a three-point scale (ranging from 1 = not true or hardly ever true, to 3 = very true or often true). Specifically, we asked students how often they experience nervousness and worries about current activities and future events ($\alpha = 0.90$).

Hyperactivity

We used four items from the Strengths and Difficulties Questionnaire (Goodman, 1999) to capture students' hyperactivity, an important aspect of social-emotional learning. The four items were measured on a five-point scale ranging from 1 = never, to 5 = always. The items measured students' reports of sitting still, starting things and being able to finish them, doing things without thinking, and using self-control to stay out of trouble ($\alpha = 0.75$).

Covariate measures

Six constructs were measured at baseline as covariates of positive outcomes along with the intervention. Students shared their ages in one of four categories (≤12, 13, 14, and ≥15 years old), which were collapsed to "14 or younger (0)" and "15 or older (1)," reflecting the common age distribution of these ninth-grade students. Students were asked to self-report their grades from their last report card or progress report from an A to an F average. Academic achievement was dichotomised to "A or B average (1)" and "C, D, or F average (0)" to accommodate the distribution. Gender was reported as one of three options: female (1), male (2), or another gender identity (3). However, the low proportion of participants ($n = 14$) self-identifying as another gender identity precluded their inclusion in the final analyses.

Adverse Childhood Experiences

We used ten items adapted from the Adverse Childhood Experiences (ACE) scale (Felitti et al., 1998) to assess adverse childhood experiences on a yes/no basis, which included any life experiences of physical/emotional abuse, sexual abuse, neglect, and unstable home environments. Based on previous adolescent research (Duke, 2020; Jimenez et al., 2016), we coded ACEs as a dichotomous measure of whether students had any ACEs exposure versus no ACEs exposure ($\alpha = 0.71$). Sensitivity analyses examining ACEs with a cutoff of four (Hughes et al., 2017; Wade et al., 2016) did not change the results.

Peer attachment

We used four items from the Multidimensional Scale of Perceived Social Support (MSPSS: Zimet et al., 1988) to capture students' attachment to their peers on a true/not true scale. We asked whether students could count on their friends when things go wrong, share good and bad times with them, talk about their problems with them, and feel their friends try to help them. These four items were averaged to create a peer attachment scale score ranging from 0 to 1 ($\alpha = 0.83$).

Parent attachment

We used four items from Gage and colleagues' (2005) work to measure students' attachment to their mother and their father by asking students how easy it was to talk to their mother and father about things that bother them and how close they felt to their mother and father (on a four-point scale ranging from 1 = no relationship, to 4 = very good/close). We averaged the two items asking about relationships with the student's mother and father to create separate scales for mother attachment ($\alpha = 0.80$) and father attachment ($\alpha = 0.85$).

Propensity score matching measures

We collected additional measures at baseline that we used for propensity score matching (methods elaborated below). We collected participants' self-reported sleep quality (number of hours slept), which we dichotomised (1 = seven hours or fewer, vs 2 = eight hours or more). We also matched participants based on the school they attended because many factors we could not account for otherwise (i.e., socioeconomic status, race, ethnicity, school quality) vary at the school level.

Data analysis

We conducted all analyses using SPSS 24.0. To ensure that participants in the intervention and comparison conditions did not differ on scores for outcome variables at baseline, we conducted baseline comparisons using *t*-tests. The outcomes of interest included participants' self-reported scores at follow-up for (a) resilience, (b) self-compassion, (c) hostility, (d) suicidal ideation, (e) peer violence victimisation, (f) peer violence perpetration, (g) depression, (h) anxiety, and (i) hyperactivity. Our hypothesis was tested using a series of one-way ANCOVAs for each outcome variable with baseline score, gender, peer attachment, mother attachment, father attachment, and ACEs exposure entered as covariates. We conducted individual one-way ANCOVAs to control for participants' baseline scores to match baseline score covariates with the outcome variable of interest for each model. For example, analyses examining differences in resilience at follow-up could be entered with participants' baseline scores for resilience at baseline as a covariate, resulting in a more conservative test of the impact of the intervention. We used estimated marginal means (adjusted for covariates) for post hoc analyses. Analyses testing our hypothesis examined the main effects between youth in the intervention and comparison conditions. Post-hoc analyses examined differences moderated by the interaction between condition and academic achievement.

Propensity score matching

We matched participants across conditions (intervention vs comparison) on age, gender, ACEs history, school, and baseline measurements of several psychosocial variables expected to be affected by the intervention (i.e., resilience, self-compassion, depression). After evaluating various matching methods, balance was achieved using optimal pair matching, a variant of

nearest-neighbour matching whereby cases are matched one-to-one with their most optimal match (rather than the first acceptable match) (Rosenbaum, 1989; Stuart, 2010). We used preferential within-cluster matching based on the school participants were attending such that the propensity matching model first tried to find a match within the same school, and if it did not find one, it looked for a match across schools (Arpino & Cannas, 2016). The balance results can be found in Appendix A.

The final sample ($n = 462$) represents matched students (matching process elaborated on in the Data Analysis section) who fully completed both Fall 2021 and Spring 2022 surveys, split evenly across conditions: intervention ($n = 231$) and comparison ($n = 231$). We attempted propensity score matching using 2:1 and 3:1 proportions, but those matched samples indicated less balance across groups, so we used 1:1 matching for the final analytic sample. For the final matched sample, most participants identified as female ($n = 279$; 60.3%), reported higher academic achievement ($n = 379$; 81.0%) and had previous ACEs exposure ($n = 301$, 64.3%). A description of the participant sample can be found in Table 2.

Table 2. Descriptives of full participants using propensity score matching by experimental condition

Variable	Total (*N* = 468)	Experimental condition			
		Intervention male (*n* = 100)	Intervention female (*n* = 134)	Comparison male (*n* = 89)	Comparison female (*n* = 145)
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Age					
≤14	238 (50.9)	50 (50.0)	76 (56.7)	41 (46.1)	71 (49.0)
≥15	230 (49.1)	50 (50.0)	58 (43.3)	48 (53.9)	74 (51.0)
Academic achievement					
A or B average	379 (81.0)	80 (80.0)	112 (83.6)	70 (78.7)	117 (80.7)
C, D, or F average	89 (19.0)	20 (20.0)	22 (16.4)	19 (21.3)	28 (19.3)
ACEs					
No exposure	167 (35.7)	37 (37.0)	47 (35.1)	42 (47.2)	41 (28.3)
Any exposure	301 (64.3)	63 (63.0)	87 (64.9)	47 (52.8)	104 (71.7)
Matched variables	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)
Peer attachment	0.84 (0.30)	0.85 (0.30)	0.82 (0.32)	0.85 (0.29)	0.83 (0.30)
Mother attachment	3.00 (0.80)	2.96 (0.84)	2.94 (0.79)	3.15 (0.77)	2.98 (0.80)
Father attachment	2.50 (0.95)	2.54 (0.96)	2.40 (0.92)	2.78 (0.95)	2.40 (0.94)
PV victimisation	1.39 (0.57)	1.34 (0.47)	1.40 (0.54)	1.40 (0.55)	1.43 (0.66)
PV perpetration	1.15 (0.40)	1.17 (0.40)	1.12 (0.35)	1.18 (0.33)	1.15 (0.48)
Suicidal ideation	0.12 (0.29)	0.08 (0.23)	0.13 (0.30)	0.08 (0.24)	0.17 (0.32)
Resiliency	3.68 (0.67)	3.79 (0.67)	3.60 (0.63)	3.74 (0.72)	3.65 (0.67)
Hostility	1.85 (0.66)	1.74 (0.60)	1.92 (0.70)	1.68 (0.57)	1.97 (0.68)
Self-compassion	3.09 (0.61)	3.03 (0.71)	3.08 (0.47)	2.98 (0.73)	3.20 (0.55)
Depression	2.00 (0.64)	1.95 (0.68)	2.05 (0.59)	1.93 (0.67)	2.03 (0.62)
Anxiety	1.98 (0.56)	1.84 (0.56)	2.08 (0.54)	1.77 (0.54)	2.10 (0.55)
Hyperactivity	2.53 (0.95)	2.54 (0.86)	2.53 (0.98)	2.35 (0.96)	2.64 (0.98)

PV = peer violence; ACEs = adverse childhood experiences

Total female participants *n* = 279 (60.4%). Total male participants *n* = 183 (39.6%)

Mother attachment, father attachment, resiliency, self-compassion, peer violence victimisation, peer violence perpetration and hyperactivity measured on a 5-point scale; Hostility and depression measured on a 4-point scale; Anxiety measured on a 3-point scale; Suicidal ideation and peer attachment measured on a 0 (no) to 1 (yes) scale; Higher academic achievement = 1; lower academic achievement = 0

Results

Baseline comparisons

No significant differences emerged between participants by condition at baseline on any variables except for self-compassion (comparison mean = 3.12, SD = 0.64; intervention mean = 3.01, SD = 0.58), mother attachment (comparison mean = 3.03, SD = 0.83; intervention mean = 2.89, SD = 0.87), and father attachment (comparison mean = 2.58, SD = 0.99; intervention mean = 2.43, SD = 1.00). Across all three variables, participants in the comparison condition scored significantly higher than participants exposed to the intervention; thus, we controlled for baseline scores in all analyses.

Initial descriptive and correlation analysis

As shown in Table 3, hostility and suicidal ideation were significantly correlated with all other variables at baseline. Resilience was significantly correlated with all variables except participants' self-reported grades. Participants' reported father attachment was significantly associated with all variables except self-compassion. Peer violence victimisation was significantly associated with all other variables except mother attachment. Higher grades were positively associated with father attachment and negatively associated with hostility, suicidal ideation, peer violence victimisation, peer violence perpetration, and hyperactivity.

Main effects of the SBWH intervention on outcomes

As seen in Table 4, after controlling for participants' baseline scores for the outcome variable and covariates, omnibus tests indicated no main effects of condition on resilience ($F(1, 457) = 1.57$, $p = 0.21$), self-compassion ($F(1, 455) = 1.86$, $p = 0.17$), hostility ($F(1, 459) = 0.04$, $p = 0.85$), suicidal ideation ($F(1, 460) = 0.70$, $p = 0.40$), peer violence victimisation ($F(1, 460) = 1.51$, $p = 0.22$), peer violence perpetration ($F(1, 455) = 0.54$, $p = 0.46$), depression ($F(1, 451) = 0.24$, $p = 0.63$), anxiety ($F(1, 458) = 0.09$, $p = 0.76$), or hyperactivity ($F(1, 458) = 0.44$, $p = 0.51$). Our hypothesis was not supported.

Post-hoc observation: effects of the SBWH intervention on students with lower academic achievement

While our main hypothesis was not supported, post hoc analyses indicated that the SBWH intervention may have had made a difference for lower academic achieving youth. As indicated in Table 5, after controlling for participants' T1 scores for the outcome variable and covariates, omnibus tests indicated significant differences among students with lower academic achievement in condition on (a) resilience ($F(3, 455) = 4.32$, $p = 0.005$, $\eta^2 = 0.03$). The least significant difference post-hoc comparisons of adjusted means suggested significant differences based on condition assignment among students with lower academic achievement for resilience. The omnibus tests did not indicate significant differences across students grouped by self-reported grades for (b) self-compassion ($F(3, 453) = 1.79$, $p = 0.15$, $\eta^2 = 0.01$) or (g) depression ($F(3, 449) = 1.88$, $p = 0.13$, $\eta^2 = 0.01$). However, as seen in Table 5, post-hoc comparisons of adjusted means suggested significant differences attributable to the intervention among students with lower academic achievement for self-compassion (intervention mean = 3.11, SD = 0.52; comparison mean = 2.89, SD = 0.52; $p = 0.05$) and depression (intervention mean = 1.91, SD = 0.53; comparison mean = 2.17, SD = 0.54; $p = 0.03$).

Neither omnibus tests nor post-hoc comparisons of adjusted means suggested any significant differences among lower achieving students for (c) hostility ($F(3, 457) = 0.32$, $p = 0.81$), (d) suicidal ideation ($F(3, 458) = 0.46$, $p = 0.71$), (e) peer violence victimisation ($F(3, 458) = 0.53$, $p = 0.66$), (f) peer violence perpetration ($F(3, 453) = 0.27$, $p = 0.85$), (h) anxiety, ($F(3, 456) = 0.50$, $p = 0.69$), and (i) hyperactivity (SDQ) ($F(3, 456) = 1.58$, $p = 0.19$). Our second hypothesis was partially supported.

Table 3. Zero-order correlations between variables (N = 462)

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Academic achievement	1	−0.043	−0.058	0.004	**0.127****	0.060	0.066	**−0.135****	**−0.137****	**−0.133****	**−0.114***	−0.031	0.047	**−0.093***
2. ACEs	−0.043	1	**−0.161****	**−0.275****	**−0.320****	**−0.154****	0.045	**0.218****	**0.256****	**0.163****	0.057	**0.183****	**0.195****	**0.218****
3. Peer attachment	−0.058	**−0.161****	1	**0.108***	**0.134****	**0.100***	−0.087	**−0.136****	**−0.183****	**−0.205****	−0.086	**−0.126****	**−0.149****	−0.074
4. Mother attachment	0.004	**−0.275****	**0.108***	1	**0.339****	**0.278****	−0.046	**−0.252****	**−0.267****	−0.075	−0.072	**−0.206****	**−0.180****	**−0.195****
5. Father attachment	**0.127****	**−0.320****	**0.134****	**0.339****	1	**0.228****	0.001	**−0.272****	**−0.279****	**−0.195****	**−0.123****	**−0.253****	**−0.245****	**−0.240****
6. Resilience	0.060	**−0.154****	**0.100***	**0.278****	**0.228****	1	**0.278****	**−0.096***	**−0.207****	**−0.130****	**−0.124****	**−0.196****	**−0.223****	**−0.225****
7. Self-compassion	0.066	0.045	−0.087	−0.046	0.001	**0.278****	1	**0.204****	**0.099***	**0.168****	0.064	**0.138****	**0.322****	**0.121****
8. Hostility	**−0.135****	**0.218****	**−0.136****	**−0.252****	**−0.272****	**−0.096***	**0.204****	1	**0.307****	**0.372****	**0.247****	**0.210****	**0.278****	**0.443****
9. Suicidal ideation	**−0.137****	**0.256****	**−0.183****	**−0.267****	**−0.279****	**−0.207****	**0.099***	**0.307****	1	**0.240****	**0.192****	**0.240****	**0.286****	**0.229****
10. PV victimisation	**−0.133****	**0.163****	**−0.205****	−0.075	**−0.195****	**−0.130****	**0.168****	**0.372****	**0.240****	1	**0.610****	**0.184****	**0.230****	**0.241****
11. PV perpetration	**−0.114***	0.057	−0.086	−0.072	**−0.123****	**−0.124****	0.064	**0.247****	**0.192****	**0.610****	1	**0.107***	0.029	**0.176****
12. Depression	−0.031	**0.183****	**−0.126****	**−0.206****	**−0.253****	**−0.196****	**0.138****	**0.210****	**0.240****	**0.184****	**0.107***	1	**0.265****	**0.258****
13. Anxiety	0.047	**0.195****	**−0.149****	**−0.180****	**−0.245****	**−0.223****	**0.322****	**0.278****	**0.286****	**0.230****	0.029	**0.265****	1	**0.413****
14. Hyperactivity	**−0.093***	**0.218****	−0.074	**−0.195****	**−0.240****	**−0.225****	**0.121****	**0.443****	**0.229****	**0.241****	**0.176****	**0.258****	**0.413****	1

PV = peer violence; ACEs = adverse childhood experiences. Mother attachment, father attachment, resiliency, self−compassion, peer violence victimisation, peer violence perpetration and hyperactivity measured on a 5-point scale; Hostility and depression measured on a 4-point scale; Anxiety measured on a 3-point scale; Suicidal ideation and peer attachment measured on a 0 (no) to 1 (yes) scale. Higher academic achievement = 1; lower academic achievement = 0;
*p < 0.05; **p < 0.001

Table 4. Adjusted means and standard deviations across condition

	Intervention n = 234	Comparison n = 234
Resilience	3.75 (0.52)	3.68 (0.53)
Self-compassion	3.08 (0.53)	3.02 (0.53)
Hostility	1.77 (0.47)	1.78 (0.47)
Suicidal ideation	0.11 (0.23)	0.09 (0.23)
PV victimisation	1.34 (0.40)	1.29 (0.40)
PV perpetration	1.12 (0.32)	1.10 (0.32)
Depression	2.00 (0.53)	2.03 (0.53)
Anxiety	2.02 (0.43)	2.01 (0.43)
Hyperactivity	2.50 (0.73)	2.45 (0.73)

Baseline scores, gender, ACEs exposure, peer attachment, mother attachment, and father attachment entered as covariates
PV = peer violence; ACEs = adverse childhood experiences; Mother attachment, father attachment, resiliency, self-compassion, peer violence victimisation, peer violence perpetration and hyperactivity measured on a 5-point scale; Hostility and depression measured on a 4-point scale; Anxiety measured on a 3-point scale; ACEs, suicidal ideation, and peer attachment measured on a 0 (no) to 1 (yes) scale; *p < 0.05 using least significant difference post-hoc comparisons of adjusted means

Table 5: Adjusted means and standard deviations across condition by academic achievement

	Higher academic achievement		Lower academic achievement	
	Intervention *n* = 192	Comparison *n* = 187	Intervention *n* = 42	Comparison *n* = 47
Resilience	3.74 (0.53)	3.74 (0.51)	3.75 (0.50)*	3.46 (0.51)*
Self-Compassion	3.08 (0.51)	3.05 (0.52)	3.11 (0.52)*	2.89 (0.52)*
Hostility	1.76 (0.47)	1.77 (0.46)	1.82 (0.47)	1.82 (0.47)
Suicidal Ideation	0.11 (0.23)	0.09 (0.23)	0.08 (0.23)	0.10 (0.23)
PV Victimisation	1.33 (0.40)	1.29 (0.39)	1.35 (0.40)	1.28 (0.40)
PV Perpetration	1.12 (0.33)	1.10 (0.32)	1.13 (0.32)	1.12 (0.33)
Depression	2.02 (0.53)	1.99 (0.53)	1.91 (0.53)*	2.17 (0.54)*
Anxiety	2.03 (0.43)	2.00 (0.42)	1.97 (0.43)	2.06 (0.43)
Hyperactivity	2.52 (0.73)	2.41 (0.72)	2.41 (0.73)	2.64 (0.74)

Baseline scores, gender, ACEs exposure, peer attachment, mother attachment, and father attachment entered as covariates. Higher academic achievement = As or Bs. Lower academic achievement = Cs, Ds, or Fs. ACEs = adverse childhood experiences. Mother attachment, father attachment, resiliency, self-compassion, peer violence victimisation, peer violence perpetration, and hyperactivity measured on a 5-point scale. Hostility and depression measured on a 4-point scale. Anxiety measured on a 3-point scale. ACEs, suicidal ideation, and peer attachment measured on a 0 (no) to 1 (yes) scale. *$p < 0.05$, using least significant difference post-hoc comparisons of adjusted means

Discussion

As psychological distress among youth continues to increase (Office of the Surgeon General, 2021) and violence exposure remains prevalent (Underwood et al., 2020), the need for efficacious youth resilience interventions becomes increasingly apparent. We report on an experimental pilot evaluation of the Smart Brain Wise Heart (SBWH) SEL intervention, which uses a neurophysiological approach to address youth resiliency, self-compassion, peer violence exposure (perpetration and victimisation), internalising behaviour (depression, anxiety, suicidal ideation), and hyperactivity.

Although we hypothesised a universal impact of the training for ninth grade students, the results of this experimental pilot test did not indicate significant positive changes in targeted outcomes resulting from the SBWH intervention. However, given the preliminary evidence supporting the efficacy of HeartMath SEL resilience interventions among high school students (Bradley et al., 2007, 2010; McCraty et al., 2000b; McLeod & Boyes, 2021), these null findings regarding universal impact may be explained by the unprecedented difficulty of implementing a school-based intervention amid ongoing COVID-19 restrictions. While the intervention techniques were imparted, our implementation partner reported only partial fidelity to the full eight-unit curriculum in some classrooms, with many teachers absent due to illness, leading to a teacher shortage. Many of the students in the intervention condition were being instructed in a large gym with over 75 students in a single class at one time (i.e., in suboptimal implementation conditions). Illustrating the challenges felt by the teachers, the participating school district cancelled Friday classes for three weeks during the Spring 2022 semester (during Spring data collection) to combat teacher burnout due to the omicron COVID-19 variant. While it may indeed be that the SBWH intervention is not an effective intervention for universal adolescent populations, it is impossible to discern at this stage. Future research is needed which replicates this experimental pilot test under more stable school and social conditions to better assess its potential efficacy for ninth grade students.

Our post hoc analyses of the effect of the intervention based on academic achievement indicated an incidental finding that students with lower academic achievement who received the SBWH intervention scored significantly higher for resilience and self-compassion and lower on depressive symptoms than their peers in the comparison condition. This positive finding persisted even after controlling for baseline outcome scores, gender, father attachment, mother attachment, peer attachment, and ACEs exposure. While we do not have the context for these students' academic

difficulties, correlational analyses indicated that lower self-reported academic achievement was also significantly associated with lower father attachment and higher hostility, suicidal ideation, violence exposure (perpetration and victimisation), and hyperactivity. Lower academic achievement is inversely related to resilience (Scales et al., 2006), which is strongly tied to self-compassion levels among youth (Neff & McGehee, 2010). As lower achieving youth are also at elevated risk for depression (Huang, 2015), this finding suggests potential constructive value of the SBWH program for students struggling academically. If the SBWH intervention can serve as a buffer by increasing resilience and self-compassion while reducing depression among this subpopulation — which is likely disproportionately disadvantaged (Rothstein, 2013) — the intervention may have potential implications for the developmental trajectories of high-risk youth. HeartMath's ability to increase self-compassion among lower academic achieving students is promising. Youth who score higher on self-compassion are more likely to implement adaptive coping strategies when confronted with academic failure, thus suggesting self-compassion is highly beneficial in learning contexts (Neff et al., 2005). Self-compassion also appears to help facilitate the learning process by freeing individuals from self-criticism, isolation, and over-identification in the face of failure (Neff et al., 2005). Higher levels of self-compassion among youth are also associated with lower levels of distress (Marsh et al., 2018), reduced violence exposure (perpetration (Morley, 2015) and victimisation (Múzquiz et al., 2023)), and reduced intrapersonal violence (i.e., self-harm, suicidal ideation) (Cleare et al., 2019).

Our findings reinforce that resilience is a vital target outcome in youth interventions. At baseline, emotional resilience was associated with all outcome variables, including increased self-compassion and diminished hostility, suicidal ideation, peer violence (victimisation and perpetration), depression, anxiety, and hyperactivity. This observation is in line with previous youth resilience research (Anderson & Bushman, 2002; Anderson et al., 2022; Dray et al., 2017; Hirschtritt et al., 2015; Kim, 2021; Ng et al., 2012; Resnick et al., 2004; Salami, 2010). Future research may benefit from using structural equation modelling to further explore the relationship between resilience and internalising and externalising disorders among youth to tailor interventions further to maximise emotional resilience's benefits.

One of the more surprising observations was that this SEL intervention utilising a neurophysiological approach did not make a significant difference in hyperactivity. It is possible that implementation issues resulting from COVID-19-disruptions precluded effectiveness. Indeed, many intervention activities involve more hands-on training and the use of electronic equipment, including youth being trained to use self-regulation technology to assess their current neurophysiological status. Teacher illness and shortage negated tech access and hindered these self-regulation trainings.

Despite these challenges, it was notable that the findings suggest that the SBWH intervention may have made a significant difference in hyperactivity among youth experiencing lower academic achievement. Indeed, as hyperactivity and lower academic achievement are often associated (Flores et al., 2022), these students may have been able to utilise other SBWH techniques (i.e., Quick Coherence) to improve their self-regulation skills. Nonetheless, more research is needed to explore the efficacy of the HeartMath techniques as taught through the SBWH curriculum on related outcomes.

Limitations and future recommendations

The limitations of this study are worth noting. Most importantly, the COVID-19 pandemic hampered the fidelity of the intervention, which we suspect severely reduced our ability to assess the efficacy of the SBWH intervention in this context. Although we did not observe any main effects, we strongly encourage researchers to replicate this study to better assess the potential effects of the SBWH curriculum under circumstances supportive of higher fidelity implementation. Another limitation of our study was the limited data on individual characteristics, which were initially intended to be gathered via school district administrative data (missing values precluded the use of these data provided by the District) and through parent data, the collection of which was cancelled in response to the pandemic. The research team prioritised outcome metrics for the baseline and follow-up surveys and relied on the propensity score matches to adjust for assignment to the two

study conditions. Further, baseline data from the comparison group (November–December) was collected about two months after baseline data collection for the treatment group (September-October), introducing some variation in exposure to the new school year, social interactions, as well as time elapsed between the baseline and follow-up. We also failed to capture participants' race and ethnicity or other sociodemographic factors via school administrative data. Adding measures of race, ethnicity, food/housing security, English as a second language, absenteeism, and disciplinary experiences to the student surveys in subsequent research protocols is advised to assess the efficacy of the SBWH intervention or other SEL interventions.

This study is also limited based on design and measurement choices. For example, students may maintain consolidated emotional growth over time whereas other students' skills may decay. Subsequent research would be stronger with a longer-term follow-up to discern the durability of intervention effects. Also, given the school conditions at the time, we conducted propensity score matching to ensure accurate treatment effect estimation (Rosenbaum & Rubin, 1983). In future research, we encourage researchers to pursue randomisation to treatment where possible. Randomisation would also address the potential for student selection effects according to their class assignments. However, ninth grade students in the participating district were required to participate in health and physical education classes as well as their core academic classes, and thus the treatment and comparison samples were drawn from the same underlying population. Moreover, for school-based studies, adapting to scheduling challenges is paramount for sustainable programming. Next, we fielded the original ACEs scale, which excludes measures of bullying, racism, community violence, and other adverse conditions that occur outside the home. We encourage researchers to utilise an ACEs scale accounting for these potential conditions as well in future work (Cronholm et al., 2015). Finally, while we cannot explain the difference based on academic achievement in intervention completion, we hypothesise that it may be explained by competing commitments and different priorities among the higher-performing students.

Conclusion

The findings of our pilot experimental test of the Smart Brain Wise Heart intervention suggest that a neurophysiological approach to SEL may have important implications for reversing adverse trajectories for lower achieving students by significantly improving their emotional resilience, self-compassion, and depressive symptoms during a vital developmental stage. However, it is crucial to note that the Smart Brain Wise Heart skillsets may also support some students with higher academic achievement, who often contend with anxiety and depression due to perfectionism and grade concerns (Endleman et al., 2022). More research is urgently needed under optimal conditions to assess the universal implementation of the program. Nevertheless, these findings provide a promising glimpse into the potential of SBWH programming for empowering youth with emotional skills that will serve them well as they learn to navigate adolescence and adulthood.

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ORCID iDs

Alex Kresovich – https://orcid.org/0000-0001-6467-7991
Kai MacLean – https://orcid.org/0009-0006-2060-7565
Caroline M. Lancaster – https://orcid.org/0000-0003-1162-4807
Elizabeth D. Torres – https://orcid.org/0000-0002-5177-5442
Jeff R. Temple – https://orcid.org/0000-0003-3193-0510
Elizabeth A. Mumford – https://orcid.org/0000-0002-4932-2524

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Appendix A

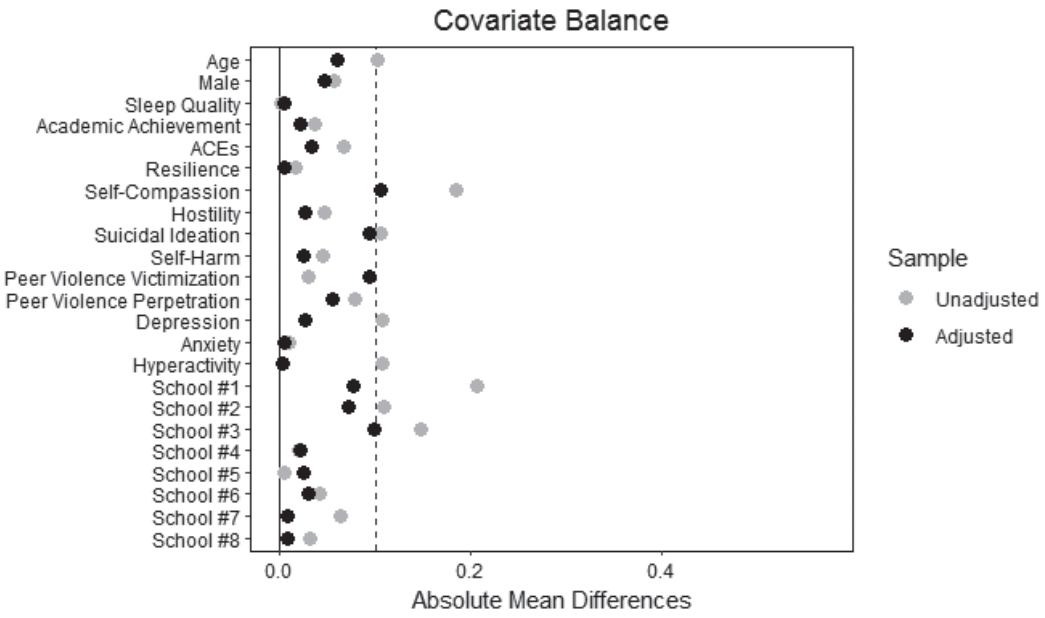

Figure A1: Propensity score matching balance plot