# Respiratory Biofeedback Sensor for Yoga Practice for Youth with Chronic Pain

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## Significance

Chronic pain is a public health concern, affecting 11-38% of youth worldwide [1]. The impact of pediatric chronic pain on children, families, healthcare systems, and societies is immense. Youth with chronic pain experience considerable functional impairment, including poor school attendance, increased anxiety and depression, reduced participation in social and extracurricular activities, and lower quality of life [2,3]. Treatment for pediatric chronic pain is most effective when completed through an interdisciplinary team including a combination of cognitive behavioral therapy, physical and occupational therapy, integrative medicine (biofeedback, yoga, massage), and/or medications. There has been an increase in outpatient interdisciplinary pain treatment programs and several studies have demonstrated the effectiveness of this treatment, with findings suggesting improvements in functioning and reductions in distress for youth with chronic pain [4]. Despite the recommendation for integrative medicine approaches, there has been a lack of research focused on the role of yoga in the treatment of chronic pain.

Yoga is an ancient Indian practice, which means “union”. The National Center for Complementary and Integrative Health classifies yoga as a mind-body medicine modality [5]. The practice of yoga involves breathing and body postures that unite the mind and body and help reduce stress and pain [5]. The American Academy of Pediatrics (AAP) recommends yoga as a safe, effective method to help children cope with emotional, mental, and physical conditions [6]. Yoga helps the person focus on connecting the breath and movement, to be in the moment, and handle problems with greater ease [7].

As a complementary therapy, yoga has shown positive effects in children coping with chronic pain and stress-related conditions [5]. Learning mind-body skills, such as yoga, can help children increase their confidence and resiliency during painful or difficult experiences [5]. Other studies have shown yoga to improve anxiety, concentration, emotional balance, and stress levels [7]. Yoga’s postures and breathing can help balance the physiological (frequency and intensity) and psychological (anxiety) states of pain [8]. Breathing patterns during yoga have health benefits related to strengthening respiratory muscles and control of breathing with slower and deeper breaths [9]. A pilot study showed yoga helped improve quality of life, reduce anxiety, and headache pain in youth, and most participants reported yoga was pleasant and helped with their sleep [10].

Breathing taught during yoga, or pranayama, has been shown to improve pulmonary function in yoga groups compared to no changes in control groups after 12 weeks of yoga practice [11]. In a 2017 national survey, about 1 out of 12 U.S. children practiced yoga in the previous year [6]. When practiced regularly, yoga has been shown to improve balance, increase strength, and relieve tension [6]. The postures and breathing techniques in yoga have been shown to reduce levels of anxiety and decreased heart and breath rates [12]. Yoga is a holistic approach that can help children address not only physical, but also emotional and mental health concerns [12].

Biofeedback is a useful tool in enhancing the mind-body connection. Biofeedback utilizes electronic sensors to measure physiological signals associated with activation of the autonomic and voluntary nervous system, such as breathing rate, heart rate, and temperature. During biofeedback, patients are provided with physiological feedback supporting the evidence of the connection between the mind (e.g., cognitive, and emotional processes) and the body (e.g., physical symptoms) [13]. In turn, the patient is better able to utilize techniques outside of the biofeedback session to navigate activation of the nervous system.

Research using biofeedback for the treatment of chronic pain suggests biofeedback is an efficacious treatment modality for migraine, headaches, irritable bowel syndrome, and back pain [14]. Breath training is highlighted as the primary mechanism surrounding the success of these treatments. Specifically, when examining the pathophysiology of pain, disrupted breathing patterns lead to pH imbalance and metabolism contributing to vasoconstriction and lack of oxygen delivery to organs [14], resulting in pain. Diaphragmatic breathing leads to activation of the parasympathetic nervous system, which can lead to a reduction in pain. Thus, biofeedback plays a crucial role in ensuring that patients are utilizing adequate breathing techniques.

While the role of breathing is highlighted in yoga interventions, to date, there have been no studies specifically quantifying breathing in yoga through an objective measure. Providing the direct feedback to patients during yoga could enhance their understanding of how the poses are helpful and give corrective guidance to ensure

that the breathing is optimal. However, the biofeedback devices in use today are not suitable for assessing breathing during yoga.

We propose the use of a novel, non-invasive, real-time breathing sensor to show the beneficial effects of asana (posture) and pranayama (breathing) in the use of yoga for youth with chronic pain. The sensor consists of two inductive bands worn around the chest and abdomen that differentiate and measure diaphragmatic and chest breathing through Respiratory Inductance Plethysmography (RIP). Readings are wirelessly transmitted to an iPad. Measures include the phase angle between the chest and abdomen; percentage breathing through the ribcage; respiratory rate; and labored breathing index. This sensor takes little time to set up and readings are provided in real time.

Apps related to mindfulness and breathing for mobile phones are ubiquitous. Christmann et al [15] evaluated 62 stress management apps available on Google play and found that strategies employed in them were in line with those found in conventional stress management interventions. Mindfulness and meditation, diaphragmatic breathing, and seeking social support were most frequently used in these Apps. A similar study [16] evaluated 60 stress management apps available on the Apple store and concluded that these apps have the potential to effectively supplement medical care. Of the delivered strategies, the most common were mindfulness and meditation (73%) and diaphragmatic breathing (25%). Chittaro et al [17] considered breathing apps through the Apple store and classified them into either audio or visual instruction format. They found that the visual format was superior. A recent study [18] used the phone placed on the abdomen to record abdominal breathing as biofeedback. It showed that abdominal breathing biofeedback improved instructed breathing, however, this did not carry over to self-reported relaxation due to the increased cognitive load.

Biofeedback video games are an attractive new stress therapy in which players use their physiological signals to implicitly control gameplay. Heart Rate Variability (HRV) biofeedback [19] games account for a large portion of all biofeedback games. Respiratory biofeedback games [20] are another important variant. What sets respiratory biofeedback apart from other variants, including HRV, is that respiration is a parameter that the player can directly control to improve game performance. One study [21] used a modified *Pac-Man* game with breathing feedback and results showed that onetime training with the biofeedback version of the game was not only more effective, but also led to improved performance in a later stressful task, both in terms of lowered breathing and improved test scores, compared to the non-biofeedback version. Similar stress reduction video games with paced breathing biofeedback have been developed and show positive results [22,23]. Although there are many breath pacing apps, none use synchronous breathing between the belly and chest.

The patented *Pneu*RIP sensor is being used in research studies for premature babies, neuromuscular disease, cerebral palsy in four academic hospitals. The app is available in the app store. This proposal would expand the use of the *Pneu*RIP for yogic breathing for youth with chronic pain with software modifications.

## Innovation

*Pneu*RIP sensor

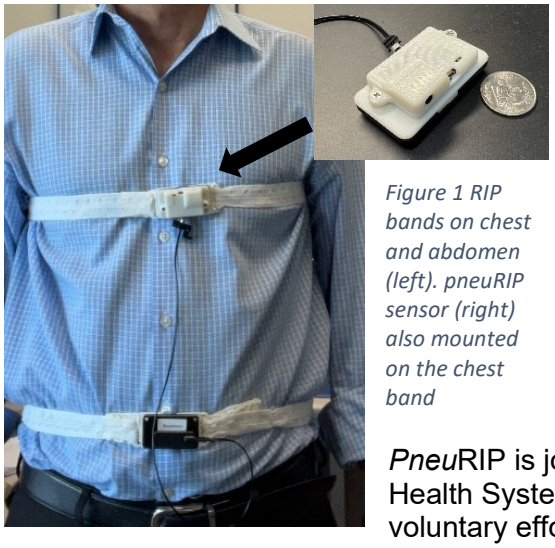

*Figure 1 RIP bands on chest and abdomen (left). pneuRIP sensor (right) also mounted on the chest band*

The *Pneu*RIP (Fig 1, 2) includes a circuit board enclosed in the 5cm x 3cm casing that is connected to the chest band fastened around the rib cage. A wire connects the chest band to the abdominal band. The bands measure change in volume (plethysmography) in the rib cage and abdomen as the person breathes, through changes in inductance. The rib cage and abdominal excursions are measured and transmitted wirelessly to a tablet. The data are then converted to Work of Breathing (WOB) indices and plotted and displayed in real time on the tablet (fig 3). Readings are collected 10 times per second. The information can be emailed to patient medical records, or for post processing. The software that records and displays the breathing data is controlled through an App readily downloaded through the App store. The *Pneu*RIP is jointly developed by Creative Micro Designs and Nemours Children's Health System. It measures WOB parameters non-invasively without requiring voluntary effort by the subject. It has been used as a research tool in monitoring

children with neuromuscular disease, premature babies, cerebral palsy, Morquio syndrome and animal studies [24,25,26,28,29]. Other comparable devices using Respiratory Inductance Plethysmography (RIP) are used in sleep studies [27] but they are much larger and do not provide real-time feedback.

***We will develop a modified version of the PneuRIP sensor to monitor yogic breathing. The <u>innovation</u> of the project is the ability of the sensor to record established measures of breathing during yoga and provide feedback to the user on how they are performing. The salient measurement in the pneuRIP is phase angle between chest and belly breathing. For optimal breathing both these compartments should be moving synchronously. The phase angle can be measured during yoga to indicate efficiency of breathing and with the aid of biofeedback can be optimized. Another variable measured is the percentage ribcage, which is a measure of how much the belly and chest are individually contributing to breathing. Yoga emphasizes deep breathing which would involve both compartments which can be measured and used in a feedback loop to improve breathing.***

*Figure 2 PneuRIP shown with the two bands around the subject and iPad display of data*

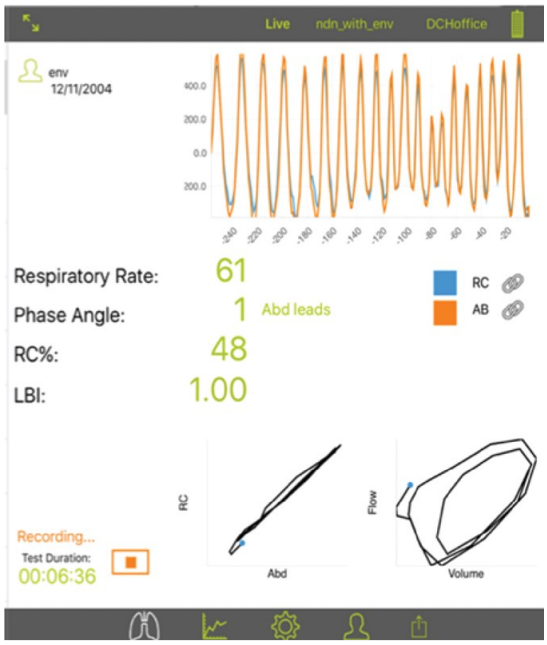


*Figure 3 Respiratory data displayed on iPad in real time*

<u>Diverse Team</u>

The team combines academic and commercial investigators and brings expertise in engineering and clinical domains. Drs. Rahman and Shaffer have a track record of NIH funding and publications in respiratory disease and medical devices and have a combined 48 patents. Ralph Page has been working in industry as an accomplished electrical engineer and was the founder of CMD. Dr. Adam Page is a PhD in Electrical Engineering with specialty in signal processing. Dr Salamon is a pediatric psychologist specializing in pediatric pain management. Christina Russell is a registered nurse, a certified yoga instructor, and a certified healing touch practitioner and the program coordinator for the yoga program at the Nemours Children's Hospital - Delaware.

## Approach

Utilizing biofeedback will create two important changes. First, the yoga therapist would be able to update practice in real time. Objective data on breathing technique would allow correction in the moment so that a patient does not practice suboptimal breathing outside of the sessions and allow the therapist to adapt poses to ensure success. In turn, adequate practice at home could lead to a stronger treatment response. Secondly, the use of the biofeedback monitor would also allow for better introspection into the mind-body connection and improved adherence to practicing the skill.

*Subjects:* We will follow 20 subjects from the Integrated Pain and Wellness Program at Nemours Children's Hospital – Delaware. The program is embedded across multiple departments within the hospital system under the guidance of Dr. Salamon (Behavioral Health Department) and Christina Russell (Integrative Medicine Department). All subjects will be recruited in the latter 6 months of the project. Inclusion criteria: a) youth presenting for an initial evaluation within the Integrated Pain and Wellness Program, b) between 10 and 18 years old, c) prescribed yoga therapy as part of the treatment plan. Exclusion criteria include any medical condition precluding the use of yoga therapy.

The **feasibility** of the modified *pneu*RIP will be tested in this phase I proposal. The goals are to modify the existing *pneu*RIP software in the first 6 months then test it with a small cohort of subjects from the pain program in the second 6-month period. We will test the *pneu*RIP by recording respiratory data before and after individual yoga sessions, and before and after the entire regimen. Half of the subjects will be provided

instructions to breathe deeply and synchronously between belly and chest while their breathing is recorded. The other half will additionally be provided biofeedback while they perform the same therapy.

***Specific aim 1: Development of a Biofeedback App***

The current *pneu*RIP app was developed primarily as a clinical tool to provide real-time monitoring of patient's breathing. The mobile application makes it very easy to quickly connect and provide the clinician with real-time, quantitative metrics. To be a successful tool in yoga therapy, we believe that the feedback mechanism is critical and must align with the Zen tenet of yoga. Rather than providing heavily numerical measurements and plots as the current App is set up to be, the application's interface will provide subtle visual cues to guide the subject. Visualizations of the respiratory process have been shown to both objectively and subjectively (users' preferences and perceived effectiveness) improve the effectiveness of breathing training [17]. Additional studies have shown the utility of using auditory and haptic feedback to help aid the user's breathing [30]. However, for phase I, we will only provide visual feedback on an iPad to keep the interface simple and gauge the efficacy of biofeedback.

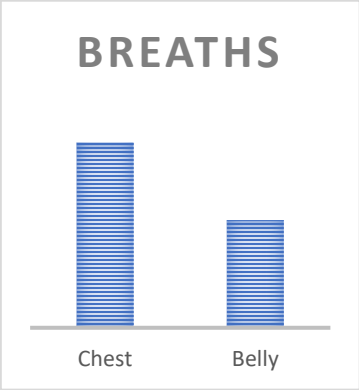


*Figure 4 Biofeedback representing Chest and Belly motions*

The visualizations will be used to represent both the phases of respiration as well as the salient breathing measurements such as phase angle and percentage ribcage. Existing studies and mobile applications typically employ one of two breathing visual techniques [17]. The first common approach utilizes a circle-based visualization that depicts a circle expanding and contracting with the breathing cycle. This is often supplemented with colors or sounds to mark the different phases of breathing: inhalation, holding, and exhalation. In our case to keep the presentation simple we will have two moving bars that correspond to the chest and belly (Fig. 4). In addition to capturing the respiratory phase, the bars will help depict synchronization of the chest and belly as well as their corresponding contribution to breathing. The goal of the participant will be to keep the height of the bars the same as they go up and down. This ensures that the belly and chest are both exerting equally AND that they are working in phase for most efficient breathing. The phase angle and the percentage rib cage as measured from the existing algorithm will be used to calculate the interactive bars. These metrics are computed directly on the pneuRIP hardware and are transmitted wireless to the application via Bluetooth Smart as BLE characteristics. On the front-end, the application will leverage modern web technologies including React framework and D3.js to render and animate the visuals.

***Specific aim 2: Determine the immediate and cumulative impact of biofeedback on breathing by using the pneuRIP by measuring breathing pre- and post- individual, and multiple yoga sessions.***

The **Rationale** for aim 2 is to determine the feasibility and utility of providing biofeedback on belly/chest breathing synchrony to participants in a clinical yoga setting for youth with pain. Subjects will be randomized into two groups: One will receive instruction on correct (synchronous) breathing technique, and the other will receive instruction and biofeedback. Youth enrolled within the Integrated Pain and Wellness Program at Nemours Children's Hospital - Delaware are referred to Integrative Medicine for yoga Therapy. As part of the program, youth are offered eight integrative therapy sessions at 30-60 minutes per session.

**Group with instruction and monitoring**. A group of 10 participants will be randomly selected and instructed to breathe in a synchronous manner utilizing the belly and chest muscles. The plethysmography bands will be attached to their chest and belly prior to the session. Their quiet breathing will be monitored prior to the first session. The protocol is shown in figure 5. They will be instructed by the yoga practitioner on how to synchronize belly and chest while breathing prior to beginning their session. For the initial 5 minutes of their yoga session, they will be asked to breathe synchronously. At the end of the first session, they will again be asked to breathe synchronously for 5 minutes. These breathing intervals will be continuously recorded by the *pneu*RIP.

**Group with instruction and monitoring with biofeedback**. A second group of 10 subjects will be selected and will follow the same protocol as the first group but will get biofeedback on an iPad while they are synchronously breathing.

Respiratory indices will be measured at the aforementioned intervals using the *pneu*RIP, pulse oximeter, and heart rate monitor. Standard measures of pain will be measured before and after the entire yoga regimen.

Each session will begin and end with the individual sitting and breathing normally without manipulation for 5 minutes. This does not include the square breathing technique listed in the protocol. The protocol for an individual session is as follows: Seated crossed legged connecting to breath by utilizing square breathing (inhale 4 seconds, hold 4 seconds,

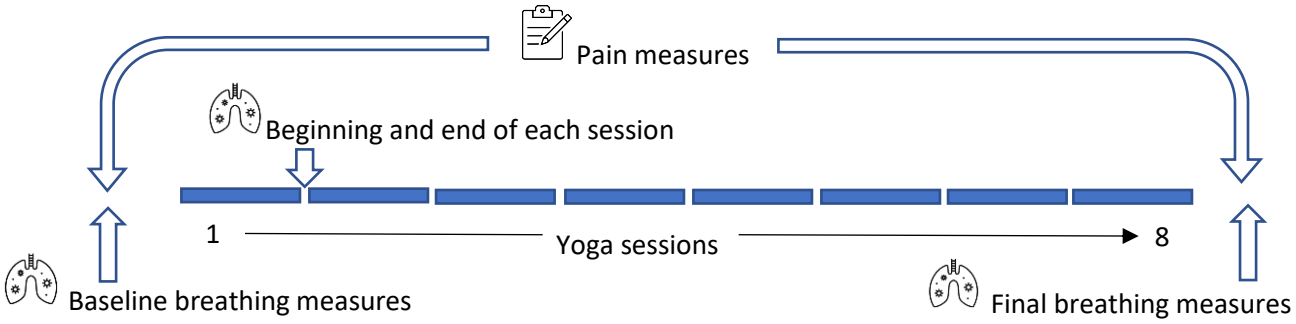


*Figure 5 Data collection timeline*

exhale 4 seconds), seated spinal twist, seated side stretches, table top with cat/cow, thread needle, bird-dog, down dog, mountain side stretches, mountain raising arms overhead and out to side, forward fold, chair, warrior 1, warrior 2, reverse warrior, extended side angle, wide leg standing fold, tree, warrior 3, forward fold, plank, cobra, sphinx, pigeon, bridge, reclining spinal twist, happy baby, reclining butterfly, Seated crossed legged—connecting to breath by utilizing square breathing (inhale 4 seconds, hold 4 seconds, exhale 4 seconds). Instructor reminds individual to breathe while holding postures. Postures that are not flowing into other poses are held for at least one minute.

**Outcome Measurements**

**Respiratory Measures**

- *Phase angle:* This is a measure of the synchronicity between the belly and chest while breathing. Ideally the phase should be 30 degrees or less for efficient breathing.
- *Labored breathing index (LBI):* The LBI is an indication of the additional work of breathing when breathing is asynchronous. Ideally, LBI is 1 when breathing is perfectly synchronous, and this index goes up as breathing gets more asynchronous.
- *Percentage ribcage (%RC):* %RC is a measure of how much effort the chest is putting out relative the belly.
- *Respiratory rate:* Breaths per minute
- *Oxygen saturation and heart rate:* Blood oxygen level and pulse rate, measured by a finger clip-on device.

**Pain Measures**

Demographic information will be assessed through a brief self-report questionnaire regarding the youth's age, ethnicity/race, gender/biological sex, typical pain intensity (rated on a 0-10 numeric rating scale), and pain location(s). Medical diagnoses to be obtained through review of the electronic medical record (EMR).

- The *Chronic Pain Acceptance Questionnaire, Adolescent Version* (CPAQ-A) [31] is a 20-item self-report measure for youth with two subscales: 1) Pain Willingness (i.e., willingness to experience pain without attempting to control, reduce, or avoid it) and 2) Activity Engagement (i.e., participation in valued life activities despite pain). Questions are rated on a 5-point Likert scale from 0 (never true) to 4 (always true). Higher scores indicate greater pain acceptance. Prior research suggests the CPAQ-A has adequate psychometric properties [31,32,33].
- The *PROMIS Pediatric Pain Interference Scale* [34] is an 8-item self-report questionnaire assessing the extent to which pain interferes with functioning (e.g., emotional, academic, physical) over the past 7 days.

Items are rated from 1 (never) to 5 (almost always). Normative data are available, and raw scores are transformed to T-scores. Higher scores indicate greater levels of pain interference.

- *The PROMIS Youth Anxiety Short Form* [35] is an 8-item form derived from the item bank for Pediatric Anxiety developed by the NIMH-sponsored PROMIS. This measure assesses fear (e.g., fearfulness), anxious misery (e.g., worry), and hyperarousal (e.g., nervousness) over the past week. Adolescents and parents/guardians rate how often they experienced feelings in a variety of contexts, including home, school, and social activities on a scale from 0 (*never)* to 4 (*always*). Normative data are available, and raw scores are transformed to T-scores. Higher scores indicate greater levels of anxiety.

Data analysis: Numeric data will be summarized using mean (SD) or median (Interquartile range) as appropriate, and categorical data will be summarized using frequencies and percentages. Baseline and demographic characteristics will be compared using t-test, Mann-Whitney U test or Fisher exact tests as appropriate. A mixed effects repeated measures analysis of variance (ANOVA) will be used to compare the mean changes in breathing phase angle (degrees), labored breathing index (unit), blood oxygen level (%), respiratory rate (unit), pain acceptance scale, PROMIS pediatric pain interference scale, and PROMIS youth anxiety short form over time. Likert scale measures will be used as both numeric and categorical forms, thereby, a generalized mixed effects model will also be used to compare the changes in Likert scale over time. Model assumptions will be checked before analysis. All tests will be two-tailed at the level of significance of 0.05. Statistical software SAS, version 9.4, or R (version 4.05) will be used for the analysis.

Sample size and power: The primary goal is the change in breathing phase angle from baseline to after the yoga therapy regimen. In accordance with data from a previous study [29], the baseline mean (SD) phase angle is 40 (12) degrees, and after 8 weeks of yoga therapy we expect the phase angle to be 15 (9) and 30 (9) in the instructional + biofeedback group, and instructional alone group, respectively. A sample size of 8 subjects in each group can detect the above changes in phase angle with a power more than 80% at the level of the significance of 0.05. Assuming 25% attrition rate a sample size of 20 (10+10) subjects is planned for this study.

### *Potential problems, alternate strategies, benchmarks for success*

Yoga is one of a few other therapies (cognitive behavioral therapy, physical and occupational therapy, massage, and/or medications) participants in this study may simultaneously be receiving. This makes it difficult to determine whether the breathing with biofeedback is the cause of improvement. However, this will be further examined in phase II with a controlled trial with a larger sample size.

Success of this feasibility study will be measured by statistically significant improvement in the standardized measures of pain before and after the yoga therapy regimen as a whole. Improvement in respiratory measures will be recorded after each session and as a cumulative measure. Longer term retention of gains made will not be measured due to time constraints but will be implemented in phase II.

### *Timeline*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
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| Aim 1 Biofeedback App Development | | | | | | | | | | | | |
| Aim 2 Subject Recruitment | | | | | | | | | | | | |
| Clinical Trial | | | | | | | | | | | | |
| Data Analysis | | | | | | | | | | | | |