Calibrating Respiratory Strain Gauges: What the Numbers Mean for Monitoring Respiration

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How can you be sure that a larger abdominal waveform, as compared with a smaller chest waveform, means that a client is breathing more abdominally than thoracically? Could this difference be due to discrepancies in the sensitivity of the sensors? This article describes a procedure for measuring the sensitivity of respiratory strain gauges and provides practical recommendations for accurate measurement and display of the relative expansion and contraction of the chest and abdomen.

Respiration belt sensors placed around the thorax (chest) and abdomen are used to measure increases and decreases in the expansion of the chest and abdomen associated with breathing (Peper, Tylova, Gibney, Harvey, & Combatalade, 2008; Shaffer, 2015). Clinicians record breathing patterns to identify dysfunctional breathing (e.g., shallow thoracic breathing, paradoxical breathing in which the abdomen decreases in diameter and the chest expands during inhalation, gasping, sighing, breath holding, and exclusive abdominal movement). They may also be used to train effortless diaphragmatic breathing in which the predominant expansion during inhalation occurs in the abdomen to restore psychophysiological balance and heart rate variability (Chaitow, Bradley, & Gilbert, 2013; Peper & Tibbits, 1994). Typically, two strain gauges are used to monitor breathing: one around the chest and the other around the abdomen, as shown in Figure 1.

The units of strain gauge lengthening/shortening are relative units. The voltage output of a strain gauge is proportional to the increase in distance between the attachment points of the stretchable rubber tube. The respiration sensor amplifies the signal and is displayed as the respiratory signal in relative units of 0 to 100, called relative units of stretch (RUS) voltages, as shown in Figure 2.

**Strategy to Determine Abdominal or Chest Contribution to Breathing**

The standard deviation of the respiration signal is a convenient measure of the trough-to-peak and peak-to-trough voltages. These trough-to-peak and peak-to-trough measures estimate the relative expansion or constriction of the chest and abdomen during the breathing cycle and, therefore, the relative contributions of each location to respiration. When the ratio of the abdominal and thoracic standard deviations exceeds 1.0, this indicates abdominal dominance, and when it falls below 1.0, it signals thoracic dominance. In Figure 1, the abdominal-thoracic ratio is 0.76 (3.34/4.4), which means that the person’s chest expanded more than the abdomen if the two strain gauges possess equal sensitivity. However, if their sensitivities to stretch differ, this can distort their RUS voltages and render the abdominal-thoracic ratio meaningless.

**Considerations when Interpreting Their Signals**

To accurately measure abdominal-thoracic balance, each sensor signal (RUS voltage) must be displayed with the same visual amplification in the software display. When two signals (e.g., thoracic and abdominal voltages) are on different scales or graphs, the difference in settings for maximum and minimum (max – min) voltage must be calibrated to have the same range for each sensor. This way, relative differences in the waveforms on the screen will reflect actual differences in the signals produced by different amounts of stretch. When the two signals lie on the same axis of a graph, the thoracic band should be a bit tighter than the abdominal band, so that the thoracic signal will appear above the abdominal signal. This should help clients visually differentiate between the two signals and facilitate biofeedback training to achieve greater thoracic-abdominal balance.
Challenges with Respiratory Measurements

Placement
Careful placement of the sensor is required to make sure that you monitor abdominal and thoracic movement. You will need to control movement artifact through instructions, observations, and artfacting, to ensure valid measurements. One external factor that affects the expansion of the abdomen and chest is constrictive clothing, which can act like a corset, such as a tight belt, slimming underwear, constrictive pants, or a very tight bra (MacHose & Peper, 1991).

Sensor Sensitivity Variations
Differences in the sensitivity of the sensors themselves will influence the output per unit of stretch or the RUS voltage. Therefore, careful understanding of a particular sensor’s RUS voltage is necessary to accurately interpret the ratio of thoracic and abdominal signals. This study focuses on analyzing the consistency between respiratory strain gauges and for each strain gauge during repeated measurements, and it suggests a behavioral test to calibrate the strain gauges.

- How much variation is there in the sensitivity (change in RUS voltage) of the respiratory sensors?
- How reliable are repeated measurements with the same sensor?
- How reliable are the relative thoracic and abdominal values using different sensors placed in two locations

Figure 1. Location of thoracic and abdominal respiratory strain gauges.

Figure 2. One-minute recording of respiration in which the subject breathes more thoracically (indicated by the larger amplitude of the black thoracic tracing and the ratio of the abdominal/thoracic standard deviations: 3.34/4.40 = 0.76).
(e.g., chest and abdominal regions) that may not have the same sensitivity because of physical changes in the sensor due to age and/or prior use?

**Procedure**

**Equipment**

Fourteen respiratory sensors regularly used by students in a university biofeedback teaching/laboratory class were selected for the study. All of these sensors were produced by Thought Technology, Ltd. Some of the respiratory strain gauges have been used for many years, and others were relatively new. The manufacturer suggests that the rubber tube not be stretched to greater than approximately double (twice) its initial length.

**Procedure**

One end of the sensor was clamped on a millimeter ruler, and the other end was stretched sequentially in 5-mm increments from 0 to 40 mm, and this measurement was repeated 1 month later, as shown in Figures 3 and 4. At each of these points, the values were recorded with a BioGraph ProComp Infiniti running Infiniti version 6.1 software.

**Results**

Any single strain gauge produced repeatable linear readings when stretched systematically between 0 and 40 mm during two trials, 1 month apart. However, the RUS measurement between strain gauges varied significantly. The relative range for strain gauge measurements for stretching from 0 to 40 mm varied significantly from 16 to 55 units, as shown in Figure 5. To compare the data, the initial zero stretch value was subtracted (offset) from the measurements when systematically stretched. For the offsets, the RUS voltage for unstretched sensors ranged from 4 to 23 RUS voltage ($M = 11.2, SD = 5.8$). One indicator of sensor sensitivity is the slope of the line. The average slope for the sensors was 0.82, ranging from 0.33 to 1.5. The length of the strain gauges' rubber tube varied from 55 to 90 mm.

**Discussion**

When using two sensors, they should have the same sensitivity (slope) when they are stretched. There is a danger of misinterpreting the meaning of the data when two different strain gauges are used at random to measure how much one body area expands or contracts as compared with another. Thus, strain gauges should not be randomly interchanged and should be selected for the same placement with a similar sensitivity (slope) for a given subject consistently over time. One way to ensure the sensors will have similar responses is to measure the length of the rubber tubes to ensure that they are approximately equal.1

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1 Thought Technology Ltd. has informed us that their newest sensor is made with a different process and provides a close match in linearity and range between sensors.
The calibration assessment was limited to a quick systematic measurement of stretch between 0 and 40 mm in 5-mm increments. The procedures required that the experimenter manually held the sensor during the stretch, and minute variations of length (e.g., 5.1 mm as opposed to 5.1 mm) probably occurred. The difference between repeated measures within sensors was mainly due to the error of experimenter measurement.

**Recommendations**
1. Use the same strain gauge for repeated measures and between sessions. The measurements will reliably show changes whether the area more or less expands or constricts.
2. If two strain gauges are used, select those that have a relative similar range (e.g., 3 units per 5 mm) for stretching.
3. Calibrate your own strain gauges against each other using the methodology described above and apply a correction factor to the recording.

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References


Figure 5. Comparison of the sensitivity of respiratory sensors (relative units of stretch/millimeter).

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