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A Guide to Cleaner Skin Temperature Recordings and More Versatile Use of Your Thermistor

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Valid peripheral temperature measurements ensure the integrity of client assessment and biofeedback training. Accurate measurements require understanding of the signal and potential influences on measurement fidelity, and developing bulletproof monitoring procedures. In addition to their use in temperature biofeedback, thermistors can assist heart rate variability biofeedback practice and monitor breathing when a respirometer is not available.

"Cold hands, warm heart" or "She is a warm person" are phrases that reflect beliefs about the interconnection between emotions, body, mind, and spirit. Temperature biofeedback focuses on the literal measurements of body temperature. Most biofeedback techniques take temperature readings from the skin. More specifically, peripheral skin temperature measurements reflect the blood flow through the vessels under the skin. Temperature biofeedback training can be used to help a person regulate body temperature.

Temperature training was originally initiated in the late 1960s by Elmer Green and associates at the Menninger Foundation and was partially derived from yoga and autogenic training (AT) techniques (Green & Green, 1977). Autogenic training techniques related to temperature training use phrases such as "My arms are warm and heavy" to induce a feeling of peripheral warmth and heaviness (Luthe & Schultz, 1969). In addition, autogenic training encourages use of a passive and nonjudgmental attitude. A major goal of autogenic temperature training is to develop an autogenic state that is the opposite of the state triggered by the alarm reaction. Dr. Green and his colleagues adapted these autogenic phrases and combined them with temperature monitoring. Much of their training included encouraging patients to adopt a passive, nonjudgmental attitude.

Edward Taub (1978), another early researcher in peripheral temperature control, explored some of the factors that affect temperature biofeedback recording and training. Dr. Taub observed the importance of the interpersonal dynamics associated with temperature self-regulation. He observed the *person effect*. For example, an experimenter with "an impersonal attitude toward the experimental participants was able to train only 2 of 22 individuals to control their skin temperature while another experimenter, using exactly the same technique, was more informal and friendly, and trained 19 of 21 subjects" (Taub & School, 1978, p. 617). This example illustrates the effects of social interaction on autonomic learning. Conditions that elicit striving, fear, anxiety, and performance anxiety appear to inhibit initial learning of hand warming, whereas conditions that elicit safety, support, caring, and acceptance of others facilitate peripheral hand warming (Peper, Tylova, Gibney, Harvey, & Combatalade, 2008).

Clinicians monitor skin temperature using a *thermistor*, which is a sensor that converts temperature measured from the skin surface into an electrical resistance value. Three important properties of a temperature probe are response time, accuracy, and resolution.

Factors That Can Affect Peripheral Temperature

Four major factors affect the peripheral blood flow that underlies skin temperature (Taub & School, 1978). First, core temperature regulation impacts skin temperature. If a subject's core body temperature decreases while sitting in a cool room, the biological response is peripheral vasoconstriction (blood vessel narrowing) to reduce heat loss. Vasoconstriction cools the skin (Peper et al., 2008). Conversely, sitting in a warm room can trigger vasodilation (blood vessel widening) to remove excess heat. Vasodilation, which is largely mediated by beta-adrenergic agents, warms the skin (Freedman, 1991; see Figure 1).

Second, pharmaceutical agents can cause peripheral vasoconstriction (e.g., caffeine and nicotine) or vasodilation (e.g., alcohol).

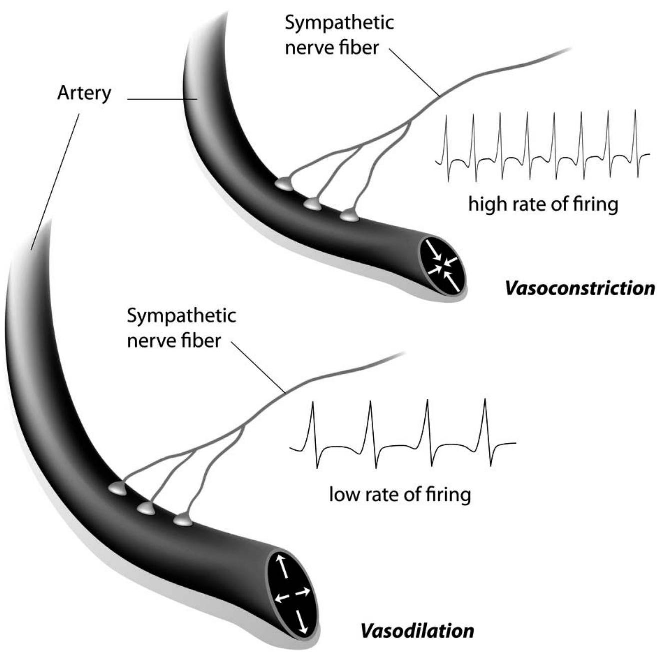

Figure 1. Vasoconstriction and vasodilation.

Third, sympathetic arousal, especially fear, causes peripheral vasoconstriction, while anger will sometimes cause peripheral vasodilation.

Finally, respiration can produce peripheral vasoconstriction or vasodilation. Hyperventilation, which results in low end-tidal CO_2 values (the percentage of CO_2 in exhaled air), usually causes vasoconstriction. In contrast, breathing more slowly than six breaths per minute, which can increase end-tidal CO_2, often produces vasodilation (Lynch & Schuri, 1978).

R. Gevirtz (personal communication, April 7, 2016) has recommended adding inexpensive temperature monitoring to heart rate variability biofeedback (HRVB) practice, since many clients will exhibit hand warming when they breathe at their *resonance frequency* (the rate that most effectively stimulates their cardiovascular system). Conversely, Peper (personal observations, 2016) points out that a decrease in peripheral temperature usually indicates that the person is "trying too hard" to breathe correctly at the resonance frequency and may be unknowingly overbreathing.

Thermal Process of Temperature Recording with a Thermistor

A thermistor does not directly measure skin temperature. It measures its own temperature, which is the result of heating or cooling through thermal conduction/radiation to the skin and the air. For example, if the actual skin temperature is 92°F and the room temperature is 74°F, the side of the thermistor touching the skin is warmed to 92°F. The side covered by tape and exposed to the room radiates heat to the room, thereby slightly cooling the thermistor. Thus, the recorded finger temperature is most likely 90.5°F and depends upon the degree of thermal insulation by the band or tape.

This phenomenon can easily be checked by recording the temperature of the index finger and thumb and then touching the index finger and thumb together. When they touch, the temperature will go up 1° to 2°F. The resultant temperature will be the actual temperature of the finger and thumb as confirmed by thermographic measurements.

Response Time

When providing skin temperature biofeedback, there is normally a noticeable delay between a physiological change and the time the temperature signal starts responding. The hardware contribution to this delay is called the *time constant* of the thermistor. It takes the bit of time to warm up or cool down. A time constant is a period required for the thermistor to reach 63.2% of a final value. You're sitting in a 74°F room. How long should a thermistor with a time constant of 1 second take to register a hand temperature of 92°F? The thermistor will reach 99.8% of your hand temperature in 5 time constants, or 5 seconds. Peper et al. (2008) described a procedure for measuring response time of the thermistor.

The skin's contribution to this delay is more important. It takes time for the skin to warm up or cool down when there is dilation or constriction of cutaneous blood vessels. When comparing skin temperature and blood volume pulse amplitude, there is a greater delay in skin temperature than blood volume pulse responses to a stressor, approximately 30 seconds versus approximately 0.5–3 seconds (see Figure 2).

Temperature can also be measured from a distance using an infrared sensor. Since it is a camera, a passive infrared (pIR) sensor responds more quickly to changes in infrared radiation from blood circulation than a thermistor (see Figure 3). Passive infrared is generally designed to monitor temperature from a wider area than a thermistor. The further a sensor is from its target, the larger is the surface area it records. Since a pIR sensor must be positioned a short distance from the skin, it is a poor choice for temperature training. Also, the pIR signal appears noisier because the infrared camera detects very small changes in the heat radiating from the surface of the skin. The signal must be slightly smoothed (averaged) to reveal longer trends in temperature change.

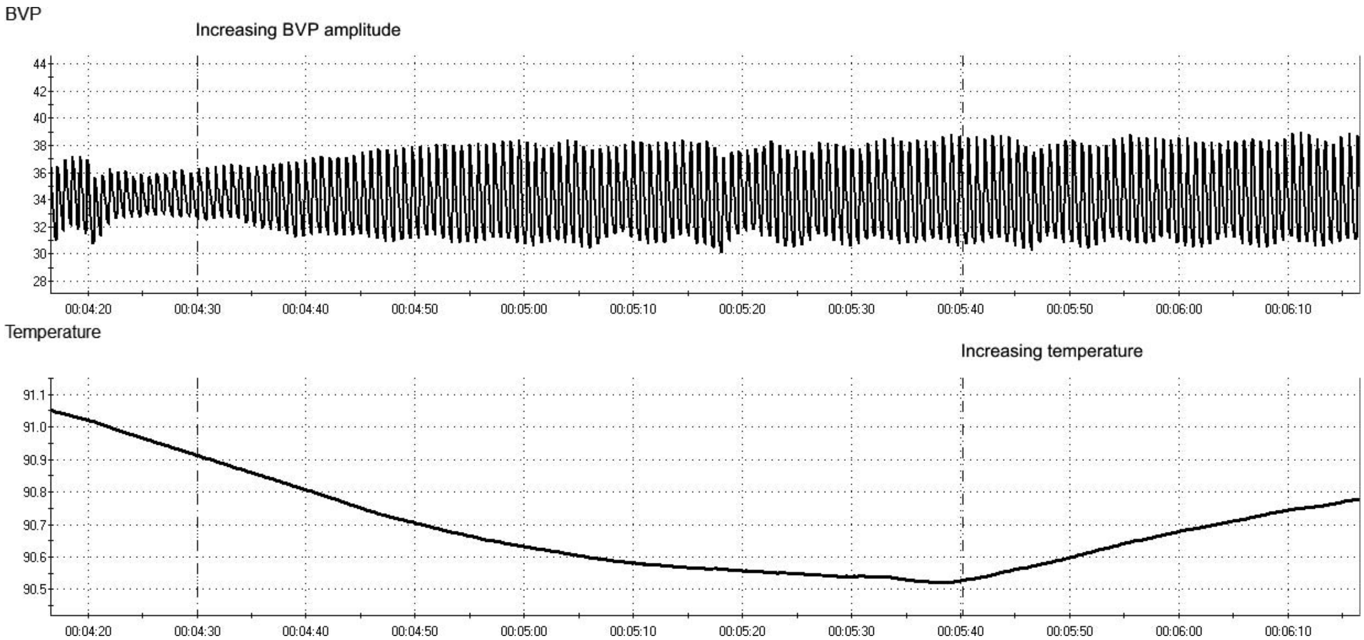

Figure 2. Comparison of photoplethysmograph and thermistor signals.

Since a temperature probe only contributes a few seconds to this lag, response time is not critical. The major advantage of the pIR sensor is that the sensor is not in contact with the tissue; thus, it can be used to monitor temperature of open wounds to facilitate blood flow (Olesen & Peper, 1985).

Accuracy

An absolute accuracy of ±1°F should be adequate for temperature biofeedback training (Peek, 2016). Generally, the immediate detection and display of relative physiological changes is more important to biofeedback training than absolute accuracy. Use a laboratory-grade alcohol or

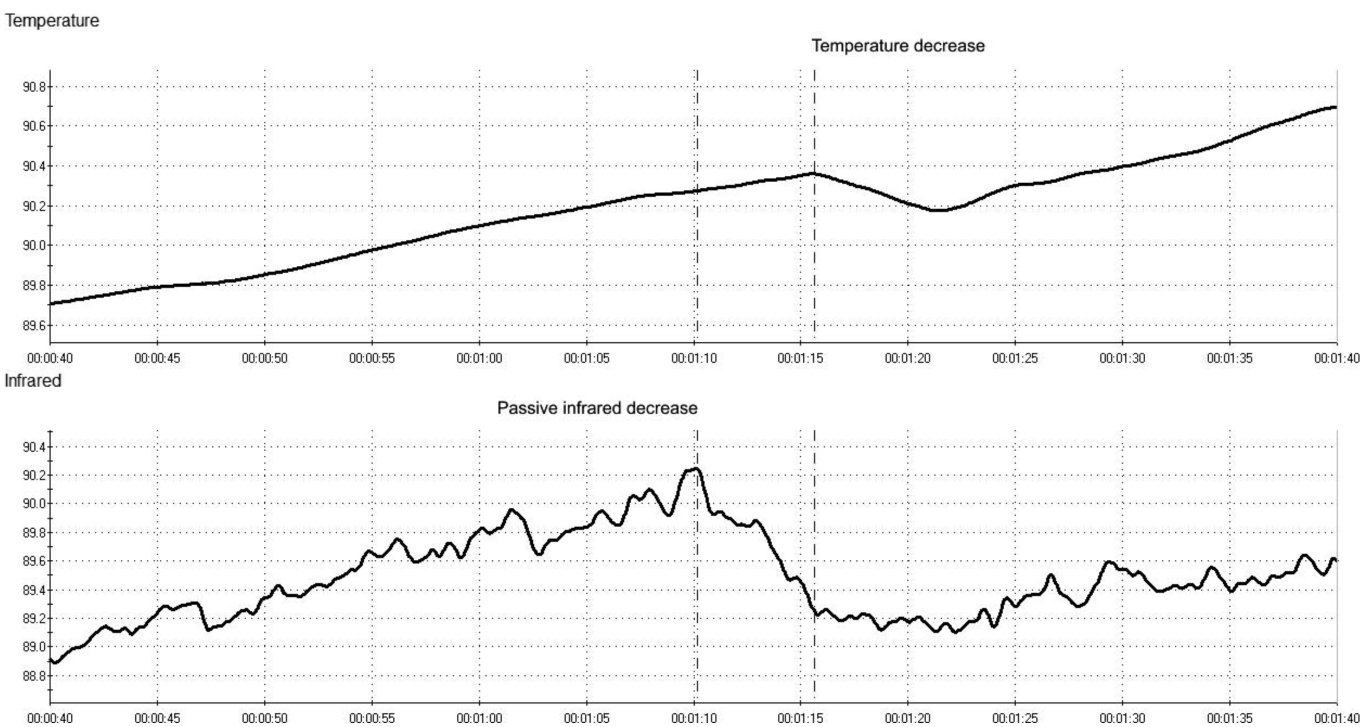

Figure 3. Comparison of thermistor and passive infrared (pIR) signals.

Figure 4. Infrared thermometer monitoring a vasoconstricted thumb.

mercury thermometer as your reference to test feedback thermometer accuracy. Place the thermistor next to the mercury thermometer and compare room temperature values. Peper recommends that professionals know their typical measurements so that they can use themselves as "test equipment" when values appear questionable (Peper et al., 2008, pp. 118–120).

Absolute accuracy is important when you want to teach people to warm to specific criteria such as their hands to 95°F and feet to 93°F as suggested for the treatment of hypertension (Fahrion, Norris, Green, Green, & Snarr, 1986). In these cases, you will need the accuracy of a clinical-grade thermistor. In addition, you have to allow for the cooling effect of the room. A recorded value of 95°F may in fact be 96.5°F if the room has chilled the thermistor by 1.5°F.

Resolution

The *resolution* of a temperature biofeedback instrument is the smallest increment of change that it can measure and display. If a sensor's resolution is too low, it will be unable to detect small changes in temperature. If it is too high, it will detect minute temperature changes and noise, which will increase signal variability and cause erratic feedback, possibly interfering with the learning process. A resolution of 0.1°F is a good compromise value because it provides rapid feedback that is relatively insensitive to artifacts (false signals) due to sources like circuitry heating, drafts, and movement.

Ceiling Effect

Skin temperature is limited by core body temperature. As a result, success in hand warming does not depend on increasing the temperature by a certain number of degrees, but rather on the number of degrees of change relative to a ceiling of approximately 97°F. This phenomenon is called a *ceiling effect*. If a person's hand temperature starts at 67°F, it can be increased by 30°F before it reaches a temperature of 97°F—near the core body temperature. On the other hand, if a person's hand temperature starts at 95°F, the total temperature can only increase by 2°F. In both examples, hand temperature increases of 30°F or 2°F represent very successful peripheral warming (Peper et al., 2008).

Thermistor Placement

Temperature biofeedback is about monitoring the changes in skin temperature that are caused by autonomic and endocrine activity. These changes are easier to detect in the peripheral circulation, so hands and feet are ideal locations. A thermistor should be attached using Velcro® or Coban™ tape to a site on the hand or foot that is well-supplied with blood vessels. When fastening the sensor, be sure that the tip (bead) of the sensor is pressed against the fleshy part of the finger or toe, but be careful not to wrap the Velcro® or Coban™ tape so tightly that circulation is reduced.

Meehan et al. (manuscript in preparation) found that the back of the index and middle fingers of the left and right hands were at least 1°F warmer than the palmar aspect of these digits in a sample of 49 undergraduates (20 men and 29 women), ages 18–26.

Besides digits, the web dorsum, located on the back of the hand between the thumb and index finger, is also a good place to attach the sensor. Adhesive porous tape would be used in this case.

Despite competing claims for the superiority of specific hand sites or hands, there is no peer-reviewed evidence that a single site is most responsive to stressors or relaxation exercises across a majority of patients (Peek, 2016). Further, during an individual patient's training session, an initially responsive site may *plateau* (cease to warm). Since temperature biofeedback to produce hand warming can be overly specific (warming could be confined to just the left index finger), several sites should be monitored during a session to determine the generalization vasodilation. Since thermistors are expensive, two options are to move the same sensor to different sites or to scan the hands using an inexpensive infrared thermometer (see Figure 4).

We usually recommend placing a thermistor on the end of the index finger or thumb because of their greater temperature range (see Figure 5). The lowest temperature is

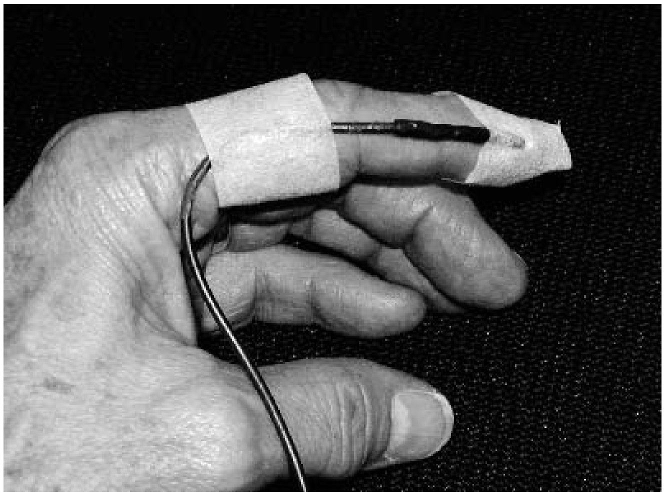

Figure 5. Thermistor placement at the fingertip.

observed at the tips of the fingers if room temperature is lower than core temperature. In addition, the ends of the fingers have higher densities of proprioceptive receptors than the web of the hand. This allows clients to more easily feel the sensations of warmth. Usually when finger temperature is about 90°F, subjects start to feel the throbbing of their pulse at the fingertip.

Monitoring Conditions

The room should be around 74°F when measuring temperature. Rooms below 68°F may produce a downward temperature drift as peripheral blood vessels constrict to reduce body heat loss and maintain core temperature. Remove your patient from drafts and cool surfaces and provide seating with sufficient neck and knee support. Plants may be used to diffuse drafts. Conversely, warm rooms may elevate temperatures. A cadaver's hand temperature will be 90°F in a 90°F room. Experienced professionals record room temperature along with client baseline values.

Usually, it is easier for subjects to warm their hands when the palm faces downward and feels the warmth of the thigh than when it faces upward and feels the coolness of the air.

Quality Control

The most important rule is to record under similar conditions since only then can you compare data. While it is valid to compare temperature values within a single session, across-session comparisons are less valid because many conditions may have changed between sessions. For example, the client's initial temperature, office temperature, and sensor placement may have changed. You can reduce these sources of variability by standardizing your methods. While trend graphs (plotting values across multiple sessions) may often show considerable variability between adjacent sessions, they should help you demonstrate a learning curve. If your client is learning to self-regulate, you should see a warming trend in the session-to-session values. This, along with improvement in your client's symptoms or performance, should help you document temperature biofeedback training effectiveness.

Professionals should take precautions against five temperature recording issues: constriction, blanketing, warming by the thigh, movement, and position.

First, *constriction* occurs when tape is tightly wrapped around the circumference of the digit, which could reduce blood flow and produce lower readings. Instead, apply tape over the bead and cable, following the cable.

Second, *blanketing* results when too much material is used to wrap around the finger and heat is trapped inside. Zerr et al. (2015) found that this raised finger temperature by nearly 1°F. When using Velcro®, be sure to wrap around the sensor so you can see the bead close to the edge of the band. When using tape, don't cover the bead fully or use porous tape that will allow air to flow. If the tape thermally insulates the probe and finger, it will reduce the observed vasoconstriction of the fingers because the fingers are staying warm because of the tape. This is similar to wearing gloves in colder weather. For consistency, use a single layer of tape.

Third, *warming by the thigh* can directly and indirectly heat a thermistor, so that the recorded temperature is somewhere between finger and thigh temperature (see Figure 6). When the thermistor attached to a cold finger touches the thigh, it may increase the temperature as much as 10 or more degrees. The thermistor is exposed to heat radiating from the thigh, this may increase temperature by 0.5 to 1.0°F (Meehan et al., in press). A thick towel, which should be replaced between clients to mitigate infection transmission, can avoid this problem.

Although you can instruct clients to rest their hands on the thigh with the palms up, this often will cause cooling of the fingers as the person becomes aware of the cool air and the slight sweating of the exposed palms cools the fingers. Also, be aware that the fingers can curl in such a way that the thumb, or an adjacent finger, will touch the sensor and warm it up. Booiman (personal communication, March 26, 2016) recommends recording from the inner aspect of the thumb, since there is gap between the thumb and index finger. A compromise is to secure the thermistor on the side of the index finger.

Figure 6. Thermistor warming due to contact with the thigh.

Fourth, *movement* can decouple the thermistor from the skin by tugging on the sensor cable. This can lift the sensing bead from the skin (see Figure 7). You can minimize this problem by taping the thermistor cable down to your patient's shirt or blouse (and possibly also to a reclining chair) with sufficient slack.

Finally, a *positional effect* results when the hand is placed above the heart and gravity lowers temperature by reducing the amount of blood perfusion in the skin. Figure 8 shows the effect of moving the client's hand above and below heart level. It also shows how movement artifacts occur each time the subject moves. When recording, standardize hand elevation.

While early biofeedback texts warned clinicians against the *stem effect*, cooling due to not securing the first 3 inches of a thermistor, Zerr et al. (2015) found no evidence of this artifact when recording from undergraduates. The disappearance of this phenomenon may be due to improved thermistor design.

The Importance of Temperature Scale

One last thing to be careful about, when providing skin temperature biofeedback, is the scale setting on the screen's feedback graph. Temperature is a very slow signal that rarely exhibits much variability. Setting the scale too widely or too narrowly can give inconsistent feedback to the client and cause confusion. A scale that is too wide will flatten out the signal and small but meaningful changes will never be shown. A scale that is too narrow will make insignificant changes seem like large ones and confuse your client.

Observe the temperature changes during the baseline period and set the scale's maximum value slightly above the maximum and its minimum value to below the lowest baseline reading. For temperature training and to reveal temperature changes, we often set the range at plus or minus 2°F of the baseline value.

Tracking Test

A *tracking test*, previously called a behavior test, checks the relative integrity of the entire signal chain from the thermistor to the encoder, the correct software selection of input channels, and display settings. You can determine whether a temperature display mirrors the thermistor's temperature changes by performing a tracking test, during which you gently blow on the thermistor bead to warm it.

Be sure to bring it very close to the mouth; otherwise, you may be moving the cooler room temperature over the thermistor. Temperature should increase while you blow and then decrease when you stop.

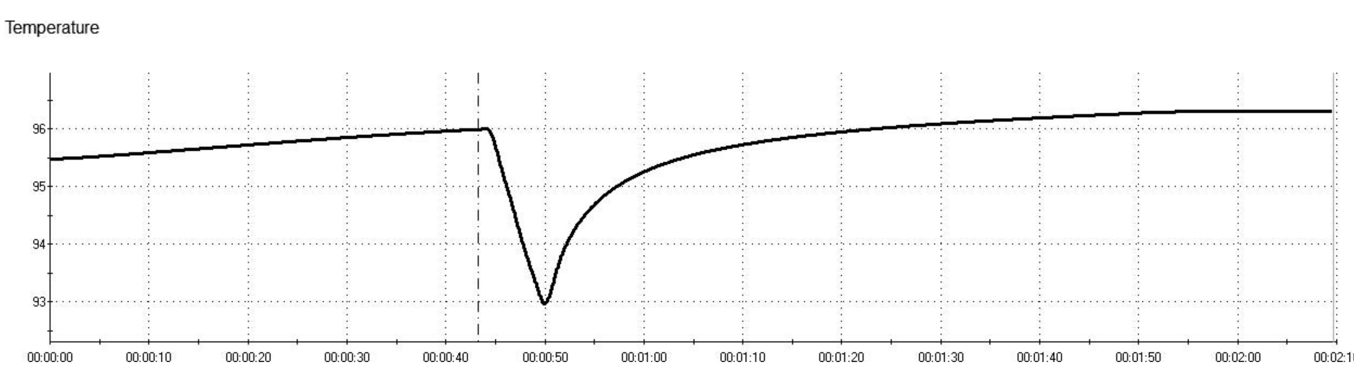

Figure 7. Thermistor decoupling due to movement.

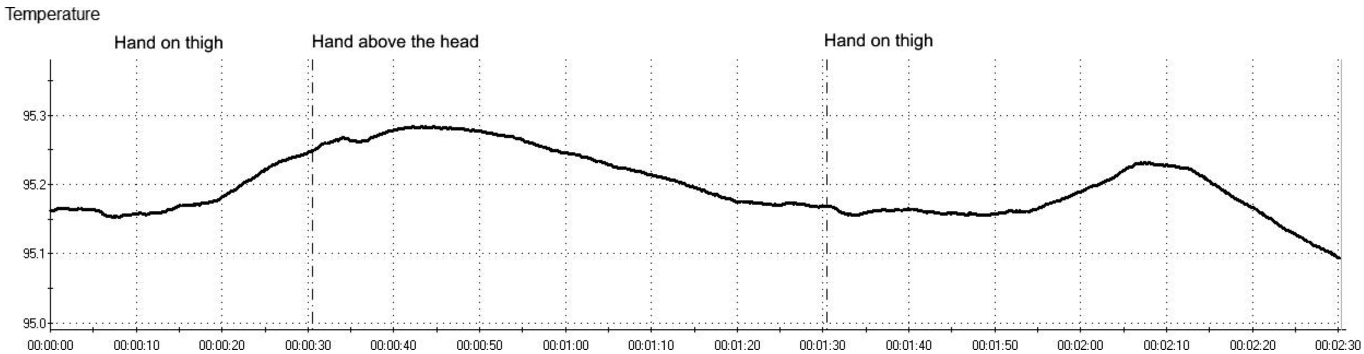

Figure 8. Effect of hand position with respect to the heart on skin temperature.

If the tracking test fails, review each element in the chain. Check that the sensor is properly inserted into the correct encoder channel, double-check your sensor placement, and make sure that you're not actually replaying previously recorded data. If you have more than one probe, try substituting probes to see if the first one might be defective. Finally, if all else fails, contact your vendor's technical support department.

To check the relative accuracy of the thermistor, place it underneath your armpit, wait a minute, and the temperature should approach core temperature.

Baselines

Temperature baselines are resting measurements obtained while a client is resting without feedback. For publishable research, a baseline period should allow temperature to stabilize within 0.5°F for at least 5 minutes. Stabilization happens at two levels. First, the sensor itself needs sufficient time to reach the client's skin temperature. Then, the client has to adapt to your room's ambient temperature (see Figure 9).

Baseline length will vary with each subject between 15 and 45 minutes in a 74°F room. Cold outdoor temperature can delay stabilization by 20 minutes (Khazan, 2013).

Due to practical concerns, clinical baselines are often as brief as 3 minutes during training sessions. Be cautious that if a patient hasn't stabilized before the training session starts, warming during the session may reflect adjustment to the room environment instead of self-regulation. As soon as clients sit in the training chair, let them hold the thermistor in their hand, even unconnected, to start warming it right away. Then, affix it to the clients' finger when you have finished your setup procedure.

A baseline measurement is usually only meaningful in the first few sessions. After people have learned peripheral warming, sitting in the baseline condition will usually evoke hand warming. The hand will progressively warm as they relax.

Normal Values and the Circadian Rhythm

The average core body temperature is usually around 98.6°F and varies by 1.3°F during the day due to the endogenous circadian rhythm (lowest in early morning and higher in late afternoon). The time of day can significantly affect skin temperature. Higher skin temperatures are more

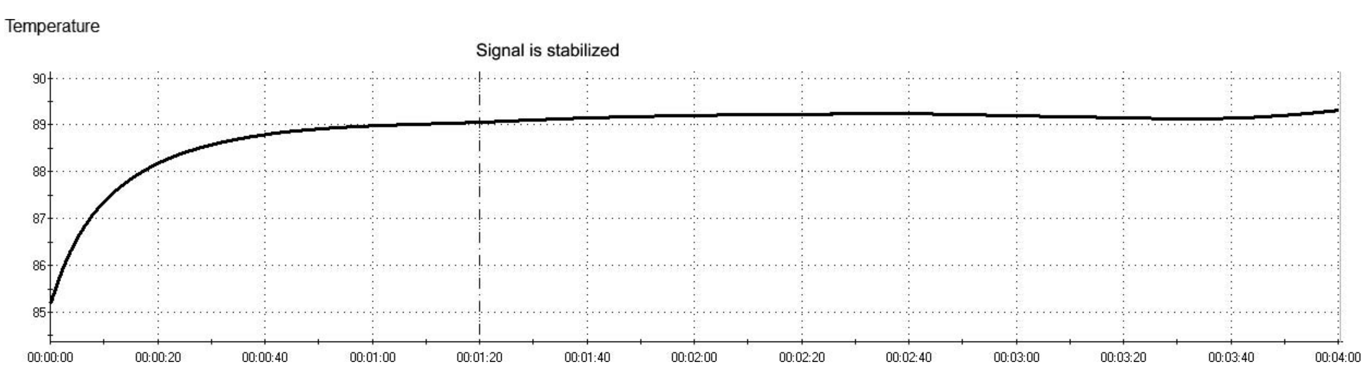

Figure 9. Temperature stabilization.

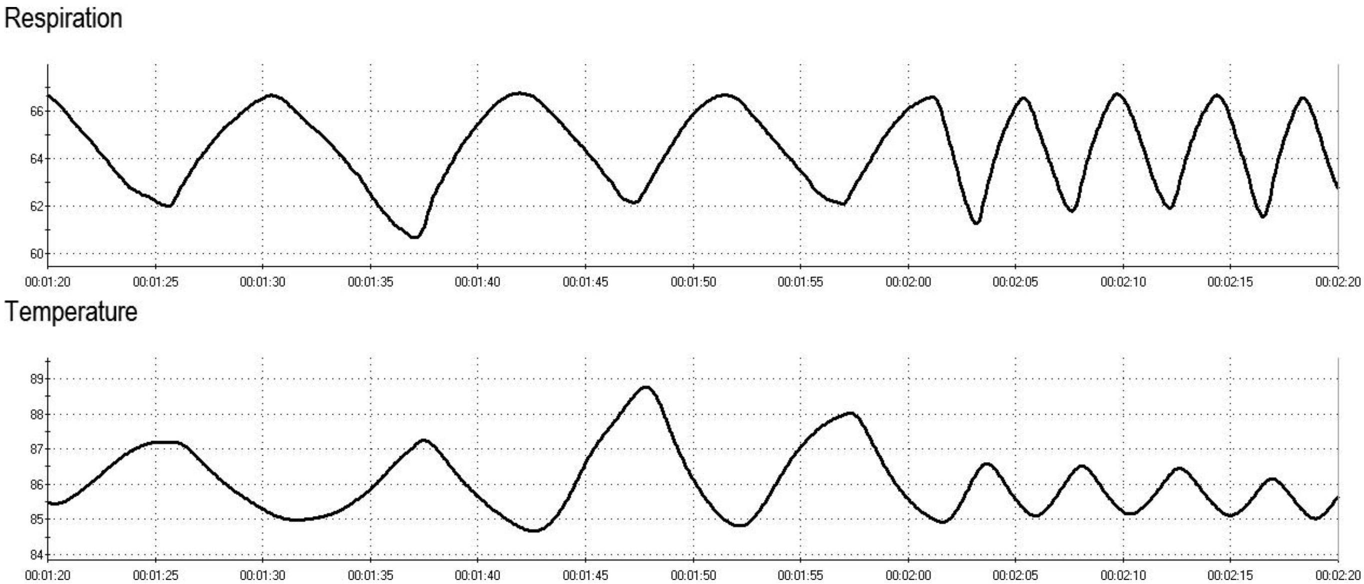

Figure 10. Respirometer and nasal thermistor waveforms.

easily attained in the late afternoon and early evening. This is relevant for clinicians because they often see clients early in the morning before they go to work (normal core temperature 97.7°F) or late in the afternoon/early evening when they come from work (normal core temperature 99.0°F) (Duffy, Dijk, Klerman, & Czeisler, 1998). Again, when recording, the maximum temperature can be slightly higher in the early evening than early morning. When analyzing data, be sure to compare absolute data from similar times of the day.

Peripheral temperature detected from the hands and feet is much lower. Normal finger temperatures range widely. Temperature values for men fall along a normal curve; those for women are bimodal. Finger temperatures exceed 88°F and toe temperatures reach about 85°F. Men have average hand temperatures of 90°F compared with 87.2°F for women; a 2.8°F difference (Conant, 2016).

Depending upon the degree of heat loss from the fingers to a cooler room, clinicians can up-train finger temperature to 95°F and toe temperature to 93°F in a 74°F room (Khazan, 2013, pp. 45, 159). If the room is warmer than 80°F, you can up-train finger temperature to nearly 96.5°F and foot temperature to 95°F.

Temperature Variability

Shusterman (1995) reported that the skin temperature signal contains oscillations in the 0.015–0.04 Hz range for both healthy subjects and those diagnosed with coronary artery disease. These oscillations are termed *temperature variability* (TV). The power spectra for TV and heart rate variability (HRV), which overlap, showed parallel changes in response to stressors. TV was more sensitive to stressors than mean temperature.

Thermistor Monitoring of Respiration

R. Gevirtz (personal communication, March 11, 2016) recommended placement of a temperature probe below the nostril to monitoring breathing when you don't have a *respirometer* (flexible respiration sensor placed around the abdomen or chest). This technique was discussed in the 1970s and works when the nostril is unobstructed and the probe is located at the opening of the nostrils.

As shown by Figure 10, there are three caveats to this approach. First, the temperature-based respiration signal is the reverse of a respirometer waveform (inhalation = colder = down; exhalation = warmer = up). Second, the two signals will be slightly out of phase since a thermistor tracks temperature changes more sluggishly. Finally, as a client breathes more rapidly or more shallowly, the thermistor is less able to respond to briefer or less marked temperature changes, and the signal flattens out.

Summary

Skilled temperature monitoring requires familiarity with clean signals, normal values, and understanding of the factors that can affect signals. As with all biofeedback modalities, visual inspection of the raw signal is essential to ensuring measurement fidelity. While clinicians primarily use thermistors to monitor peripheral temperature during thermal biofeedback, they can provide valuable information during HRVB practice and detect respiration when a respirometer is not available.

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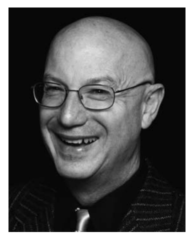

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