SPECIAL ISSUE

A Guide to Cleaner Electrodermal Activity Measurements

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Valid electrodermal measurements ensure the integrity of client assessment and biofeedback training. Accurate measurements require understanding of the signal and potential artifacts (sources of contamination) and developing “bulletproof procedures.” Peper, Shaffer, and Lin have recommended the following guidelines for ensuring accurate psychophysiological monitoring: (a) understand the physiological mechanisms that generate the signal, (b) always record and inspect the raw signal because this will allow you to identify artifact, (c) question whether displayed values make sense (e.g., skin conductance levels that rapidly fluctuate, exceed 40 μS/cm², or fall below 1 μS/cm² should be suspect in a client who is sitting quietly), (d) recognize the appearance of common artifacts and how they alter derived measurements, and (e) intentionally create artifacts so that you can better recognize them (e.g., rhythmically move the fingers attached to a skin sensor, loosening or tightening the sensors if they are attached with the Velcro® finger straps, and review both the raw signal and calculated skin conductance values). This article reviews the anatomy and physiology, measurement procedures, sources of common artifacts and their control, tracking test for recording electrodermal activity, and common response patterns.

Anatomy and Physiology

The skin is the largest organ in the human body (see Figure 1). It is composed of three layers: the epidermis, the dermis, and the hypodermis. The epidermis protects the body from exposure to ultraviolet radiation, toxins, and bacteria and helps with thermoregulation (Tortora & Derrickson, 2014). The skin also mirrors attentional, defensive, and problem-solving processes through tonic (baseline values) and phasic (transient changes from baseline values) electrodermal activity (EDA) that depends on eccrine sweat glands (Andreassi, 2007).

The skin contains apocrine and eccrine sweat glands (see Figure 2). Apocrine sweat glands usually open into hair follicles and are mainly distributed in the armpits and genital region. These sweat glands can expel sweat from their tubules and produce the odor of sweat. Although researchers can measure EDA from the armpits and genital regions, it is seldom done.

Eccrine sweat glands are distributed across the body, except for areas such as the lip margins, outer ear, clitoris, and glans penis. They are densest on the palms (palmar surface) and soles of the feet (plantar surface). A square inch of palmar surface may contain about 3,000 sweat glands (Jacob & Francone, 1970). Cadaver studies indicate that the entire body may contain from 2 to 5 million sweat glands (Fowles, 1986).

Although eccrine sweat glands are mainly concerned with thermoregulation (temperature control) through evaporative cooling, they are also responsible for EDA. Whereas all eccrine sweat glands respond to cognitive activity, emotion, and temperature, palmar and plantar sweat glands appear more responsive to emotional stimuli because of their higher density (about 1,000 glands per cm², compared with 100–200 per cm² on the trunk and limbs). Palmar sweating seems specialized for grasping objects, increasing tactile sensitivity, and protecting our skin from damage (Hugdahl, 1995).

EDA is typically recorded from the fingers and palmar surface of the hands. It is possible that different areas of the body (e.g., armpit) may respond differently to diverse stimuli. Only a few studies have monitored EDA from other regions, such as the forehead when training patients to inhibit motion sickness.

The sympathetic nervous system, the autonomic nervous system branch that regulates activities that expend stored energy, primarily controls EDA (see Figure 3).
Increased sympathetic nervous system activation results in greater sweating from the palms. This does not mean that EDA amplitude increases equally in both hands. Discrepancies between left and right hand values mainly reflect left/right brain function, but may also signal pathology (Banks, Bellerose, Douglas, & Jones-Gotman, 2012). Skin responses may also be affected by which dermatomes, areas of skin innervated by a single spinal nerve, are activated.

Eccrine sweat glands are mainly innervated by sympathetic motor neurons that release acetylcholine, which is a parasympathetic neurotransmitter. Researchers have also found nearby adrenergic fibers. Neurotransmitters such as vasoactive intestinal peptide may complement acetylcholine and norepinephrine (Shields, McDowell, Fairchild, & Campbell, 1987).

Three Methods Are Used to Measure EDA
EDA is measured using three methods: conductance, resistance, and potential. Both conductance and resistance are exosomatic measures (because the electrical current comes from outside of the body) and are obtained by passing an imperceptible electric current through the skin. Skin conductance (SC) measures how easily an external current passes through the skin and is measured as skin conductance level (SCL) and skin conductance response (SCR). Skin resistance (SR) is the reciprocal of conductance. Also called galvanic skin response (GSR), SR reflects opposition to external current movement and is measured as skin resistance level (SRL) and skin resistance response (SRR).

Skin potential (SP) is an endosomatic measure (because the voltage is generated by the body), which detects the electrical potential (voltage) between two electrodes on the skin surface. SP is measured as skin potential level (SPL) and skin potential response (SPR).
In general, level is a tonic measure of EDA that quantifies the average amplitude over a specified period of time and indexes baseline values. Response is a phasic measure of EDA that represents a spontaneous or stimulus-elicited change in sweat gland activity and refers to change from the baseline values, as shown by Figure 4.

**The Relationship Between SR and SC**

Until the 1980s, the common terminology for most skin electrical measurements was GSR. Commonly, GSR was calculated as the SR, the reciprocal of SC, and measured the same physiological response (see Figure 5). When reviewing scientific literature, be sure to include the term GSR. Otherwise, no article will be retrieved before 1980. SR and SC are measured in a similar way, by placing electrodes on adjacent areas of the palmar or plantar skin. The tonic index is SRL. Typical values are 10 to 500 Kohms/cm² (Hassett, 1978). The phasic component is SRR. Edelberg (1972) suggested that the criterion for an SRR should be 0.1% of baseline resistance. SRR latency is the same as SCR latency, which is 1 to 3 seconds (Schwartz & Andrasik, 2003).

SC is the reciprocal of SR (SC = 1/SR). Researchers prefer SC because it is more normally distributed than SR and increases linearly as the sympathetic nervous system activates more sweat glands (Andreassi, 2007).
Sensor
SC and SR values vary with electrode recording surface; SP values do not. SC values are expressed in $\mu$S (microsiemens) per cm$^2$. In 1971, during the 14th General Conference on Weights and Measures, the mho (inverse of ohm) was replaced by the siemen as the official unit of conductance (“General Conference on Weights and Measures,” n.d.). SC values using finger straps range from 0.5 to 20 $\mu$S/cm$^2$ and using a palmar placement range from 5 to 30 $\mu$S/cm$^2$. Normal resting SCL readings using finger snaps are less than 5 $\mu$S/cm$^2$ (Khazan, 2013, p. 46).

Electrodes should be nonpolarizing. They should not create separate regions of positive and negative charge because this artifact reduces conductance values. Biomedical engineers reduce polarization by coating a metal with its own salt. Silver/silver-chloride or zinc/zinc-sulphate electrodes are both used. Silver/silver-chloride electrodes are also used to monitor the electroencephalogram and electromyogram (EMG).

The electrode recording area should be as large as possible. A larger recording area reduces resistance (and thereby increases SC) and spreads the electroderymograph’s current across more sweat glands, reducing sweat gland irritation (Stern, Ray, & Quigley, 2001). Standard electrodes applied to palmar or plantar sites range from 1.5 to 2 cm in diameter. Finger electrodes are typically 1 cm or less in diameter (Andreassi, 2007). For valid comparisons, you should analyze only measurements obtained using the same electrode size, composition, and placement (see Figure 6).

Sensor Placement
Clinicians secure SC electrodes with double-backed adhesive collars (used in EMG), surgical tape, or elastic bands. Velcro® is frequently used to attach finger electrodes, as shown in the SC sensor in Figure 7. The conductive electrode in each finger strap should be placed against the inside part, that is, the palmar surface of the finger.

One choice for placement is to use the index and ring finger. Skip a finger to avoid physical contact between the sensors. A second placement uses the index and middle finger because they are both within the median nerve dermatome (Hugdahl, 1995). Close the Velcro® straps around the fingers so that contact is snug yet comfortable. Loosen the straps if the fingers throb (or change color). Use the intermediate phalange of each finger to prevent the sensors from slipping off and to permit performance of some motor tasks. The distal phalange is slightly more

Figure 6. Comparison of voltages recorded using finger-strap electrodes and pregelled electrodes. Reproduced with permission from Peper, Gibney, Tylova, Harvey, and Combatalade (2008).
reactive, as it has a higher density of eccrine sweat glands; however, the finger straps sometimes fall off. Thus, the intermediate phalanges are commonly used.

Place the cables directed inward to keep them out of the way (see Figure 8). Tape the cables to your client’s blouse or shirt to restrict sensor movement (Peper, Gibney, Tylova, Harvey, & Combatalade, 2008).

**SC Recording**

Attach electrodes to the palmar surface of the hands or fingers or the plantar surface of the foot where there is the highest density of eccrine sweat glands (about 1,000 glands per square centimeter; Hugdahl, 1995). Figure 9 shows palmar and finger placements for SC sensors. A palmar placement results in larger SCL values because of a greater recording area and is less vulnerable to artifact than a finger placement. The intermediate phalange may be preferred to the first phalange because of its lower incidence of abrasion or cuts, which can alter the skin’s electrical properties.

We always recommend a palmar placement if a finger placement yields SCL values less than 1.5 \( \mu \text{S/cm}^2 \) because low values make the recording more susceptible to artifacts.

**Skin Potential**

SP is very useful because it can differentiate between orienting and alarm reactions (Sokolov, 1963). However, it is more difficult to record because the signal contains a direct current component. The majority of commercial biofeedback systems record SC instead of SP.

When recording SP, the selection of electrode locations is crucial. SP is measured using a monopolar placement, where one electrode is over an active site (such as the palmar surface of the hand) and the reference electrode is over a relatively inactive site (forearm), as shown in Figure 10. You may place an additional ground lead on an inactive site (forearm) on the same side of the body when 50/60–Hz artifact is a problem (Andreassi, 2007).

SP is the voltage difference between sweat glands and internal tissues (Hassett, 1978). Unlike SC and SR, SP measurements do not depend on electrode recording surface. The tonic component is SPL. Typical values are +10 to −70 mV (referenced to the inactive electrode). The phasic component is SPR, which typically includes a negative limb up to 2 mV and a positive limb up to 4 mV (Stern et al., 2001).

Whereas SC and SR are often measured using dry electrodes (no conductive gel), SP measurements, like electrocardiogram or EMG measurements, are cleaner and less prone to artifacts when using conductive gel.
preparation may involve abrasion of the inactive site using an abrasive paste. The bias or potential difference between the two electrodes should be kept below 1 mV to prevent confusing gradual electrode drift with a gradual change in SPL. A researcher can measure bias before and after data collection by placing the electrode pair in a saline solution and measuring the resulting SPL (Stern et al., 2001).

Measurement Precautions

There are four concerns when monitoring EDA. Clinicians should consider individual differences, movement artifact, skin condition, and room temperature for optimal measurement.

Individual differences can significantly affect EDA measurement. Researchers have shown that age, race, lability-stability (Lacey & Lacey, 1958), and stage of the menstrual cycle influence EDA (Stern et al., 2001). Usually, older people with drier hands or those with calloused hands have significantly lower SCLs and SCRs, whereas children have higher SCLs and SCRs.

Movement artifact (see Figure 11) results when movement increases electrode contact area (pressing against the skin) or decreases area (lifts an electrode off the skin). This problem is less severe with recessed precious metal electrodes prepared with conductive gel. Movement artifact can be reduced by instruction to minimize movement and confirming compliance. Tape the sensor cable to the client’s blouse or shirt for strain relief. Ensure that the client is in a stable, comfortable position. Sensors may also be placed on the nondominant hand during tasks that require one hand. When this artifact occurs, it is easily discriminated from valid EDA waveforms by visual inspection of the raw waveform (Peek, 1987).

Skin condition affects EDA in several ways. Calluses may increase epidermal resistance and lower SC values (Peek, 1987), whereas abrasions through the highly resistant epidermis can raise SC readings. Epidermal abrasions are very rare. These problems can be prevented by not placing electrodes over sites that have been callused or abraded.

Depending on individual differences, SCL values can fall sharply after washing hands with soap and water because this removes surface salt. Measurement reliability may be increased by asking the patient to not wash (or wash) immediately before each session (Peek, 1987). To ensure valid comparisons, always use the same skin preparation procedure.

Hand temperature may lower or raise EDA values. When clients are cold, SC may decrease. Warmer-than-normal rooms may increase SC (Venables & Christie, 1980). Excessively high temperatures and humidity may produce thermoregulatory sweating and increased SC that are unrelated to psychophysiological activity (Peek, 1987). Room temperature and humidity should be regulated across sessions to prevent artifactual values. Time of day, day of week, and season should also be controlled as potentially confounding environmental variables (Stern et al., 2001). Respiration pattern can subtly affect SCL values. For example, rapid, shallow, thoracic breathing and (especially) sighing may increase SCRs.
Usually, when people sigh or habitually breathe shallowly and thoracically, SCL measurements are higher. See Unit 3 in Biofeedback Mastery: An Experiential Teaching and Self-Training Manual (Peper et al., 2008) for a detailed methodology to investigate SCL artifacts.

Other types of artifact can distort the SC signal. Loose electrodes will cause variations in the area of electrode touching the skin and will generate sudden rises and falls in the signal, which are too fast to be normal SCRs. To check for loose electrodes, gently tug on each electrode lead while watching the signal on the screen. Tightening the electrode band or using a clean adhesive electrode will fix the problem.

On some systems, you may occasionally observe slow upward drifting of the baseline value. This type of drift is not related to physiological responses and may be caused by electrode polarization or sweat buildup. Using fresh silver/silver-chloride electrodes, using finger band electrodes instead of adhesive ones, and making sure that the person’s hands are not closed (preventing air circulation) may reduce the occurrence of drift. Many EDA systems use a bandpass filter (0.05–2 Hz) to remove both drift and high-frequency artifacts.

Occasionally, clinicians will place two SC sensors on a person to measure SC bilaterally and assess left/right brain dominance. Placing the sensors on each hand should be acceptable, but if the two sensors are placed too close together, they may interfere with each other. This would appear as a stair step pattern in one of the signals.

### Be Consistent: Always Compare Apples to Apples, and Not to Kiwis

You can best compare changes in client EDA activity if you use a consistent measurement protocol. Standardize handwashing (yes or no), sensor placement, room temperature, and task (e.g., eyes-closed resting baseline) so that within- and across-session comparisons will be valid. Never provide real-time feedback while recording baselines because this would introduce an unpredictable source of variability.

Although more difficult to monitor, internal stimuli can cause unpredictable SCRs. Consistent with Green and Green’s (1977) psychophysiological principle, when an SCR occurs in a person sitting quietly with no external stimuli, it may be a response to a covert change in breathing, cognition, or emotion. Keep in mind that many individuals, especially those who are vigilant or feel unsafe, respond with an SCR to stimuli such as sounds, lights, being touched, and people moving closer.

### Tracking Test

When starting a session, you can determine whether the signal that you see on the screen is really mirroring your client’s EDA by performing a tracking test. The purpose of the test is to create a condition that should have an obvious and fairly instantaneous response. You can, for example, instruct your client to inhale deeply and then exhale rapidly and audibly or clap your hands behind the client. Both of these actions should cause a rapid increase in SC (or decrease in SR) within 1 to 3 seconds (see Figure 11). After the EDA response, the signal should slowly recover within 120 seconds (Peper et al., 2008).

### SC Patterns

SCRs are produced by sympathetic activation triggered by internal emotions, imagery, memories, and thoughts and external stimuli such as ringtones. Toomim and Toomim (1975) proposed three response patterns:

- **Variable reactors** produce SCRs in response to a stimulus such as a loud clap and then quickly return to baseline (see Figure 12).
- **Overreactors** continuously produce SCRs as if they need excessive sympathetic arousal. They overreact to stimuli with high-amplitude responses and slowly return to baseline (see Figure 13).
- **Underreactors** produce low-amplitude SCRs and show minimal emotional reactions (see Figure 14).

In most cases, as clients relax and feel safe, SCL will slowly decrease. In rare cases, humidity and temperature may cause sweat to collect under the sensor, and this can lead to a slight increase in SCL over time.

When a person responds to a stimulus such as a loud noise, being touched, gasping, being embarrassed, or an emotion-evoking thought, SCL will usually increase and decrease in less than 90 seconds. There is a normal latency between a stimulus and the response of about 1 to 3 seconds (Schwartz & Andrasik, 2003). If the response activates fear or a traumatic memory and the person struggles to terminate this reaction or no longer feels safe, increased SCLs will persist or even increase. Conversely, individuals who are victims of abuse or other trauma may show a paradoxically flat SC pattern. Marjorie Toomim described this dissociative response as “going 90 miles per hour with the brake on” (Smith, 2005).

A stress assessment protocol can be used to assess a person’s ability to return to a resting baseline level by alternating periods of mild stress with periods of relaxation (see Figure 15).
SC Biofeedback

For educational and clinical purposes, the two most important components of EDA are SCR amplitude and the time it takes for the SCL to return to baseline. SC biofeedback training generally consists of teaching individuals to lower their SCL and decrease the number of SCRs. At first, when participants observe a display of their EDA, an initial response to an externally generated stimulus may be followed with a reaction to their own internally generated stimulus. This is analogous to the experience of blushing. You start blushing, become aware of the blush, and then blush more.

For many people, when they sigh, SCR increases, and if the topic is emotionally charged, the SCR will not return to

![Figure 12](image12.png)  
**Figure 12.** A variable reactor’s skin conductance signal shows occasional skin conductance responses and a progressively decreasing skin conductance level. Note the amplitude scale between 0 and 5 μS.

![Figure 13](image13.png)  
**Figure 13.** An overreactor’s skin conductance signal shows multiple skin conductance responses and a high skin conductance level. Note the amplitude scale between 0 and 16 μS.
baseline until they let go of the emotion. Figure 16 shows an 18-minute recording of both EMG and SC. From minutes 4 through 14, the person discussed a very stressful event. Each spike in the EMG represented a sigh.

By practicing SC biofeedback, clients will learn to recognize which internal processes tend to generate more SCRs or increase SCL. A skilled practitioner can coach them to learn mental strategies that will help them disengage from the emotions driving overactive EDA and rapidly lower their resting levels. At first, the feedback given by the rise and fall of the SC signal is important to make a connection between internal processes and EDA, but in time, clients will be able to recognize the feeling of activation and relaxation and be able to do this without feedback. This transfer process is an important aspect of biofeedback training.

Figure 14. An underreactor’s skin conductance signal shows very low-amplitude skin conductance responses and a low skin conductance level. Note the amplitude scale between 0 and 16 µS.

Figure 15. Note the skin conductance responses during the mild stress trials and recovery during relaxation trials. The amplitude scale is between 0 and 5 µS.
Summary
Skilled EDA monitoring requires familiarity with clean signals, normal values, and common response patterns and understanding the factors that can affect signals and precautions to minimize recording artifacts. As with all biofeedback modalities, visual inspection of the raw signal is essential to ensuring measurement fidelity.

References

Figure 16. Electromyogram and skin conductance response changes while discussing a very stressful event. Reproduced with permission from E. Peper, unpublished manuscript.


