An EDA Primer for Polygraph Examiners

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Introduction

Of all the signals collected and analyzed during psychophysiological detection of deception (PDD) or polygraph testing, the electrodermal response (EDR) is the most robust and informative. The EDR is easily collected and is simple to measure and interpret (Blalock, Cushman & Nelson, 2009). Several studies indicate the electrodermal component provides the greatest contribution to diagnostic accuracy in the comparison question test (Blalock, Cushman & Nelson, 2009; Capps & Ansley, 1992; Harris & Olsen, 1994; Kircher & Raskin, 1988; Krapohl & Handler, 2006; Krapohl & McManus, 1999; Nelson, Krapohl & Handler, 2008; Raskin, Kircher, Honts, & Horowitz, 1988). The basic premise underlying the interpretation of EDRs is that the magnitude of response is commensurate with the degree of psychological importance that the examinee imparts to each stimulus question during testing. Peterson (1907), a student of the famous psychologist Carl Jung wrote: "It is like fishing in a sea of the unconscious, and the fish that likes the bait best jumps to the hook....Every stimulus accompanied by an emotion produced a deviation of the galvanometer to a degree of direct proportion to the liveliness and actuality of the emotion aroused" (p. 805).

Despite the pragmatic simplicity and robustness of EDRs, the psychophysiological mechanism underlying them is complex and incompletely understood (Lykken & Venables, 1971). Unfortunately, there are many misconceptions of the EDR with the polygraph profession and elsewhere. This paper is offered as a primer/reference on EDR for the practicing and student polygraph examiner. We describe the present state of the scientific knowledge of the integumentary system and EDRs, and provide a description of the use of EDRs in the science of Psychophysiological Deception Detection (PDD) testing. The paper is organized along natural divisions, and leads the reader from history, through physiology, to the latest scientific understandings and finally arrives at what most examiners consider the most interesting — how to apply the EDR to deception detection.

Terminology[1]

The term electrodermal activity (EDA) is a relative newcomer and was first introduced in 1966 by Johnson and Lubin (1966). Johnson and Lubin (1966) proposed its use as an umbrella term under which all electrical phenomena in skin might be subsumed. Brown (1967) and Venables and Martin (1967a) proposed the standard

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[1] The material in this section is derived from the major scientific sources describing the terminology of electrodermal activity. Readers interested in the original scientific sources should see Boucsein, 1992.

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nomenclature for psychophysiological terminology, which is still used today in the science of psychophysiology.

Electrodermal recordings that apply a voltage or current to the skin are called exosomatic and in polygraphy a direct current (DC) is used to measure aspects of EDA. Constant voltage DC systems record EDA as skin conductance (SC) for which the units are Siemens (S) or *mhos*, which is the inverse of ohm in both spelling and in computation. Constant current systems measure and record skin resistance (SR), which is measured in ohms. EDL is the accepted abbreviation for electrodermal level and refers to the tonic or baseline level at any given moment, while EDR is reserved for the phasic response or reactions to stimulation. The designators R and L may be appropriately applied to the type of measurement taken, for example SRR (skin resistance response) or SCL (skin conductance level) (See Table 1.) Spontaneous or non-specific EDRs (NS.SCR and NS.SRR) are those that cannot be attributed to an identifiable stimulus. Differential amplifiers can also be used to directly measure the electrical activity generated by the sweat glands. That approach to measuring EDA is referred to as an endosomatic measurement and the resultant measure is known as Skin Potential which is measured in micro-volts (μV).

Table 1. Abbreviations for electrodermal recording methods, units of measurement and recording method

Abbreviation	Measurement	Units of Measure	Recording Method
EDA	Electrodermal Activity	Varies by method	Varies by method
EDL (tonic)	Electrodermal Level	Varies by method	Varies by method
EDR (phasic)	Electrodermal Response	Varies by method	Varies by method
SCL (tonic)	Skin Conductance Level	Siemens or mho	Exosomatic
SCR (phasic)	Skin Conductance Response	Siemens or mho	Exosomatic
SRL (tonic)	Skin Resistance Level	Ohms	Exosomatic
SRR (phasic)	Skin Resistance Response	Ohms	Exosomatic
SPL (tonic)	Skin Potential Level	Micro-volts	Endosomatic
SPR (phasic)	Skin Potential Response	Micro-volts	Endosomatic

Various suffixes may be added to the abbreviations to further describe features of the phasic component: amplitude (e.g., SRR amp) would describe the height of a single response and latency (e.g., SRR lat.) would describe the time delay from stimulus to beginning of response. There are a large number of features that can be measured from the EDR; many were described in detail by Kircher and Raskin (1988).

Galvanic skin response or galvanic skin reflex (GSR) is an outdated and incomplete term (Boucsein, 1992). A galvanic cell is one that uses a chemical reaction resulting from electrical contact between two

dissimilar metals to produce an electrical current. The term GSR implies the skin functions as a galvanic cell, which is inconsistent with how the EDR is obtained in modern polygraphy with exosomatic technology. Additionally, the term *reflex* infers that EDRs are reflexive in nature which is inconsistent with the notion of psychologically elicited EDRs that are thought to be the result of an emotional response to, or cognitive appraisal of, verbal test stimuli during PDD testing. The Galvanic Skin Response (GSR) was named for Luigi Galvani, an Italian physician and physicist who found that by attaching the legs of a frog to dissimilar metals or an electrical source, he could make them twitch and move. The discovery that dissimilar metals could produce an electrical charge later led to the development of the battery, though not by Galvani. The phenomenon of electrical activity observed in the skin has inaccurately borne the GSR label for many years and nothing is gained by retaining this archaic term.

History

Studies on changes in electrical property of the skin can be traced back to the works of Germany's DuBois-Reymond in 1849 and that of French neurologist Jean Charcot in the late 1800s (Boucsein, 1992). One of the earliest documented experiments showing a relationship between sweat gland activity and current flow in the skin was performed by Hermann and Luchsinger (1878) who reported an association between electrical nerve stimulation and foot pad sweat secretion in a cat (Boucsein, 1992). Hermann was one of the first to note that the palmar and finger areas of the hand showed greater responses than other body areas, a first step toward appreciating the areas with the greater densities of sweat glands. Boucsein (1992) credits Vigouroux (1879) with the earliest association of EDRs and psychological stimuli.

Russian physiologist Tarchanoff (1889) was one of the first to report changes in skin potential measurements following a variety of sensory and physical stimuli. Tarchanoff correctly attributed these changes to sweat gland activity. Féré (1888) found changes in resistance to a number of stimuli using a constant current model, and is thus credited with the discovery of exosomatic EDR recording. Féré, however, was convinced the changes in resistance were a result of vasomotor changes, a theory which is no longer considered viable[2].

In 1906 Veraguth published a monograph entitled *The Psychogalvanic Reflex Phenomenon* in which he focused on EDRs as psychophysiological events. Richter (1929) was one of the earliest investigators to propose that endosomatic EDA (skin potential) owed its cause to sweat gland activity *and* epidermal mechanism (Boucsein, 1992). Advances in equipment development through the 1900s allowed for better measurement and recording of EDA. Polygraphs, advances in electronics, and much later, computers improved on the ability to store and analyze data electronically that had been recorded simultaneously from numerous sites.

Attempts at detecting deception with the aid of scientific instruments can be traced to the 1890s when Cesare Lombroso (Trovillo, 1939) used pulse rate and possibly blood pressure changes to infer deception. Hugo Munsterberg (1908) made some of the earliest suggestions for use of instrumentation in deception testing in legal cases. Munsterberg (1908) advocated for experimental psychologists to research the phenomena of psychophysiology but cautioned against any rush to judgment or use, as he foresaw the deceptive subjects. Marston employed a specificity to deception problem clearly and early on. In approximately 1914, Benussi reported observing differences in inhalation-

[2] We now know that the vasomotor center is a cluster of sympathetic neurons in the medulla concerned with the regulation of blood vessel resistance. Vasomotor activity causes changes in the sympathetic fibers regulating this resistance by changing the degree of contraction of the smooth muscle in the walls of the blood vessels. Changes in muscle contraction results in changes in vessel diameter which is what modifies the resistance. Increased sympathetic activation results in increased contraction and raises the resistance of the vessel. While vasomotor activity is often a covariant with EDR, they are separate processes.

exhalation ratios between truthful and discontinuous blood pressure measurement to determine when an examinee was engaging in deception, a practice that became the focus of the famous case of the *United States v. Frye*. The *Frye* decision ultimately set the standard for the introduction of scientific evidence into legal proceedings in the U. S. Federal Courts for 70 years. Larson combined aspects of the Benussi and Marston approach, improving on both in terms of instrumentation and theory. Larson developed a polygraph capable of recording continuous relative blood pressure pressure changes, pulse rates and movement associated with breathing in 1921 (Trovillo, 1939).

One of the earliest records of the use of EDRs to detect deception was by Alfred Stickler in approximately 1897, which he described in his contribution to Carl Jung's book *Studies in Word Association* (1919). Larson (1932), credits Chester Darrow with adding a skin resistance measurement to early polygraphs and experimented with a galvanometer himself, but reportedly decided to forego its use in favor of cardiographic-type response measurement. Marston (1938), reportedly experimented with the EDR component while devising deception tests for the United States Army in 1917, but wrote that he was unimpressed with the lack of specificity to deception. Marston realized that numerous emotional arousals could, and did, cause EDRs.

Reverend Walter Summers (1936), reported high levels of sensitivity to deception when using EDR measurements in both a laboratory setting and in limited criminal field applications. Krapohl (1993) comments;

> "Summers used his device and technique on only about 50 criminal suspects and he claimed tremendous success, though his verification of those results would not stand up to current standards of proof. His work, like that of Lombrosso and Marston, had garnered enthusiastic support only from the creator of the technique. Reverend Summer's Pathometer encountered limited general use." (p. 7).

Leonarde Keeler is commonly given credit for adding the EDR component, the recording of respiration, and relative blood pressure as early as 1949 (Reid & Inbau, 1977). Trovillo (1939), reported that Wilson, a colleague of Keeler, actually developed a polygraph that simultaneously recorded the three channels of respiration movement, cardiograph and electrodermal activity in approximately 1930. With the exception of a photoelectric device to record vasomotor changes, these components have remained the primary psychophysiological channels for detection of arousal associated with deception since the 1930s.

Anatomy and Physiology of the Skin[3]

The skin is called the integumentary system and consists of a complex set of organs that provide protective and sense functions. Skin protects the body from environmental threats such as temperature, chemical, mechanical and infectious agents by acting as a selective barrier. Skin can aid in the removal of substances like water and solutes from the bloodstream through the sweat glands. From a sensory standpoint, skin houses various receptors to provide afferent information related to touch, pain and temperature (Venables & Christie, 1973).

In many areas, skin allows for perspiration, which helps keep the skin moist and may contribute to flexibility, though this is less likely on the plantar and palmar surfaces (soles of the feet and palms of the hands). These areas have increased potential to be subjected to load bearing and friction and are considerably thicker, 600 microns as compared to the 15 microns found in many other areas (Venables & Christie, 1973). Skin also helps maintain a constant body temperature by controlling heat loss which is

[3] The material in this section is derived from the major scientific sources describing the Anatomy and Physiology of the skin (e.g. structure of the skin). Readers interested in the original scientific sources should see: Boucsein, 1992; Fowles, 1986; and Venables & Christie, 1973.

regulated by adjusting blood flow to areas near the surface of the skin and through thermoregulatory sweating. Increasing blood flow near the surface allows for cooling of the passing blood and this cooling is then passed on to lower lying tissue. Thermoregulatory sweating cools the surface of the skin by removing the latent heat when liquid water evaporates on the surface of the skin. At palmar and plantar sites thermoregulatory sweating occurs only in relatively high ambient temperatures (upper 80s F). Sweat glands on the soles and palms are more responsive to central nervous system (CNS) activation than to ambient temperature changes.

Skin is composed of various characteristic layers, though all layers are not uniformly found in all skin. Skin can be hairy or glabrous (hairless). Skin essentially consists of two main layers; an outer layer called the epidermis and a thicker lower layer, the dermis. The epidermis of glabrous skin as found on the palm is generally divided into three regions which compose five layers with each layer becoming progressively tougher and calloused toward the surface. The stratum malpighii region is comprised of the two deepest layers of the epidermis which are the strata germinativum, and spinosum. The stratum intermedium region consists of the stratum granulosum, and stratum lucidum. The latter is recognizable in limited body sites, primarily in palmar and plantar skin and is visible only if the horny layer is removed. The outermost region is called the stratum corneum and can be divided into a lower, middle and upper zone based upon the form of the cells and the space between the cells, which decreases as it approaches the surface (Boucsein, 1992).

The thicker layer of skin, the dermis, consists of two main parts; the papillary layer which contains a thin arrangement of collagen fibers and the thicker reticular layer, of thick collagen fibers that are arranged parallel to the surface of the skin. The dermis contains many specialized cells and structures. These include; nerve cells called Meissner's and Vater-Pacini corpuscles that transmit the sensations of touch and pressure, hair follicles with their associated oil and scent glands, erector pili muscles that attach to each hair follicle, blood vessels and nerves that transmit sensations of pain, itch, and temperature, and eccrine sweat glands, which are the putative source of EDRs.

Beneath the dermal layer lies the subcutis, also called the hypodermis, which attach the skin to connective tissue covering the muscles. This is also where the secretory part of the eccrine sweat gland may lie, along with blood vessels and nerves supplying the rest of the skin. When located here, the secretory portion of the eccrine sweat gland is embedded in fatty tissue and is supplied by the capillary network of that area with water and electrolytes (Boucsein, 1992). For the location of these structures, as well as the general location of the various layers of skin, see Figure 1.

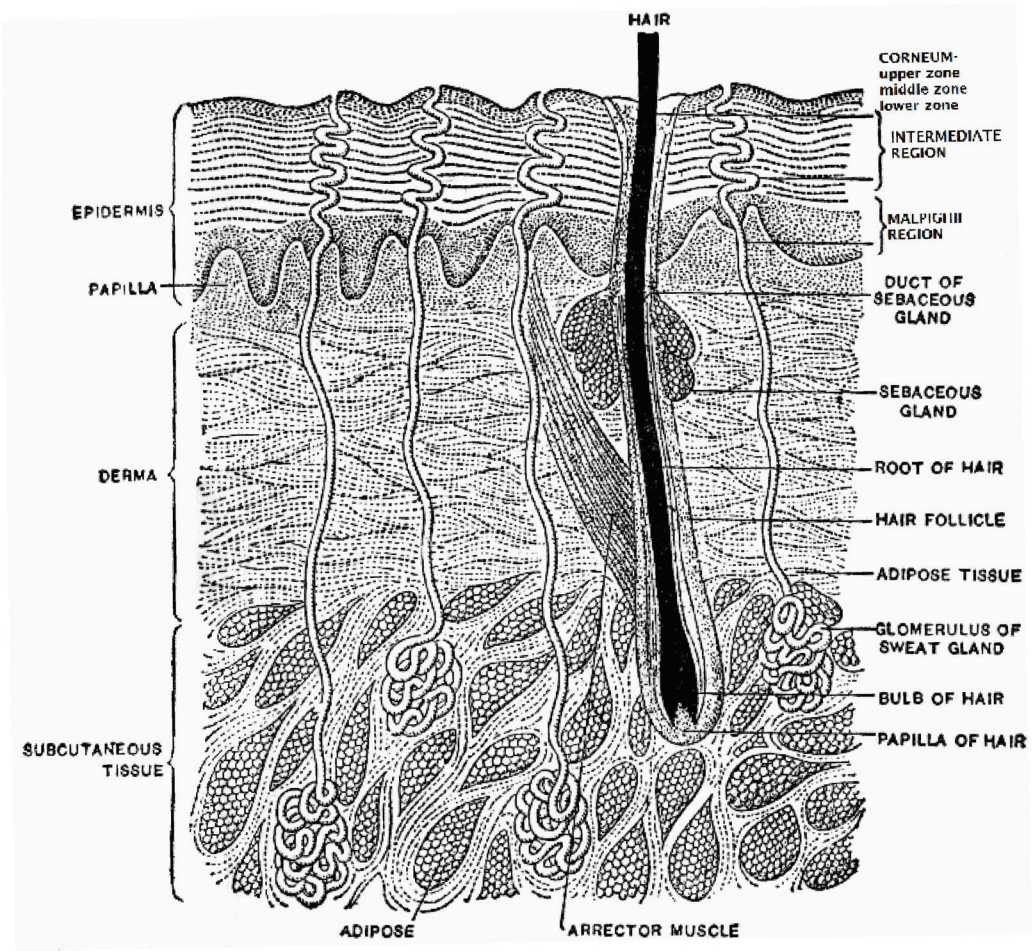
Sweat Gland Types, Distribution and Properties[4]

Humans have two basic types of sweat glands, apocrine and eccrine. Apocrine sweat glands are large in size, discharge into hair follicles, and become active during puberty. They are mainly found in the armpit and genital areas and are not the source of the EDRs measured and evaluated in psychophysiology or polygraphy. Eccrine sweat glands, on the other hand, are distributed throughout the body, but most are concentrated on the palms, soles and forehead and least dense on the arms, trunk and legs. Estimates place the number of eccrine sweat glands between 2 and 5 million (Fowles, 1986) and the total number of sweat glands is fixed at birth.

They are called eccrine because they contain comparatively little gland cell cytoplasm (the water based, jelly-like substance that fills the cell). The eccrine sweat gland consists of a coiled secretory portion

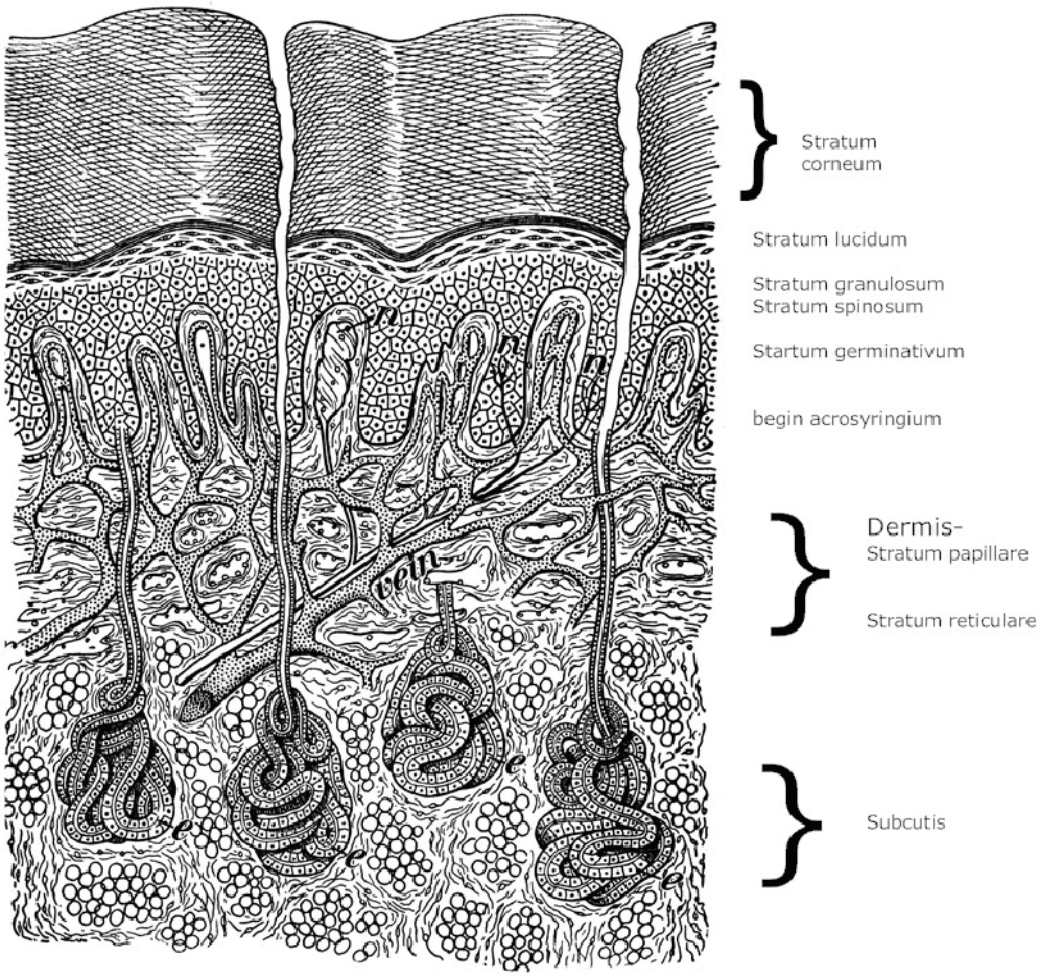
[4] The material in this section is derived from the major scientific sources describing sweat gland physiology and distribution. Readers interested in the original scientific sources should see: Boucsein, 1992; Fowles, 1986; and Venables & Christie, 1973.

Figure 1. Anatomy of the skin. Pope, Amy E. *Anatomy and Physiology for Nurses* (New York: G. P. Putnam's Sons, 1913) 439. Clipart courtesy FCIT, http://etc.usf.edu/clipart. Retrieved 9 February, 2010, from http://etc.usf.edu/clipart/52300/52321/52321_skin.htm.



(glomerulus) about .4 mm in diameter (see Figure 2) located in the subdermis and a ductal discharge tube that winds its way through the dermis and then follows a spiral course through the epidermis terminating at a pore on the skin surface. Both the secretory and most of the ductal segments are formed by two-to-three layers of cells (Figure 2). The wall of the ductal tube that passes through the epidermis is called the acrosyringium and it has no cells in its walls. Essentially it is a coiled duct surrounded by concentrically arranged epidermal cells. Since the acrosyringium has no wall cells (see Figure 2), it is possible for sweat working its way up the duct through the epithelium to escape the ductal tube without being deposited on the surface and hydrate the corneum (Fowles, 1986). If the corneum adjacent to the acrosyringium is adequately hydrated, discharge from the tube may then be directed to the surface of the skin. As the corneum becomes hydrated with ion-laden sweat, its ability to conduct a current will increase. When the sweat glands are completely full of sweat, however, the electrical conductance of the skin is presumed to increase markedly (Boucsein, 1992).

Figure 2. Layered construction of human skin shown in relation to the eccrine sweat gland including the secretory portion, the straight duct and the acrosyringium. Adapted from Chancellor, William E. *Standard Short Courses for Evening Schools* (New York: American Book Company, 1911) 244. Clipart courtesy FCIT, http://etc.usf.edu/clipart. Retrieved 9 February, 2010, from http://etc.usf.edu/clipart/44000/44013/44013_skin.htm.



The Sweating Action of the Eccrine Sweat Glands[5]

Efferent fibers from the sympathetic nervous system innervate the eccrine sweat glands secretory segment and dermal portions of the duct. These sudorisecretory fibers are intermeshed with fibers innervating pilo-erector muscles of the hair and fibers that innervate blood vessels, making it difficult to study them individually. The sudorisecretory fibers surround the secretory part of the eccrine sweat gland and use acetylcholine for innervation. No synaptic clefts have yet been identified and it is presumed that the neurotransmitter substance is released in the vicinity of cholinergic receptors on the secretory cells resulting in their depolarization and activation (Boucsein, 1992).

[5] The material in this section is derived from the major scientific sources describing sweating action of eccrine sweat glands. Readers interested in the original scientific sources should see: Boucsein, 1992; Fowles, 1986; and Venables & Christie, 1973.

Human precursor sweat contains relatively high concentrations of sodium (Na+), potassium (K+) and chloride (Cl-), all of which are vital to life. By the time the sweat reaches the surface of the skin, the concentration of those very important ions has been reduced drastically, presumably through the processes of active and passive reabsorption. Active reabsorption has been compared to the same action that occurs in the renal tubules of the kidneys (Boucsein, 1992). Relative to the interior of the body, sweat has fewer ions of sodium and chloride and is thus referred to as hypotonic. The concentration of surface sweat varies with the rate of sweating, presumably reflecting a limited reabsorption capacity (Fowles, 1986). The increased ion concentration during higher sweat rates may contribute to EDA changes. Reabsorption is thought to take place primarily in the dermal duct but also in the acrosyringium. Through the process of reabsorption, sweat gland ducts may help to protect the body from excessive ion loss during periods of profuse sweating. There is considerable evidence to suggest that sodium is reabsorbed via an active sodium-potassium pump. Sodium is exchanged with potassium resulting in an increase in potassium concentration in surface sweat (Fowles, 1986). Chloride concentration, however, passively diffuses down its electrochemical gradient to be reabsorbed (Fowles, 1986). While the chemical chloride ion gradient tends to oppose diffusion, the somewhat greater electrical potential facilitates it, resulting in passive diffusion.

Sato (1977) discovered that when secretory coil is not being stimulated, the lumen is almost completely collapsed. This would suggest there was an insufficient quantity of pre-formed sweat in just the resting lumen to reach the sweat pore opening and cause EDRs without some sweat contribution from the glomerulus. What Sato discovered was that when the glomerulus (secretory coil) is innervated, it contracts to about two-thirds of its original length within a couple of seconds of application of acetylcholine. When the coil contracts, the lumen dilates slightly and stays dilated until the innervation ceases. Presumably, this contraction of the glomerulus and dilation of the lumen contribute to movement of the sweat up the duct towards the surface of the skin. Sweat does not flow constantly from the secretory portion of the gland onto the skin surface. Rhythmic contractions of cells surrounding the secretory and ductal part of the gland have been observed to create sweat pulses at rates of around 20 cycles per second (Boucsein, 1992) which may help move the sweat up the duct towards the surface pore.

Suggested Biological Significance of EDA[6]

The biological significance associated with EDRs has been proffered in terms of evolutionary benefits. Explanations of the benefits of EDRs seem consistent with a number of psychological underpinnings discussed later in this paper. Edelberg (1972) suggested that thermoregulatory responses to emotionally arousing stimuli may be allostatic[7] in nature. Evaporative sweating may serve to decrease body temperature in anticipation of an upcoming burst of physical activity. Emotionally arousing stimuli, result in vaso-constriction which leads to a reduction in skin blood flow. An adaptive purpose of this vasoconstriction is to increase systemic blood pressure for increased large muscle perfusion. There is an additional benefit of reducing cutaneous blood loss should a cut occur during the state of arousal. Cutaneous blood flow plays a part in thermal regulation so a reduction in surface blood flow could lead to a rise in body temperature. Perhaps evaporative cooling via EDRs helps compensate for the reduction in heat loss resulting from vasoconstriction.

Increased palmer perspiration may allow for better tactile differentiation (Darrow, 1933), better hand grip (Boucsein, 1992; Darrow, 1933), and protection against injury

[6] The material in this section is derived from the major scientific sources describing some of the possible biological significance of sweat glands. Readers interested in the original scientific sources should see Edelberg, 1967.

[7] Allostatic refers to the maintenance of homeostasis through physical or behavioral response. A resource for readers interested in allostasis as it relates to polygraphy can be found in *Polygraph*, 37(3), 228-233.

(Adams & Hunter, 1969). Increased plantar perspiration allows for better footing; (Edelberg, 1967; Boucsein, 1992) an obvious benefit to bare foot runners and tree climbing primates.

EDA and the Electrical Properties of Skin[8]

There is ample empirical evidence to support the notion that sweat gland activity contributes to the phenomena of EDA, and allows the use of an electrical conductance/resistance model for explanation. Sweat moistened epidermal tissue contains ions which increases skin conductivity. The layers of skin below the epidermis show good electrical conductivity and do not contribute to skin resistance changes measured during an EDR (Boucsein, 1992). Most electrical models of skin assign the role of a variable resistor to the entire stratum corneum, relative to its degree of hydration. The dead cells of the stratum corneum act like a sponge, taking in moisture from above (outside the body or from any electrolyte solution) and below (from within the body). The stratum corneum is usually partially hydrated and the degree to which it is hydrated will be the primary contributor to EDL. Changes in corneal hydration will generally result in tonic level changes of EDA, but also have an effect on the amplitude of EDR (Fowles, 1986). Increased hydration reduces resistance and increases conductance while a drier stratum corneum works oppositely. When the corneum is either extremely hydrated or extremely dehydrated, EDRs are minimal. It is at intermediate levels of corneal hydration that maximal levels of EDRs are achieved (Stombaugh & Adams, 1971).

Sweat secretions result in not only corneal hydration but also in filling of the sweat duct. Both duct filling and corneal hydration lead to changes in skin conductance, though duct filling is the primary mechanism by which EDRs are elicited (Fowles, 1986). Filling the ducts results in direct electrical shunts (allows electrical current to flow directly) from the surface of the skin to and through the relatively moist dermal layers. For any given level of corneal hydration, changes in the height of the sweat in the duct will modify the resistance across the corneum: the duct works like a variable resistor. Edelberg (1983) demonstrated how the level of sweat in the duct at innervation has a marked effect on EDR amplitude. Edelberg manipulated the level of sweat in the duct prior to innervating the gland and measured the results. The conclusion was that higher initial levels of sweat in the duct produced EDRs of greater amplitude, in fact at times tripling the response.

There are many proposed theories and models of the electrical properties of the skin and a number of those were reviewed by Edelberg (1972). No single model is completely tenable and stands on its own but most accept some general facts. EDRs require the presence of active sweat glands. This fact that has been substantiated by interrupting the sympathetic nerve supply to the sweat gland through chemical blockage or sympathectomy, as performed in efforts to alleviate a condition known as hyperhidrosis. In either case, these affect EDRs at the interface between the sweat gland and the sympathetic cholinergic innervation occurring there. Beyond this point, it becomes difficult to specifically point to the mechanism responsible for EDRs. Edelberg (1972) suggested the capacitance properties of the skin and sweat glands contributed to the fast rise, phasic EDRs. When an external current is applied to the skin, the cell membranes can store electrical potentials like a capacitor. Edelberg (1971) posited that larger cell assemblages may act together to selectively allow passage of certain ions as if they were parallel capacitors. Thus the phasic EDR response observed in polygraphy could in part be due to membrane depolarization when the cells are collectively neurologically stimulated. The capacitive properties of skin and sweat gland ducts have not been well investigated compared to those that are resistive in nature. This may be due

[8] The material in this section is derived from the major scientific sources describing the electrical properties of skin. Readers interested in the original scientific sources should see: Boucsein, 1992; Edelberg, 1967; Fowles, 1986; and Venables & Christie, 1973.

in part to the difficulty of isolating the capacitance aspect of the skin and sweat duct and because capacitance measurements would require the use of the far less common AC circuitry (Boucsein, 1992). While capacitance properties likely contribute to the EDR phenomena, models built solely on resistive elements have heuristic value for EDA modeling and explanations. Edelberg (1983, Fig.1) resorts to a resistive model to explain EDA and foregoes the discussion of conductance via the active epithelial membrane. Resistive models of skin which regard each sweat duct as an individual resistor that is switched on when full and off when less than full (Boucsein, 1992) suffice to explain the phenomena of EDRs. Edelberg (1983) provided evidence that exosomatic EDRs are a function of duct-filling and the secretory component, while EDL is a function of corneal hydration. A general summary of the resistive model of eccrine sweat gland system offered by Boucsein (1992) is:

A. A fixed but low resistance area below the stratum corneum.
B. A variable resistor created by the degree of corneal hydration.
C. A fixed resistor formed by entire epidermal layer.
D. A variable resistor formed by the collective number of filled sweat glands at any given point in time.

Electrical Properties and EDA Measurement Methods[9]

Given that EDRs are typically characterized as simple resistance changes, a resistance measurement circuit can be used to quantify them. EDA responses are relatively slow moving in nature, so most measurement circuits will employ a low pass filter set to about 6 Hz to remove any extraneous circuit noise. Most circuits will also employ a high pass filter to factor out any long term tonic change or baseline movement. With both filters combined, the measurement circuit looks only at the resistance changes of actual responses, ignoring other portions of the signal which are irrelevant as far as PDD is concerned. To actually measure a resistance change, the circuit uses the principle of Ohm's Law. Ohm's law states Voltage (V) equals Current (I) times Resistance (R), represented mathematically as $V = I * R$. If a small constant current is applied to two electrodes placed on the skin, changes in voltage can be measured which are directly proportional to changes in resistance. Alternatively, holding the voltage constant allows for the measurement of current which is proportional to conductance, the mathematical reciprocal of resistance. Both skin resistance and skin conductance circuits have been described for use in field polygraph settings (Boucsein & Hoffman, 1979; Honts & Barger, 1990; Lykken & Venables, 1971) and modern polygraphs generally employ either a constant current or a constant voltage circuitry to measure and record EDA.

Discussions of superiority of how to measure EDRs either with a constant current or a constant voltage systems have often digressed to consideration of units of measure, ohms versus micro-siemens, as much as they did on method. A clear indication of the superiority of one method over another is lacking in the present literature. Honts and Barger (1990) reported equal sensitivity for constant current and constant voltage systems when comparing analog polygraphs from Lafayette Instrument. They reported examiners made substantially fewer centering adjustments, approximately one-half as many, with a constant voltage model than they did with a constant current circuit. Kircher, Packard, Bernhardt and Bell (2003) found no difference in detection of deception efficiency between SR and SC when converting conductance to resistance units after collecting with a constant voltage system. Boucsein and Hoffman (1979) made a direct comparison of EDA measurements with both models and units and reported no difference in sensitivity of measurement. Barry (1981), in a study of orienting and habituation, also reported robust EDA measurements in both constant current and constant voltage models.

[9] The material in this section is derived from the major scientific sources describing electrical properties of skin and EDA measurement techniques. Readers interested in the original scientific sources should see: Boucsein, 1992; Fowles, 1986; and Venables & Christie, 1973.

Edelberg (1967) conducted one of the earliest comparisons of the constant current vs. constant voltage methods of measuring EDA. His conclusion was that both methods suffered from individual shortcomings. Most electrical models of EDA include at least a concept of the sweat gland ducts providing a path for electrical current to flow from the electrode through the epidermis. If relatively few sweat ducts were full, the current density through those few ducts could be high. He found the constant current model produced non-linear results with subjects having high SRLs and recommended limiting current density to 10 μA/cm2 as well as using electrodes with the greatest possible surface area (guidelines which are followed on modern equipment.) Lykken and Venables (1971) expressed concern that the SRR circuit could overwhelm and possibly damage the glands in those instances with relatively few active glands. The potential for sweat gland damage posed by this hypothetical extreme case would be alleviated by use of a constant voltage system, since the current flow would be proportional to the number of ducts "switched on" (Boucsein, 1992).

Investigators interested in comparing results in terms of units often debate over whether conductance units are superior to resistance units. Lykken and Venables (1971) strongly suggest that skin conductance units are preferable with respect to reflecting the physiological model of the mechanism resulting in EDRs and should be given credit for designing the circuits that are the current standard for measuring SCR. Boucsein (1992) argues, however, that theoretic and empirical support for one unit over another is not completely convincing and points out that this discussion is mostly academic and sometimes confounded with the question of method of recording. Boucsein (1992) suggests "standard methodology" includes DC recording with a constant current not exceeding 10 μA/cm2 or a constant voltage of .5V. In polygraphy it is posited that we are concerned with the relative amplitude of one response compared to another, as plotted changes in resistance or conductance, and do not convert those changes into conductance or resistance units. Thus, units of measure may be irrelevant. When a direct comparison of units of measure is a concern, conductance units may be favored in the interest of standardization.

Another understudied phenomenon in the use of EDA in field polygraph involves assumptions about linearity of physiological response. Linear assumptions would pose that there is a straight line relationship between the number of sweat glands that "switched on" and the resultant EDR change. Linear assumptions would state that if twice as many sweat glands "switched on" then the EDR amplitude would double. There is nothing to encourage any expectation of linearity of physiological response to polygraph test stimuli, and an abundance of established wisdom regarding the non-linearity of some physiological responses. There appears to be a dearth of research aimed at investigating whether there is biological linearity with EDRs. Blank and Finesinger (1946) showed that sweat gland activity displayed graded reactions to varying frequency of neural impulse, suggesting such linearity did not exist. Some may try to infer a linearity between conductance and sweat gland activity from the work of Thomas and Korr (1957), but a careful look at their experiment shows they collected EDRs while heating the skin to dry it out thus ensuring there was no sweat in the corneal portions of the sweat duct. This is not at all consistent with how we collect EDA during field polygraphy and it would be difficult to generalize the results of that work to PDD testing. Therefore, any responsible and accountable claim of validity surrounding the use of linear assumptions in the scoring and interpretation of EDA will be premised on an articulate description of the relationship between observed or measured response and the actual volume or degree of physiological activity. This will necessarily involve a more complete description of the details of measurement and recording, and there are non-trivial complications that will inevitably hinder, and probably preclude, any effort to validate a linear paradigm for the measurement and recording of EDA.

An exercise in the conversion of resistance to conductance units can demonstrate the difference that tonic or baseline EDLs can have on linearity. Take a hypothetical situation in which a stimulus evokes a 10 K ohm EDR in both a low (20 K ohm) EDL subject and a high (100 K ohm) EDL subject. Both subjects experience an equivalent resistance change (10 K ohm), and yet the conductance change is not at all equal.

The stimulus causes 50 microsiemen change in the low EDL subject and a 1 microsiemen change in the high EDL subject (see Table 2).

Table 2. A comparison of skin resistance and skin conductance with high and low resistance baselines

	Resistance (ohms)	
	High Resistance Baseline	Low Resistance Baseline
Prestimulus	100K	20K
Post Stimulus	90K	10K
Response Amplitude	***10K***	***10K***
	Conductance (μS)	
	High Resistance Baseline	Low Resistance Baseline
Prestimulus	10	50
Post Stimulus	11	100
Response Amplitude	**1**	**50**

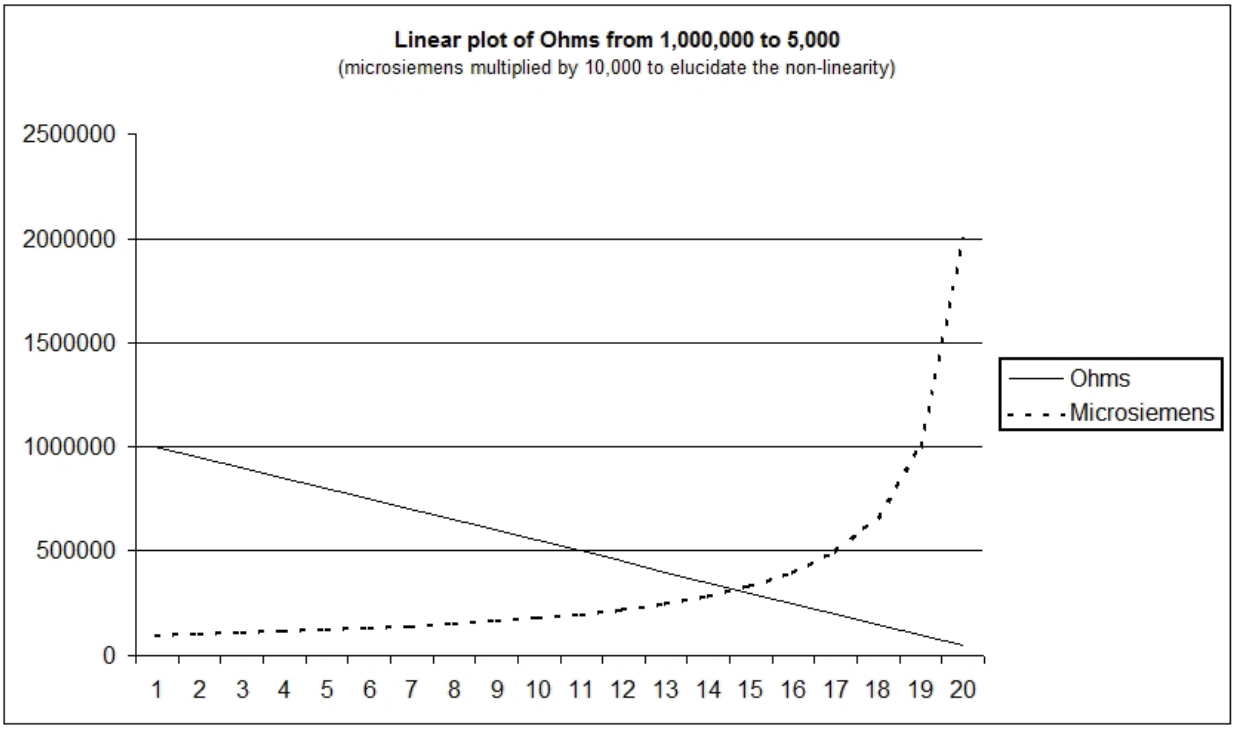
Resistance, measured in ohms, is the multiplicative inverse of conductance, measured in micro-siemens, such that a resistance of 1,000,000 ohms will have the conductance of 1/1,000,000 = .000001 (1 micro-siemen). Similarly, a resistance of 1 ohm will correspond to a conductance of 1 Siemen (1/1 = 1), and a value of .000001 Siemen will correspond to 1,000,000 ohms (1/.000001 = 1,000,000). The simplicity of these formulae can be initially misleading, until resistance values are plotted against conductance values, and it is revealed that there is a non-linear relationship between resistance and conductance (as demonstrated in Table 2). Figure 3 shows a linear plot of changes in resistance from 1,000,000 to 5,000 ohms, and illustrates the non-linearity of corresponding conductance values. For the purpose of this illustration, conductance values have been multiplied by 10,000, to better reveal the non-linear relationship (a linear relationship would remain linear with this transformation).

This exercise suggests a need to compare reactions of relatively similar tonic levels, depending on which features of the physiological data are plotted for evaluation, because a 10K ohm change in resistance at a low tonic level can be expected to produce a different change in conductance when compared with a 10K ohm change at high tonic level. Similarly, a change in conductance of 1 micro-siemen at a low tonic level would produce a different change in resistance when compared with a conductance change of 1 micro-siemen at a high tonic level.

Regardless of the measurement method, any recording of EDA will include data pertaining to both resistance and conductance, because they are mathematically related. What is important to field examiners is not the linear representation of an arguably non-linear phenomena, but a reliable recording of EDA. EDR recordings should graphically and mathematically allow for the expedient recognition of differences in response magnitude when the examinee is presented with a sequential set of test stimuli.

In support of this recommendation, Boucsein, Baltissen & Euler (1984) reported a directional discrepancy between SRR and SCRs taken from parallel sites traced to tonic level differences. At high noise levels, SCR

Figure 3. Linear plot of resistance and conductance values.



amplitudes increased while SRR amplitudes decreased with repeated presentations. The discrepancy was attributed to tonic levels of EDA and the changes in those levels over the course of the data collection. Even if the level of "true" psychophysiological arousals were able to be held constant, the SRR amplitude, or reaction, will decrease as SRL decreases over the course of the experiment. The same size arousal will not produce the same sized SRR. Conversely, SCR will tend to overestimate the measure of the true reaction as the SCL increases across the experiment. Since in polygraphy we generally compare relative SCR or SRR of stimuli close in time, the tonic level should be similar at both points of comparison, and this concern becomes moot. Indeed computer models trained on "raw data" do not isolate changes in phasic reactions from changes in tonic reactions (J. C. Kircher, personal communication, February 11, 2010). Apparently the EDR signal is robust enough to tolerate slight tonic level changes between reactions and still allow the computer model to be trained to effectively discriminate reactions of truthful from deceptive examinees. It appears, however, to provoke concern for EDL consideration when comparing waveforms that were measured apart in time. Over the course of the experiment, the EDLs can change and based on the work of Boucsein *et al.* (1984) this can affect the relative amplitude change for a given true reaction. In other words, equal psychological reactions measured at different tonic levels can produce different sized EDRs.

Recording Sites and Electrodes[10]

Most electrodermal researchers record EDA from the volar (palmar) surfaces of the fingers or the palms. Venables and Christie (1980) cite the following as considerations when determining site placement: (a) ease of

[10] The material in this section is derived from the major scientific sources describing recording techniques. Readers interested in the original scientific sources should see: Boucsein, 1992; Edelberg, 1967; Fowles, 1986; and Venables & Christie, 1973.

affixing the electrode where it will be minimally affected by movement, (b) size availability of the area, (c) likely freedom from scarring, (d) relative electrodermal activity of the area. The thenar and hypothenar eminence are slightly more electrodermally responsive than the volar surfaces of the fingers, which may also suffer from having a small area, particularly in the case of slender fingers. Following the recommendations of Edelberg (1967), when using the fingers, Venables and Christie (1980) recommend the medial phalanges of the index and ring fingers as they offer a larger surface area and are less prone to movement than the proximal phalanges. If using a palmar site, Venables and Christie (1980) recommend the thenar and hypothenar eminence of the non-dominant hand, which may be less calloused. Scerbo, Freedman, Raine, Dawson and Venables (1992) reported that SCR at the distal phalanges were 3.5 times greater than those from the medial sites and recommended the distal phalanges be preferred. (See Figure 5 for preferred volar and palmar electrode location.) Edelberg (1967) reported finding satisfactory EDR when the electrodes were placed on the medial site on the side of the foot over the abductor hallucis muscle and midway between the proximal phalange of the big toe and the ankle (See Figure 4).

Figure 4. Recommended recording sites for exosomatic recording, adapted from Edelberg (1967).

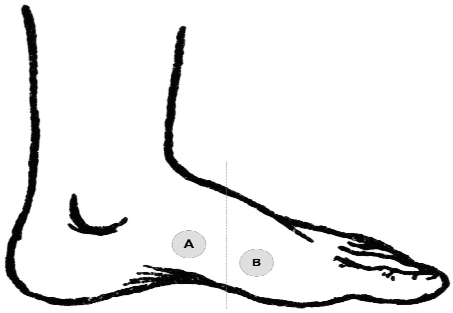
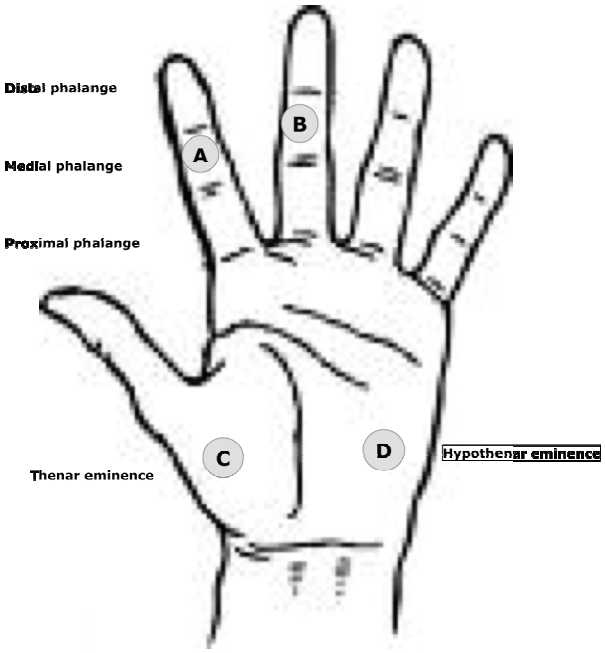


Figure 5. Suggested volar and palmar electrode locations for exosomatic recording. Sites A and B are shown on the medial phalanges as recommended by Venables and Christie (1980).



Another consideration for electrode placement is artifacts resulting from skin movement below the electrode and muscle movements in general. To achieve an optimal EDR measurement free of artifacts, the subject should be instructed to sit quietly and refrain from movement. Edelberg (1967, page 38) lists the following four mains sources of movement related artifacts; (a) disturbance of the electrolyte to skin contact below the electrode, (b) changes in the intimacy of contact between the skin and the electrode, (c) pressure induced changes, (d) body movements. Most of these can be minimized with modern disposable "wet" electrodes.

Commercially available "wet" silver/silver chloride (Ag/AgCl) electrodes with a surface area of about 1 cm^2 are considered standard (Boucsein, 1992). The wet electrodes are generally available from polygraph instrument manufacturers and are recommended over "dry" electrodes. Wet electrodes that apply via an adhesive have a number of benefits. The wet electrodes maintain an intimate contact between the electrode and the skin surface, reducing potential for artifacts. Wet electrodes contribute to decreases in the tonic skin resistance by hydrating the upper layers of cornea beneath the electrode, allowing for sweat to move up the duct to the electrode rather than outward to hydrate a dry corneum. This could allow for faster shunting of the electrical circuit in the resistive model and faster EDRs. The wet electrodes provide a level of partial hydration of the corneum that may help achieve an optimum intermediate level of hydration for maximal amplitude EDRs (Stombaugh & Adams, 1971). There seems little concern that using wet electrodes in a PDD setting will result in extreme levels of corneal hydration that could minimize amplitude of EDRs. Fowles (1986) estimates it would take approximately 86 minutes for water to completely diffuse entirely through the corneal layers into the dermal layer below.

Another aspect of using wet electrodes which bears consideration is the possibility of pore blockage. Arguably, wet electrodes retard the ability of surface sweat to evaporate. The corneum can absorb up to 600% of its weight (Fowles, 1986) in water and this causes it to swell. This swelling near the surface of the skin under the electrode can lead to occlusion of the sweat duct, which would prevent sweat from reaching the surface of the skin and the electrode, possibly reducing maximum conductance. This loss of response potential will be considerably offset, however, by the well-hydrated corneum (Fowles, 1986).

Ample time should be given after applying the electrode to allow the electrolyte to penetrate the corneum so the skin to electrolyte interface can become stable. Boucsein (1992) recommends a minimum of 15-20 minutes be allowed before recording to minimize drift due to the destabilizing effects that occur while an equilibrium is being reached. The adhesive connection allows the electrode to be attached without a cord or strap. Attaching the electrode with a strap could create artifacts from a pressure related phenomenon known as Ebbecke waves as well as from occluding circulation (Edelberg, 1972). Finally, the use of wet electrodes will help mitigate any of the potential problems mentioned when discussing the constant current versus constant voltage systems. Wet electrodes will reduce the potential for relatively few sweat ducts being filled and having a concentrated current driven through a small number of ducts. By using 1 cm^2 disposable electrodes it is likely to spread the current across the entire electrode area. With concern for a relatively few number of ducts filled in a constant voltage circuit, wet electrodes would hydrate the upper corneum below the electrode, allowing sweat to fill the duct rather than migrate out to a dry corneum.

One final concern is the electrolyte media used. Hypertonic gels, those with maximum conductivity properties, used for other biosignals like EKG, EEG and EMG *should not* be used for EDA measurements. The signals of interest in those measurements occur below the body surface and the principal measurement aim is to transduce those signals most effectively. Using hypertonic gels that have near saturation concentration of saline will result in a continuous fall in SCL and SCR over time (Venables & Christie, 1973). The gels used for EDA signals interact with the tissue from which a portion of the biosignal is produced. The electrolyte should therefore be as close as possible in ionic concentration as that found in the stratum corneum to minimize the

disturbance of the signal. Commercially available gels specifically developed for EDA collection are available as pre-treated disposable Ag/AgCl electrodes, which together offer the best solution for a number of these problems. Finally, pretreatment of the electrode attachment area by washing with soap and water (Venables & Christie, 1980) serves to remove oils and other deposits that may interfere with the electrode attachment or contact with the skin and is recommended.

Central Nervous System Control of EDA[11]

A variety of mental functions are capable of eliciting an EDR. Research concerning those eliciting states are divided into studies of EDRs from discrete stimuli and those resulting from general state changes. Discrete stimuli studies evaluated such phenomena as orienting responses (OR), defense responses (DR), and habituation. These studies also address classical and operant conditioning, learning information processing, information storage and mental work effort (sometimes referred to as load). Generalized psychophysiological state studies include investigation into general arousal, motivational arousal, emotion, stress and psychopharmacology.

Most data concerning the role of the CNS in the production of EDRs stems from animal studies. Recent fMRI studies of patients with and without brain lesions have elucidated our understanding of the CNS in terms of which brain regions become active during EDRs in humans. Several brain regions associated with stimulus significance become active concurrent with EDRs. These include areas of the prefrontal cortex, amygdala, and the anterior cingulate cortex (Dawson, Schell & Filion, 2007). The hypothalamus is regarded as the controlling center for all ANS functions, including sweat gland innervation. Hypothalamic sympathetic activity can be elicited by a number of brain structures, not the least of which includes the cerebral cortex, basal ganglia, hippocampus, thalamus and brain stem areas (Boucsein, 1992). Boucsein (1992) summarized the experimental and clinical evidence concerning CNS elicitation of EDR by dividing them into two distinct groups; a limbic-hypothalamic source (which is emotionally and thermoregulatory driven) and a pre-motor basal ganglia source occurring in preparation for motor movement.

From a polygraph perspective, studies of ORs, DRs, habituation, information processing (including learning and memory), mental load, motivation and emotion would seem most germane. These areas would best serve to inform the polygraph profession about potential sensitivity and specificity of EDRs and may help better understand the psychophysiological construct of PDD testing. While not all research in these areas will apply directly to PDD testing, each offers aspects related to PDD testing from which we may glean knowledge. A general review of each will allow an opportunity to consider what they may offer PDD testing.

ORs, DRs, and Habituation[12]

Pavlov (1927) was first to describe the orienting response (OR) or orienting reaction referring to it as the "orienting reflex." He described it as a reflex that brings an immediate response in both human and animal to changes in their surroundings. Pavlov sometimes called it the "what is it" reaction, and noted it was of great significance for survival. Some stimuli known to cause an OR include: novelty, intensity, color, surprise, a conditioned stimulus, complexity, uncertainty or conflict (Pavlov, 1927). The most prominent and perhaps best studied biological concomitants of the OR is the EDR.

The OR is nonspecific, occurring not only during changes in stimulus intensity but

[11] The material in this section is derived from the major scientific sources describing CNS control of EDA. Readers interested in the original scientific sources should see Boucsein, 1992.

[12] The material in this section is derived from the major scientific sources describing orienting and defense responses. Readers interested in the original scientific sources should see: Pavlov, 1927 and Sokolov, Spinks, Naatanen & Lyytinen, 2002.

also at stimulus onset and offset. ORs can be separated into categories of general, localized, tonic and phasic. General ORs result from a generalized increase in sensitivity of a sensory system and habituate quickly, such as when the humming of a fluorescent light fixture initially draws attention but soon becomes part of the neglected background. Localized ORs result from specific stimulation, in any modality, and require a greater number of trials to habituate. Tonic ORs are dependent upon general cortical arousal level and result in a shift in the sensitivity level of the system affected. Phasic ORs are those of most interest in PDD testing as they are considered stimulus related.

Stimuli that elicit ORs may be categorized as either signal or non-signal stimuli. Signal stimuli are those that convey important information to the organism and may be regarded as significant (Sokolov, Spinks, Naatanen & Lyytinen, 2002). An example of a signal stimulus would be the sudden appearance of a deadly predator in the local area. Non-signal stimuli are those the organism considers neutral, that is, they convey no important information, such as different pure tones (Cacioppo, Tassinary & Bernston, 2000). Novel stimuli are initially signal stimuli as they convey to the organism that something new has happened and they reliably elicit an OR. If a novel stimulus is repeated but not paired with any meaningful consequence, the OR associated with it will decrease and eventually become extinct through habituation. Habituated stimuli, which were formerly novel stimuli, do not elicit ORs.

Significant stimuli (those with signal value) can evoke an enhanced OR (Gati & Ben-Shakhar, 1990). Sokolov (1963) determined that stimulus significance (or salience) can affect the magnitude of an OR. He stated "signal stimuli" were stimuli that were not novel but rather familiar and important. From a survival standpoint, perhaps it is more beneficial to an organism to respond to a stimulus of known importance than one which is novel (Cacioppo, Tassinary & Bernston, 2000). Sokolov found that an organism could impart significance to a stimulus based on perceived importance to that particular organism. In this sense, the subject then self-assigns signal value to the particular stimulus based on a previous assessment. The OR can be an affectively neutral response as well as one that occurs concomitantly with an emotional stimulus (Ohman, Hamm & Hugdahl, 2000).

The OR can be viewed as an attention response to any significant or potentially significant stimulus, depending on the current concerns of the examinee. Data have shown stimuli with signal value elicit larger and more slowly habituating ORs than non-signal ORs (Siddle, Stephenson & Spinks, 1983). While the response patterns for signal and non-signal ORs were similar, the underlying purpose may differ. Non-signal stimuli (novel stimuli) evoke responses that may signal the organism that a potentially harmful or dangerous situation exists and prepare the organism to deal with that situation. Signal value stimuli are evaluated by the organism and possibly recognized to be associated with consequences. These consequences are postulated to be tied to memory (Ohman, 1979).

The organism evaluates the stimulus and compares it to information stored in long-term or short-term memory. The current input is compared to active memory to determine if the stimulus is new (mismatch against previously encoded information) or if the stimulus matches an element of memory that has been primed to be significant (Cacioppo, Tassinary & Bernston, 2000). In either case, an assignment of novelty or significance can result in an OR. Both signal and non-signal ORs may have the initial cognitive function of information intake and processing of the stimulus. In the case of non-signal stimuli, a mismatch results in the OR occurring. The organism may compare the stimulus to information stored in memory and assign signal value (based on recognition and possible consequences) resulting in a signal value OR.

After repeated presentations, a stimulus that caused an OR may cause an individual to adapt. For example, a person sitting in a polygraph chair may initially notice the sensation of his hand against the arm rest of the chair. After a period of time, he no longer senses the chair as his tactile sensory neural circuits adapt to the feeling of hand-to-chair contact. Another example might be the sensation of wearing eyeglasses which is adapted to after a period of time.

Repeated iterations of a stimulus may result in sensitization or the generation of a defensive response (depending on the salience or signal value of the stimulus if it is high enough) or may fail to elicit a response (habituation). ORs are said to have "selective habituation" (Sokolov, Spinks, Naatanen & Lyytinen, 2002) as habituation rates are affected by stimulus intensity. For PDD testing, this may mean more salient stimuli habituate at a slower rate than those of lower intensity.

The term Defensive Response (DR) is used to describe a protective response to a highly intense or aversive stimulus. DRs are said to be specific to stimuli that occur at painful levels of intensity. They are slow to habituate and may serve a protective function which may be directed towards escape from a dangerous situation (Graham, 1997). While the OR can be produced in the absence of an affective component, it is hard to think of an instance in humans where a DR would be elicited without an emotional or motivational aspect occurring concomitantly. The cognitive processes of the OR and DR share many of the same physiological responses. This makes sense in that they both serve to mobilize the animal for efficient action. The chief distinction between the two is cephalic vasoconstriction during DR and cephalic vasodilation during OR as well as faster habituation for the OR (Sokolov, Spinks, Naatanen & Lyytinen, 2002). Stimulus intensity can cause a shift from an OR to a DR. For example, suppose a man quietly relaxing in a small fishing boat on a river habituates to the sounds around him. Unbeknown to him there is an A-10 jet following along the river and is approaching the area where he is fishing. The man perceives the sound of the jet as it rises above his auditory threshold and he orients towards the new sound (mismatched from his previous set of stimuli input). In a moment he recognizes the sound for what it is and quickly realizes the jet will produce an aversive noise and sensation as it passes overhead. The approaching jet has now become a significant stimulus to the man, one that will likely result in a desire to withdraw. As the A-10 flies over the man at about 300 feet it causes an ear-splitting and threatening sound from which he tries to escape by covering his ears. It is highly likely that in the above scenario that the original OR changed to a DR as the stimulus became significant and aversive in nature. Lynn (1966) suggested that moderately intense stimuli can initially evoke an OR and then in later presentations can evoke a DR. A mild pain stimulus may be interpreted as a novel stimulus and initially evoke an orienting response. However, continued presentation of the painful stimulus can eventually result in a DR (Sokolov, Spinks, Naatanen & Lyytinen, 2002).

The demarcation between ORs and DRs is unclear. There have been reports of difficulty in distinguishing between the two in literature (Graham, 1979; Turpin, 1986). The general cardiac response to a non-startling, long duration stimuli includes; an initial decrease in heart rate (HR), an acceleration of HR peaking at about 4 seconds, and a deceleration or return to baseline (Graham, 1997). Turpin (Cook & Turpin, 1997) interpreted an additional large long-latency (35 seconds) acceleration of HR as a fight or flight response and attributed these long latency responses to motivational and emotional aspects of escape or avoidance. Turpin suggested that shorter latency (5 second) phasic ANS changes may be linked to attentional responses associated with stimulus intensity.

Some investigators proposed that the OR and DR produce different changes in heart rate. Graham and Clifton (1966) suggested ORs would be accompanied by a decrease in heart rate and DRs with an increase in HR. Raskin, Kotses, and Bever (1969) confirmed this suggestion in a study using sound. Moderate intensity sound (80 db) produced HR decelerations and high intensity or nociceptive (painful stimulus) sound (120 db) produced an increase in HR. Graham and Clifton (1966) reviewed a number of studies relating to HR changes to weak and moderate stimuli. They concluded the OR was accompanied by HR deceleration and that HR acceleration was most likely attributable to stimuli of "pre-pain" intensity.

Raskin (1979) found a correlation between heart rate, relative blood pressure and peripheral vasomotor reactivity that was suggestive of a DR during comparison question test (CQT) polygraph examinations. Plotting a second-by-second analysis of the

relationship among those parameters following the presentation of a relevant question, Raskin found a heart rate increase, followed by a decrease, which is indicative of a DR. The relative blood pressure measurements showed a rapid rise and then decrease, lagging the heart rate by about one second. There was a marked increase in vasoconstriction occurring concurrently with the other changes. Raskin concluded the heart rate increase and vasoconstriction caused the rise in blood pressure and baroreceptor reflexes caused a decrease in heart rate and concurrent decrease in relative blood pressure. These findings suggested a DR type response to strong signal value stimuli during CQT testing though he was unable to replicate these findings during Concealed Information Testing (CIT).

These studies focus on HR as an indicator of differentiation between ORs and DRs. Limited success has been found in using EDRs to differentiate ORs from DRs (for a thorough review see Boucsein, 1992). From a practical PDD testing perspective the differentiation of ORs and DRs may not matter. There seems the potential for either one, or both, to exist in a PDD testing milieu. Testing context, guilt status, examinee-examiner interaction, test stimuli, examinee level of socialization and psychopathology all seem to be capable of producing ORs or DRs or both.

Information Processing and EDRs

PDD testing involves presenting stimuli that require more than simple orienting and conditioning responses. Examinees are presented with questions to which they attend and evaluate for salience. CQT theory posits that truthful examinees will respond more strongly to comparison questions and deceptive examinees will show greater responses to relevant questions. Relevant questions are generally direct, behavior-based inquiries into a specific behavioral act of interest, "Did you rob the 1st National Bank?" Comparison questions refer to a category of activity, and are those for which it is either known or highly probable that the examinee is lying, "Did you ever steal anything?" PDD testing theory holds that comparison questions are more salient for truthful examinees and relevant questions are more salient for deceptive examinees. Information processing tasks such as attention, information update, mental work, decision and storage are involved in processing test questions. There is evidence for empirical and theoretical correlation between information processing load, internal cognitive processes (thoughts) and the elicitation of EDRs (Boucsein, 1992). Also, EDRs were found to be possible indicators of memory storage and retrieval processes (Raskin, 1973).

Emotion in PDD and EDR Elicitation[13]

Khan, Nelson & Handler (2009) discussed the complex emotional, cognitive and behavioral factors that are thought to play a role during PDD testing, providing a common understanding that explains the range of PDD phenomena more effectively than the traditional and simplistic attributions involving fight, flight and freeze. Although there remains no consensus in the exact mechanism of this relationship, most research has identified at least two distinct patterns, or levels, of appraisal: subconscious and conscious awareness. While both levels of appraisal trigger emotions, conscious awareness and evaluation would seem to be a prerequisite in PDD testing. Test questions in the PDD setting are perceived by the examinee and can be cognitively appraised with consideration of how they relate to his or her goals, standards or attitudes. These appraisals serve a mediating function for valence[14] and salience, and influence the type and degree of emotional and physiological responses. The exact emotions that are stimulated can vary widely among individuals based on their prior experiences, values, goals, and expectations and most importantly, how the situation is appraised.

[13] The material in this section is derived from the major scientific sources describing arousal models. Readers interested in the original scientific sources should see Boucsein, 1992.

[14] Valence in the present context refers to the quality of an emotion. For example, elation would be characterized as having positive valance, whereas fear might have negative valence.

There have been a number of models proposed to describe arousal and their neuropsychophysiological foundations, including EDRs. Evidence from brain lesion and imaging studies converges with neuroanatomical knowledge to inform us of the possible sources of EDR elicitation. Knowing the parts of the brain that contribute to EDRs is important because it can help better explain test sensitivity and specificity. If we have a better idea of what "can" cause an EDR, we are in a better position to possibly reduce those causes and their role in creating unexplained variance during PDD testing.

Describing a specific behavior at any point requires at a minimum, consideration of two basic aspects: (a) what goal is sought by the behavior, approach or withdrawal; and (b) the intensity of the behavior (Duffy, 1972). Intensity of behavior is related to an excitation process in the central nervous system (CNS) which is called arousal or activation. The Penguin Dictionary of Psychology (Reber, 1995) defines arousal as; "A dimension of activity or readiness for activity based on the level of sensory excitability, glandular and hormonal levels and muscular readiness" (Page 54). Arousal is regarded as a basic process that optimizes information processing flow from perception to behavior. Arousal not only refers to the overt activity of the organism, but also to the changes that occur in preparation for overt activity (Duffy, 1972). Theories attempt to explain how the subsystems of the brain integrate to allocate resources directed to processing information and responding to stimuli. The Boucsein model (Boucsein, 1992; Boucsein & Backs, 2009) divides arousal into four sub-systems and integrates many of the features of earlier models (De Long, Georgopoulos & Crutcher, 1983; Fowles, 1980; Gray, 1982; Le Doux, 1996; Pribram & McGuinness, 1975; Routtenberg, 1968). This model provides a comprehensive description of how EDRs presented during PDD testing can be elicited or affected. The model takes into consideration the cognitive, emotional and behavioral aspects of response potentials in the brain areas that result in EDRs.

In the Boucsein model (see Figure 6), Arousal System 1 (shown with checkered background) is referred to as the *affect arousal system* and is centered on the amygdala. The amygdala is considered to be one of the primary structures involved in the fight, flight or freeze response. Separate nuclei in the amygdala are arguably the main arousal component of fear related reactions (Boucsein & Backs, 2009; Le Doux, 1996; Gray 1982, 1987). Cholinergic fibers originating in the reticular formation activate the affect arousal system via the amygdala that in turn activates the comparator system of the hippocampus in the effort system resulting in increased focus and attention (Boucsein 1992; Boucsein & Backs 2009). If a situation changes or certain stimulation occurs, *affect arousal* will elicit an increase of frequency or amplitude of the EDR and phasic HR changes via the hypothalamus. Attention will be shifted towards the new stimulus, supported by involuntary somatomotor responses such as head- or eye movements. The preparatory activation system (Arousal System 3) will provide an increased readiness of brain areas involved in eliciting intended somatomotor actions. It seems plausible that an amygdala-based arousal could occur in the PDD setting through cortical to amygdala influences and activation, which have been well documented (Le Doux, 1996).

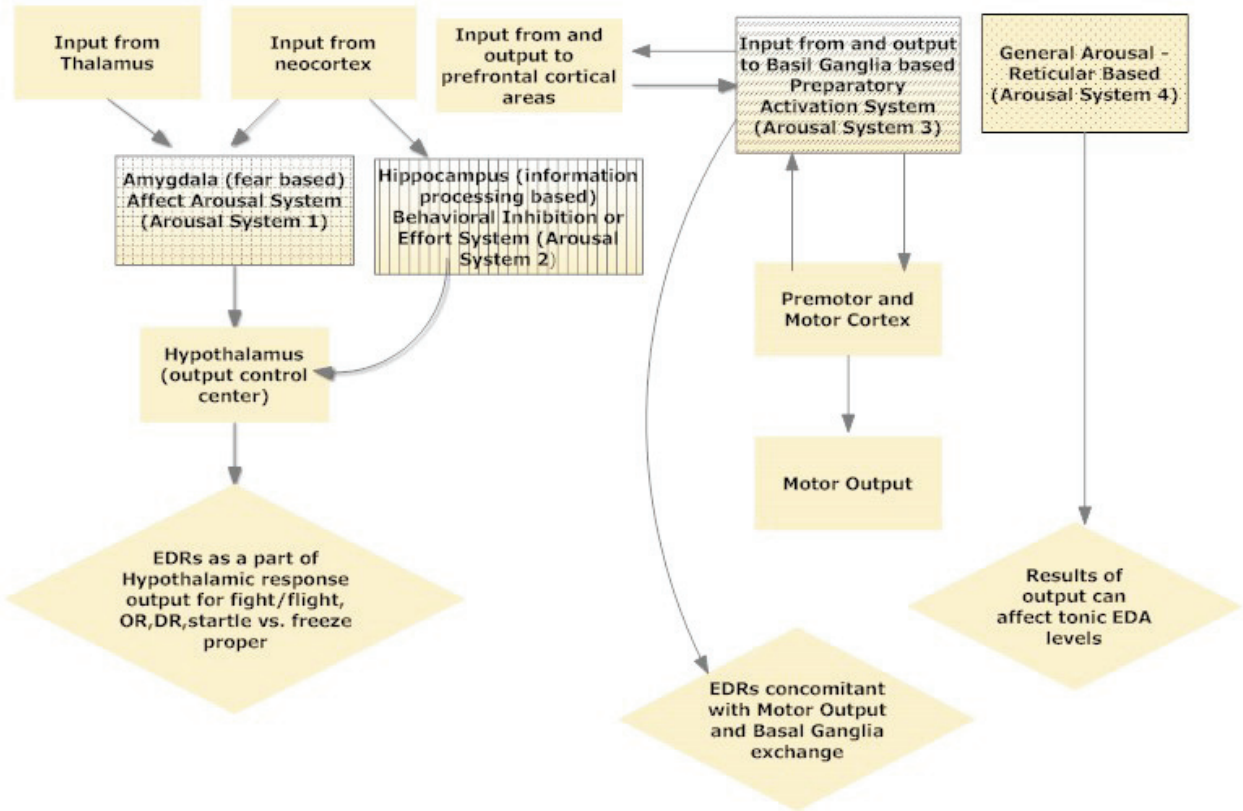
Arousal System 2 (shown with vertical lined background) is centered on the hippocampus and is called the *effort system*. Gray (1982, 1987) and Gray and McNaughton (2003) proposed the septo-hippocampal stop system was responsible for the behavioral inhibition system (BIS) and was the primary process involved in behavioral inhibition. The Boucsein effort system and the BIS model are consistent, in that they both ascribe primary responsibility for inhibition to the hippocampus and both are highly involved in arousal. If the examinee perceives a potentially threatening stimulus, there is an increased flow of information to the hippocampus. Here a comparison process begins to assess the potential threat of the stimulus by comparing stored information to recently acquired information. That information is shared with parts of the brain that are involved in motor plans (the prefrontal cortex) and classically conditioned behavioral responses (via the basal ganglia in the cognitive loop). This comparator system does not interfere if the stored and incoming information match. If, however, there is discordance between the information, the

effort system activates, resulting in motor inhibition, increased alertness, internal memory scanning and an increase in arousal. Anticipated allostatic concomitants are; rise in blood pressure, electrodermal responding, and behavioral quieting or inhibition, all of which are considered reaction in PDD testing.

Arousal System 3 (diagonal lined background), is labeled the *preparatory activation system*, is centered on the basal ganglia system and is involved in somatomotor activity. When this system activates, it prepares the body for action by alerting the central nervous system processes involved in movement. If situational circumstances alert the *affect arousal system* (Arousal System 1), attention is shifted towards the alerting stimulus and this *preparatory activation system* (Arousal System 3) prepares the body for movement. The *effort system* (Arousal System 2) can block the connection between *affect arousal system* (Arousal System 1) and *preparatory activation system* (Arousal system 3) to prevent immediate movement. This disconnection is reflected in behavior inhibition that may be observed at the presentation of a stimulus associated with potential punishment or non-reward. Outputs of Arousal system 3 are an increase of the EDR amplitude, which is concomitant with preparation of a motor output, or slight tonic increases of heart rate (Boucsein & Backs, 2009).

The fourth and final sub-system is Arousal System 4 (shown with dotted background) and it is generally based around the Reticular Activation System (RAS) a function of which is to increase or decrease general arousal. Therefore, this system is referred to as *general arousal system* and has a reciprocal relationship to the *effort system* (which is shown as a dotted line). The output of the general arousal system can facilitate tonic changes such as increases of skin conductance, heart rate and blood pressure.

Figure 6. A basic conceptual diagram of the four-arousal model of EDR elicitation via CNS and ANS routes. For explanation, see text. (Adapted from Boucsein and Backs, 2009 and Boucsein, 1992 and used with permission from the first author.)



It seems clear that cognitive appraisal can play a significant role in triggering emotion and concomitant physiological reactions during PDD testing. Applying the Boucsein model of arousal helps elucidate the potential CNS paths of EDR generation and reminds us that the cause of an EDR must be considered with caution, as it may not be clear if the reaction resulted for emotional, motivational, cognitive and/or behavioral reasons. There is no doubt that the EDR is a known physiological by-product of emotion, but we are yet unable to distinguish specific emotions using current PDD technology and EDR evaluation criteria.

EDRs in Psychopathology[15]

A fair amount of research in the areas of psychopathology assessment and medication efficacy has been done using EDA as one of the psychophysiological metrics. While not specifically addressing how any of these disease states affect EDA, researchers have assessed how EDRs and EDLs differ among groups of interest. The majority of this work was limited to disorders of anxiety and its treatment, psychopathy and anti-social behaviors, depression and schizophrenia. For a thorough review of the application of EDA to psychopathology, the interested reader is directed to Stern and Janes (1973).

Lader and Wing (1964, 1966) are often cited as studies that used EDA to attempt to differentiate anxious from healthy subjects. In summary, those studies reported that anxious patients had significantly higher SCL and generated more NS.SCRs than their matched normal controls. Additionally, normal control subjects showed an anticipated habituation of SCL, while the SCL of the anxious group increased continually. Habituation analysis revealed the normal group had higher initial OR responses and faster habituation gradients than did the anxious group, which was attributed to the ceiling effects of the law of initial values (Wilder, 1958).

Hart (1974) found contrasting results than did Lader and Wing (1964) reporting no significant difference in SCR nor SCL between anxious and non-anxious subjects. This difference can be explained by the manner in which the tone stimuli were presented to the subjects. In Lader and Wing (1964), the tones were monotonous whereas Hart (1974) varied the tone and the tone intensity, both of which can affect novelty and habituation.

EDA differences depend on how a subject is diagnosed with anxiety, whether by state or by trait. State anxiety is a better predictor of larger amplitude EDRs than trait anxiety (Boucsein, 1992). However, views of results should be tempered with the understanding of the ceiling effects of the law of initial values, as discussed earlier. Generalized increase in anxiety can result in higher EDLs which tend to reduce the amplitude of EDRs. The overall consideration for PDD examiners would be to take necessary precautions to minimize the anxiety level of any examinee, and particularly those whose levels are higher than normal.

The terms antisocial personality disorder (APD) and psychopathy (also known as sociopathy) are sometimes mistakenly used interchangeably because they share certain characteristics, like disobedience to laws. There are differences between the two, which we will highlight. According to the *Diagnostic and Statistical Manual of Mental Disorders-IV-TR* (American Psychiatric Association, 2000), the criteria for APD include a pervasive pattern of disregard for the rights of others since the age of 15, at least 18 years of age, some evidence of conduct disorder before turning 15 and antisocial behavior not occurring during periods of mania or schizophrenia and at least three of the following characteristics: repeated law breaking; lying or deceitfulness; impulsivity; irritableness and aggressiveness; repeated violation of social norms and the rights of others; financially or employment related irresponsibility; and lack of remorse.

Cleckly (1976) differentiated psychopathy from APD by placing more of an emphasis on how the person thought and felt,

[15] The material in this section is derived from the major scientific sources describing EDA and psychopathology. Readers interested in the original scientific sources should see Boucsein, 1992.

rather than on antisocial behavior. Cleckly wrote that psychopaths suffered from a poverty of both positive and negative emotion. Psychopathic persons are superficial, glib, charming, manipulative, lack a sense of guilt and most importantly from an EDA standpoint, they lack anxiety. This makes it difficult for them to learn from prior mistakes and to be emotionally biased towards good, or away from bad, decisions (Damaisio, 1999). Most researchers diagnose psychopathy with a checklist developed by Hare, Hart and Harpur (1990), who devised and normed a checklist for scaling the characteristics described by Cleckly (1976). The checklist identifies two major sub-divisions of psychopathy; emotional detachment and anti-social lifestyle. Hare *et al.* (1991) have criticized the DSM criteria for diagnosing APD because it requires historical reports of negative behavior from people who are often habitual liars, making it difficult to reconcile their past behavior with the truth. They point out that 75 to 80 percent of convicted felons meet the diagnosis criteria for APD while only 15 to 25 percent meet the criteria for psychopathy.

Hare (1978b) summarized a series of studies that compared EDA differences between psychopathic persons and non-psychopathic control subjects. There was a general finding that psychopathic persons possess a generally lower tonic EDL than the controls and had somewhat fewer NS.EDR freq., though to a lesser degree comparatively. An interesting trend reported by Hare (1978b) was that as stimulation levels increased, psychopaths' EDL decreased even further, while that of controls EDL increased or remained constant. Hare (1975, 1978a) showed that psychopaths may have electrodermal hyporeactivity (low reactivity) when compared to controls, using aversive conditioning experiments involving electric shocks. Psychopaths did not develop normal conditioned EDRs to aversive stimuli, supporting the idea that psychopaths have low levels of fear conditioning. During highly intense, fast rise-time stimulation, psychopaths who scored low in the socialization scale of the California Psychological Inventory (CPI; Gough, 1969) displayed EDRs that were commensurate significantly with their degree of socialization. This led to the speculation that EDR hyporeactivity is influenced to some degree by socialization. While no firm conclusion has been drawn from these studies, it offers some possible insight into how EDRs may be affected in cases involving persons with psychopathy. Low autonomic reactivity observed in psychopaths, as measured by EDRs, may contribute to the development of antisocial behavior because of the decreased ability to be biased emotionally away from behavior that will have negative consequences (Damaisio, 1999).

Ultimately these concerns boil down to the question of whether PDD is capable of differentiating truth from deception among people with APD and psychopathy. While there is no scientific basis for it, there is a popular notion that psychopaths or persons with APD are immune or impervious to PDD testing. Research has shown that persons with either are just as easily detected as normals (Honts, Raskin & Kircher, 1985; Patrick & Iacono, 1989; Raskin & Hare, 1978). These findings are not surprising, when considering that psychopathic persons are non-psychotic individuals with generally normal levels of intelligence, and that psychopathy is independent from psychotic and developmental disorders that may preclude an individual from maintaining adequate conceptual awareness of temporal events.

According to the *DSM-IV-TR* (American Psychiatric Association, 2000) symptoms of clinical or major depression include; fatigue or loss of energy almost every day; feelings of worthlessness or guilt almost every day; impaired concentration, indecisiveness; insomnia or hypersomnia (excessive sleeping) almost every day; markedly diminished interest or pleasure in almost all activities nearly every day (called anhedonia, this symptom can be indicated by reports from significant others.); psychomotor agitation or retardation (restlessness or being slowed down); recurring thoughts of death or suicide (not just fearing death); significant weight loss or gain (a change of more than 5% of body weight in a month).

Electrodermal hyporeactivity has been confirmed in a number of studies (Boucsein, 1992) often using EDL as the metric. Iacono *et al.* (1983, 1984a) reported finding that reduced SCLs, SCRs, and NS.SCR freq. were

reliably capable of differentiating between depressed (unipolar and bipolar) patients and controls. Both patient groups produced faster habituation rates, lower maximum individual SCR amp., lower dishabituation responses, and lower SCLs.

EDA abnormalities documented in patients with schizophrenia generally fall into one of two categories. The first is the "nonresponder" group which comprises some 40-50 % of schizophrenics (Dawson, Schell and Filion, 2007). Nonresponders are those subjects who fail to produce ORs to innocuous stimuli, like a mild tone. This high proportion of nonresponders (compared to the approximately 10-25% found in normal population) has been a reliable finding across a number of studies (Dawson, Schell and Filion, 2007).

The second EDA abnormality found among schizophrenics is higher tonic levels compared to normals. This trait is found in schizophrenics in the responder group and is measured through higher EDLs and higher frequency of NS.SCRs. The nonresponder group is characterized by hyporesponsivity while the responder group is characterized with general hyperarousal. One concern for PDD examiners would be attempting to conduct an examination during a psychotic episode. Another concern would be an attempt to conduct an examination during a non-psychotic period regarding behavior that occurred during a psychotic episode. One would hope that such an episode would become clear to the examiner and the examination postponed. There is also a concern about what effect any medications may have on the test. A number of neuroleptic drugs prescribed to schizophrenics have anti-cholinergic properties and could possibly influence CNS and PNS elicitation of EDRs. Straube (1979) found no differences in EDA between 21 drug-free schizophrenics and 29 patients tested taking neuroleptics. While medication effects on the nonresponders cannot be ruled out, the general agreement is the medication is not the underlying cause of the lack of response (Boucsein, 1992). It seems that persons diagnosed with schizophrenia who are nonresponders, will likely produce EDRs of small amplitude, whether they are taking medication or not. Alternatively, a portion of schizophrenics may display higher tonic levels of EDA. The normal concerns around ceiling effects of laws of initial value may now be warranted. Persons who function optimally while taking carefully prescribed medications may also produce PDD data of optimal interpretable quality while taking any necessary medications. No field examiner should ever make a recommendation to increase, decrease, start or stop a medication because of a PDD exam.

Factors Affecting the EDRs[16]

Factors found to negatively affect the recording and observation of EDRs include such things as movement artifacts, drugs, temperature and to a lesser degree humidity as well as physiological variables including age, race and gender. The studies of these variables were conducted using a variety of techniques, not necessarily exosomatic recordings as are conducted in polygraphy, and so should be viewed with care as to how they might influence expectations in field settings. In general, EDA is found to be sufficiently robust that it continues to provide interpretable and diagnostic information under a variety of suboptimal conditions.

Medications

As mentioned earlier, the neurotransmitter responsible for post-ganglionic sympathetic innervation of the eccrine sweat gland is acetylcholine. Sweat gland activity can be stimulated systemically using medications that mimic acetylcholine or that are cholinergic agonists. Intradermal injections of acetylcholine (Chalmers & Keele, 1952) for example, resulted in non-neurologically generated EDRs. Chemicals having anti-cholinergic properties can reduce or abolish EDRs when applied topically (Lader, 1970; Lader & Montegu, 1962;

[16] The material in this section is derived from the major scientific sources describing factors known to affect EDRs. Readers interested in the original scientific sources should see: Boucsein, 1992; Edelberg, 1967; Fowles, 1986; and Venables & Christie, 1973.

Venables & Martin, 1967b). Medications like scopolamine (a neuroleptic drug with anticholinergic properties) that pass the blood-brain barrier have been reported to suppress EDRs through a depletion of central and possibly peripheral acetylcholine (Patterson & Venables, 1981). Some beta-blockers like propranalol may exert a central nervous system influence and reduce overall EDA via their anxiolytic effects (Gruzelier & Connolly, 1979). More recent work with propranalol, however, tends to support a reduction in tonic EDL but not EDRs to specific stimuli (Grillon, Cordova, Morgan, Charney & Davis, 2004).

Anxiety reducing medications, like benzodiazepines, appear to be able to reduce various aspects of EDA, though much depends upon the anxiety-invoking conditions as well as the measurement used (Boucsein, 1992). Most studies of these minor tranquilizers used non-specific SRRs during anticipation of an aversive event as their metric. In summary, the evidence suggests it is possible to interfere with aspects of EDA pharmacologically. Most of the medications studied in PDD contexts are controlled substances that require prescriptions to obtain legally. While there is nothing to preclude an examinee from obtaining these medications illicitly, nothing suggests that any will cause a false negative or false positive test result in a properly conducted comparison question polygraph test (see the review by Honts & Amato, 2002). Examiners can expect that examinees taking some medications to have some potential for a reduction in overall EDA because of central and possibly peripheral nervous system effects. It is also possible that persons who function optimally while taking prescribed medications may produce polygraph data of optimal interpretable quality while taking any necessary or prescribed medications.

Medications with anti-cholinergic properties are available without a prescription. The cholinergic innervation at the eccrine sweat glands are called muscaranic. Muscarine is a toxic compound found in the *Amanita muscaria*, a nonedible mushroom species that activates certain types of cholinergic receptors. Antimuscarinic agents are so named, because they block innervation of the receptor and for eccrine sweat glands, this results in a reduction in sweat gland activity. Antimuscarinic medications relax smooth muscle, decrease the secretion of saliva, sweat, and digestive juice, and dilate the pupil of the eye and may be found in such over the counter preparations as cough and cold symptom alleviators and other products containing antihistamines. The extent to which these readily available products affect EDRs has not been well investigated. Examiners would be well advised to inquire of the examinee all medications they took recently, both prescription and over the counter. Ample information is available via the internet to research any antimuscaranic properties a medication might have, as well as other anticipated side-effects. PDD examiners should also inquire as to the underlying reason an examinee is taking a medication and consider what effect that may have on EDRs.

Temperature

Ambient temperature has been found to affect EDRs with colder ambient temperatures generally reducing phasic responses. This may result from cooling of the skin, which has been found to result in smaller EDR amplitudes, greater latencies, and longer rise times for phasic responses. The cause may be the temperature-dependent transfer of the neurotransmitter acetylcholine from the postganglionic sudorisecretory nerve plexus surrounding the secretory part of the gland to receptors on the gland itself. Additionally, environmental factors may affect the permeability of skin in general, which can have a secondary effect on EDRs. Fowles (1986) found the skin permeability for water to double with an increase in skin temperature of 7-8 C at normal room temperatures. There is a linear relationship between relative humidity and corneal hydration up to humidity of approximately 70 percent after which the changes are exponential (Boucsein, 1992). As the corneum is hydrated, more sweat will tend to flow up and out of the duct onto the surface of the skin. As the corneum becomes hydrated with ion laden sweat, the conductance increases and the resistance decreases. However, compared to the ducts filled with sweat, the corneum provides a relatively weak conducting path. A good rule of thumb would be to strive to maintain a

constant temperature of 73F (23C) with a constant relative humidity, as recommended by Boucsein (1992). This temperature should preclude a lightly clad person from shivering, which could create movement artifacts, and sweating, which may increase the number of non-specific EDRs.

Demographics

Age and gender differences in EDA have received more consideration than those relating to race and ethnicity. As we age, wrinkles in the skin develop as the epidermal and dermal layers become less tightly bound. As this happens, there are decreases in sweat gland production, ion concentration in sweat and active sweat glands. Additionally, the possible effect of age-related changes to CNS structures like hypothalamus involved in EDA, may contribute to detriments in producing EDRs. A summary of relevant research would suggest that age related physiological and psychological changes may result in decreased EDRs.

Gender differences have been found in both sweat gland activity and total sweat production. Women have been reported to have a greater density of sweat glands but sweat less. A general summary of data from gender studies could conclude that women may have a higher tonic EDA, owed to the greater sweat gland density. Men, however, tend to produce greater EDRs under conditions of stimulation (Boucsein, 1992).

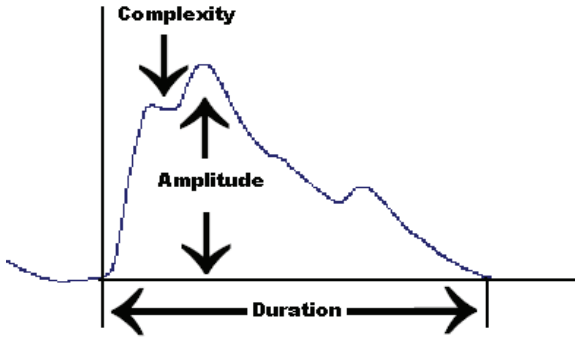
For the PDD examiner, concerns about the race of the examinee seem unwarranted as no racially related inability to produce EDRs has been reported in the literature. However, skin color has been shown to effect sweat gland density. In general, darker skinned persons, tend to have fewer active sweat glands per unit area, resulting in higher SCLs during resting conditions. Mention has been made of possible differences in EDLs from ethnic differences in sweat concentration (Johnson & Landon, 1965) though not in EDRs. Caucasian persons have been shown to be more reactive to presentations of tones or noise (Johnson & Landon, 1965). However, Korol and Kane (1978) found no difference in SRRs to noise stimuli, among persons from black and Caucasian ethnic groups to presentation of noise.

Scoring

Numerical scoring of PDD examinations can be traced back to the 1930s (Winter, 1936) Field examiners are trained to evaluate data patterns indicative of duration and complexity which are shown in Figure 7. It is possible that duration and complexity refer to a single reaction phenomenon that are both related to the duration intensity of a reaction. In contemporary comparison question testing field polygraphy, the EDR features shown to be the most predictive of deception are the vertical amplitude of increase of a reaction segment that begins after the stimulus onset, and the duration of a reaction segment (Kircher & Raskin, 1988).

Kircher, Packard, Bell and Bernhardt (1997) investigated whether EDL is related to the amplitude of EDRs during PDD examinations and whether EDL can be used to improve examination accuracy. During an extensive study (N=336) Kircher *et al.* (1997) collected tonic and phasic measures of skin conductance and skin resistance using skin conductance recordings and found some tonic measures of skin conductance to be positively related to phasic reactivity, whereas tonic skin resistance was negatively correlated with phasic reactivity. Phasic skin conductance responses correlated highly with the number of NS.SCR ($r > .66$) and the SCL ($r > .57$). Skin resistance was derived from measured skin conductance activity and transformed. The expected negative correlation between SRL and SRR was significant for the entire sample. The correlation was considerably smaller in magnitude ($r = -.20$) than the correlations obtained for skin conductance, and the correlation was not significant inferring that SRRs are less dependent on basal levels of activity than are SCRs. None of the tonic measures improved the accuracy of polygraph outcomes and tonic arousal accounted for very little (less than 2%) of the variance in the guilt/innocence criterion. The overall results suggest that the use of absolute measures of electrodermal and cardiovascular activity would do little to improve the accuracy of computer algorithms for diagnosing truth and deception.

Figure 7. Example of EDR showing amplitude, complexity and duration.



Statistical Approaches to Scoring

Kircher and Raskin (1988) described the use of discriminant analysis procedures to evaluate the contribution of electrodermal response patterns to CQT decision algorithms. They developed a decision model based on discriminate analysis and maximum likelihood estimation, using electrodermal amplitude and response duration, in addition to data from other polygraph sensors. This work was replicated by Raskin, Kircher, Honts and Horowitz (1988) who constructed a successful decision model using a single electrodermal feature, electrodermal response amplitude, without duration or recovery data. Krapohl and McManus (1999) developed an objective manual scoring method, which later evolved into a computer scoring algorithm, using amplitude as the only electrodermal feature. Other computer algorithm scoring models have also been successfully demonstrated using electrodermal amplitude as a single measurement feature (Honts & Devitt, 1992; MacLaren & Krapohl, 2003; Nelson *et al.*, 2008).

Manual Scoring: General Considerations

Before considering the traditional numerical scoring ratios for EDRs, it is important first to comment on the relationship of EDRs to the general background in which they appear. Score assignment is not simply a matter of comparing amplitudes: context is vital. For example, if EDA is very labile or noisy (see Figure 8), one can have less confidence in amplitude differences of EDRs, and a better choice would be to score conservatively. Conversely, very stable EDA (see Figure 9) imparts more meaning for phasic response amplitude differences, and a more aggressive scoring approach might be justified. The ratio systems found later in this section assume stable EDA.

The typical EDR sequence is as follows: a stimulus is presented and detected; a latency period transpires; a deflection will signal the beginning of the waveform; the tracing will rise to a peak, the amplitude of which is commensurate with the signal value of the stimulus; the rise time will be shorter than the recovery time so the slope of the EDR will be steeper on the rising side; the tracing will fall to or near the previous baseline or tonic level. Multiple peaks may occur when either arousal or lability is high, resulting in "complex" wave forms. When this occurs in polygraphy, we have traditionally measured the distance from a stable baseline to the maximum height of any peak achieved by the waveform within the scoring window to determine amplitude.

Latency

Exosomatic EDRs have relatively long latencies compared to the heart rate and blood pressure changes. Levenson and Edelberg (1985, Table 4) provided a synopsis of EDR latencies from experiments published in the journal *Psychophysiology* between the years of 1977 and 1982. They concluded that most experimenters reported latencies somewhere between 1 and 5 seconds. Venables and Christie (1980) wrote that most EDR latencies will fall within the 1 to 3 second range. As long as the EDR consistently falls within these parameters, it would seem to be acceptable by

Figure 8. Tracing of very labile electrodermal activity.

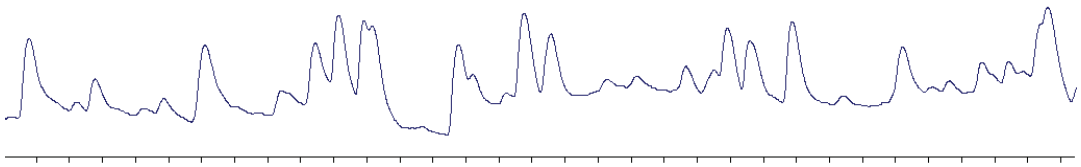
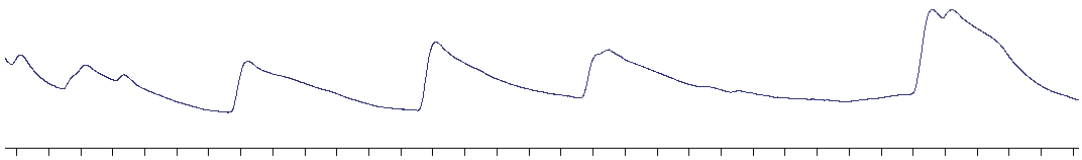


Figure 9. Tracing of stable electrodermal activity.



psychophysiology standards. If examiners plan to evaluate EDRs with longer latencies, they should also consider whether the examinee's skin temperature is low: 20 - 50 % of EDR latency is dependent upon the transport of acetylcholine in the periphery, which varies with temperature (Boucsein, 1992).

Manual Scoring: Rank-Order

Some scoring systems, such as the Lykken system for the Concealed Information Test (Lykken, 1959) turned to ranking of EDRs. Today, most CQT scoring systems involve the comparison of the magnitude differences of two EDRs, often the larger to the smaller. These ratios are taken up in the next section, titled "7-position ratios." From a purely psychometric point of view performing a rank ordering of responses is a psychologically easier task than assessing differences based on magnitude estimation. Psychometrically, it would be expected that a rank-order procedure would be more reliable and thus potentially more valid than a magnitude estimation procedure. However, magnitude estimation procedures might have a higher validity because they make better use of the information provided by the size of the differences between questions.

Honts and Driscoll (1987) contrasted a psychometrically sound rank-order approach with traditional numerical scoring using a sample of charts obtained from a mock-crime laboratory study. They reported that the rank order system to be slightly, but not significantly more reliable and valid than traditional numerical scoring. A constructive replication using confirmed field cases produced similar equivocal results, but this time with a slight, but not significant advantage for traditional numerical scoring (Honts & Driscoll, 1988). An independent replication with field data was reported by Krapohl, Dutton and Ryan (2001). They also reported equivocal results for rank order and traditional manual scoring. Miritello (1999) provided an evolution of the rank order approach that resulted in the calculation of a Rank Order Ratios that provided a potentially more interpretable index of discrimination. Miritello's approach was developed into a computer-based algorithm that is currently part of the Computerized Polygraph System software (Scientific Assessment Technologies, 2009). Unfortunately, the Rank Order Ratio approach remains without either an explicated decision model or empirical validation data. The lack of this needed research poses substantial problems for those who would like to make use of the seemingly informative output of the analysis.

Manual Scoring: Traditional Numerical

Traditional manual scoring of polygraph data involves assigning scores indicative of differential reaction between comparison and relevant questions using a magnitude estimation procedure. These procedures typically use either 3- or 7-position scales (see the next section). Manual scoring methods for field PDD exams use electrodermal features of vertical amplitude, duration of response, and response complexity, (Swinford, 1999; ASTM, 2002; Bell, Raskin, Honts, & Kircher, 1999; Department of Defense Research Staff, 2006). However, field examiners generally place primary emphasis on the vertical amplitude of increase from the tracing average, and interpret secondary features related to duration and complexity only when the comparative difference in vertical response amplitude is uninformative. Kircher, Kristjansson, Gardner and Webb (2005) reported vertical EDR amplitude was found to be a valid discriminator between truthful and deceptive cases, but that complexity and duration were not. In fact, complexity was found to be negatively associated with deception, though the correlation was not statistically significant. The complexity findings in Kircher *et al.* (2005) conflict with those obtained earlier in Kircher and Raskin (1988) but are consistent with the results reported by Honts and Devitt (1992). Honts and Devitt reported a significant negative correlation between the number of electrodermal response peaks and deception. Kircher *et al.* (2005) attributed the complexity and duration finding differences to instrumentation and data collection methods, recommending EDR complexity and duration be evaluated only when collected using scientifically acceptable techniques which would include the use of wet electrodes of sufficient contact area. Also, if complexity and duration are to be evaluated, consideration must be given to the type of filtering on the instrument, as that will directly affect the EDR waveform. However, neither of these potential explanations applies to Honts & Devitt (2002) as they used data collected with equipment and methods that met scientific specifications. Moreover a number of studies show duration to be significantly diagnostic (e.g., Honts & Devitt, 1992; Honts, Raskin & Kircher, 1994; Kircher & Raskin, 1988).

Concerns for diagnostic values of EDR complexity and duration may be moot when one considers what criteria most examiners use to evaluate the waveform. Kircher *et al.* (2005) reported finding that numerical evaluations of electrodermal responses by every interpreter in their experiment were significantly correlated with EDR amplitude. Their lens models revealed that examiners based their numerical evaluations of electrodermal responses almost exclusively on response amplitude. Of the 32 federally trained examiners participating in this study, all used EDR amplitude to assign numerical scores to the EDR channel, 2 (6%) also used complexity, and only 1 (3%) used EDR duration.

Gordon (1999) proposed an alternative feature set based on theoretical assumptions that have not been subjected to scientific evaluation and at this time are without empirical validation. In conclusion, the consistency of support for amplitude alone in subsequent studies (Harris *et al.*, 2000; Kircher *et al.*, 2005) has resulted in little interest among polygraph researchers in alternative feature development efforts.

Manual Scoring: Traditional Numerical, Ratio Rules

In comparison question testing, the phasic responses of each relevant question are compared individually to a particular comparison question designated by the scoring regimen of the chosen technique. In the US Federal System, reactions of the relevant questions are gauged against the stronger of two adjacent comparison questions, if there are two (some exceptions exist). Otherwise, the response to the relevant question is compared against that of the nearest comparison question. Other systems may employ different rules.

According to most 7-position scoring systems, when the magnitude of one response is twice as large as the magnitude of the response against which it is compared, a score of 1 can be assigned. When the reaction is three times are large, a 2 can be assigned, and if the reaction is four times as large or greater, a 3 can be assigned. The sign of the score reflects the direction of the differential reactivity. If the larger reaction is a relevant

question the sign is negative. The sign is positive if the larger reaction was the comparison question. The overwhelming majority of polygraph scoring research has used these or very similar ratios. Investigation of ratios for 3-position scoring (-1, 0, +1), a variant of the 7-position scoring method, has not been published and most practitioners default to the 7-position ratios for +/-1.

One important exception to the 4:1, 3:1, 2:1 ratio system is the "bigger-is-better" rule (Swinford, 1999.) According to this rule, a +/-1 can be assigned even when the ratios fall short of the 2:1 ratio between reaction intensities. So long as there is a visibly perceptible difference in the amplitudes, the +/-1 can be given. The rule mitigates to some degree the otherwise very conservative traditional ratios. This rule is the basic premise of 3-position scoring, which has been criticized for increased inconclusive results (Blackwell, 1998; Harwell, 2000) when using cut-scores established for 7-position scoring.

The 4:1, 3:1, 2:1 ratios have been entrenched in polygraph instruction since the 1960s (Backster, 1963), though their scientific foundation is not found in the literature. Despite the ease in which they can be memorized and employed, it would seem an exquisitely rare and fortunate mathematical coincidence that they should also prove to be optimal. Not surprisingly, the development of the Objective Scoring System (Krapohl, 1999; Krapohl & McManus, 1999) uncovered data suggesting the traditional ratios were not optimal but rather somewhat wasteful, and that lower ratios could be used to capture more diagnostic information. Subsequent research supported these findings (Krapohl & Handler, 2006), and offered new ratios. The new ratios were 3:1, 2:1, and 1.25:1. On average the new ratios added about one point more in the correct direction for manual scoring than the federal 7-position method with the "bigger-is-better" rule, and two-to-three additional points in the right direction for an automated condition that adhered strictly to the traditional ratios. Though an improvement in polygraph decision accuracy was not detected with the new ratios, it did show that more diagnostic information was available in the chart data than the traditional ratios had captured (see Table 3 for comparison of ratio systems).

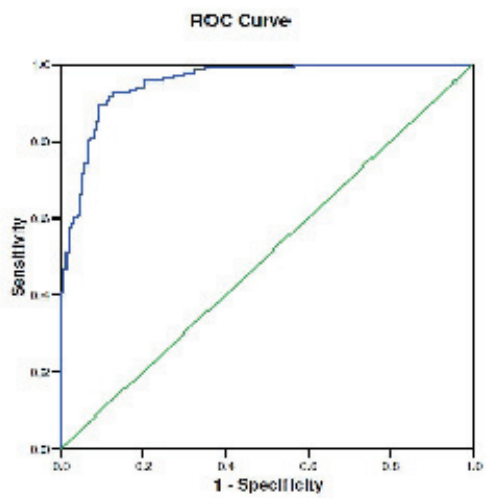
The 1.25:1 minimum ratio reported above is convenient and easy to use, but it, too, may be wasteful of data. We found no published studies that have evaluated the minimum interpretable response magnitude

Table 3. EDR ratios for score assignment in traditional, Federal and as used by Krapohl & Handler, 2006.

	EDR Ratios		
Score	Traditional	Federal	Krapohl & Handler, 2006
+/-3	4:1	4:1	3:1
+/-2	3:1	3:1	2:1
+/-1	2:1	Bigger is better	1.25:1
0	All else	All else	All else

difference that can be used for the assignment of numerical scores. There are two reported attempts to fill this knowledge gap using data from previous studies (Krapohl & McManus, 1999; Nelson *et al.*, 2008) and a statistical approach known as the step-wise receiver operating characteristics (ROC) method. ROC methods involve the calculation and plot of ratio of true positive results to false-positive errors against all possible decision circumstances. In Nelson et al. (2008) analysis revealed that a minimum EDR ratio of 1.1:1 provided an area under the curve (AUC) of .954, (95% CI = .932 to .975). Diagnostic efficiency became less efficient when attempting to use ratios smaller or larger than approximately 1.1 to 1 (see Figure 10). These results suggest that small differences in response magnitude do contain diagnostic information, and concerns that small differences in response magnitude might be unexplained variances may not be justified. Further evidence of the diagnostic contributions can be observed in computer algorithm scoring models, including those by Kircher and Raskin (1988), Raskin, Kircher, Honts and Horowitz (1988), and Nelson, Krapohl and Handler (2008), all of which will make use of continuous measurements and any measurable difference in response.

Figure 10. ROC plot of AUC for minimum EDA ratio of 1.1

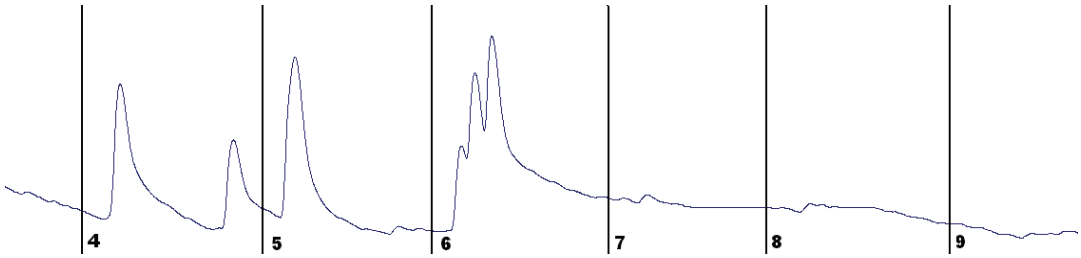


Non-Scoring Interpretation of EDRs

Seven-position scoring is not appropriate for all polygraph techniques. One such technique taught in almost all polygraph schools is called the Peak of Tension (POT). The POT, along with the CIT and Acquaintance Test, are regarded as recognition tests. As such, there is only one item in the list of items that the guilty person may be lying to, and it is the presence or absence of reactivity associated with that item that determine the outcome of the test. Like all polygraph testing, phasic responses are used in evaluation, but unlike the CQT, tonic information is also considered.

A common response pattern in the POT is for the appearance of EDRs to all items up to the critical (key) item, and a reduction in reactivity thereafter (see Figure 11). The critical item in the POT may or may not generate the largest EDR in all cases, but the reduction in reactivity after the item can be interpreted as the examinee's recognition that the critical item has passed. Because there exists no accepted scoring system for the POT, pattern analysis remains the principle method of analysis.

Figure 11. Reactivity to items up to the critical item, #6, with a drop in reactivity thereafter.



Summary

EDA is arguably the most robust and easily observed of all data collected during PDD testing. A number of researchers have suggested that it provides the greatest contribution to the final result (Capps & Ansley, 1992; Harris & Olsen, 1994; Harris, Horner & McQuarrie, 2000; Kircher, Kristjansson, Gardner & Webb, 2005; Kircher & Raskin, 1988; Krapohl & McManus, 1999; Nelson, Krapohl & Handler, 2008; Raskin, Kircher, Honts & Horowitz, 1988).

Salience, and statistical significance, is determined through the evaluation of the degree of the physiological response. Common practice, in both field and laboratory polygraph methods, is to obtain data from multiple presentations of the test stimuli. This is because measurement or observation of several iterations will provide a more reliable representation of the degree of salience of the stimuli. Because many examinees can be expected to exhibit some reaction to test questions, regardless of their deceptive or truthful status, PDD tests must be conducted in a manner that allows for the determination of which specific stimulus holds the greatest salience for the examinee. Concealed Information Test (CIT) polygraph techniques achieve this by constructing the test question stimuli so that a deceptive individual will recognize and respond distinctly to the critical item, while truthful individuals are expected to assign no difference in salience to any of the test stimuli. However, CIT methods require both a known incident or allegation and a satisfactory quantity of detail that would be known only to the deceptive individual. They also require that target stimuli be those that are likely to have been remembered by the person engaged in the act of interest (Honts & Schweinle, 2009).

Comparison question test (CQT) methods, in contrast, provide a context in which to evaluate the differential reactivity of truthful and deceptive persons by providing alternative types of test stimuli, within the examination. Truthful and deceptive individuals can be expected to respond differentially depending on the degree of salience they impart to each of the two categories of test questions. CQT methods are therefore less dependent on the existence of a known incident or allegation, and have wider applicability to field investigation and screening uses.

In field polygraphy, we are interested in measuring phasic EDRs resulting from the presentation of a stimulus. Interpretation of electrodermal signals in PDD testing, like the interpretation of other physiological signals, involves the observation or measurement of response magnitude and response pattern. Optimally, we can make a mathematical transformation of the responses elicited by various test stimuli and convert it to a single number intended to facilitate a statistical classification of the examinee into a truthful or deceptive category. In polygraphy we commonly call this scoring.

There is general agreement the actual units of measure (ohms or Siemens) are not relevant in evaluation because it is not response sizes per se that carry the diagnostic information, but rather the relative magnitudes between responses evoked by different categories of test question. Tonic levels of EDA are only of a concern in that they establish the baseline from which we measure a phasic reaction. Table 2, shown

earlier, demonstrates that tonic levels must be relatively constant, as unstable tonic levels can degrade the diagnostic information otherwise available in phasic responses.

The manual was prepared using a number of sources considered to be authoritative within their respective fields of biology, psychology, physiology, and psychophysiology. A sincere effort was made to reconcile or report when differences were found in these sources. The underlying causes, mechanisms and functions of EDA have yet to be unequivocally elucidated and years of studying this phenomenon have created as many questions as answers.

Whether a proponent or a critic, there is no escaping the conclusion that polygraphy is a fascinating and consequential field. It can be fairly stated that polygraphy has left an indelible mark on a number of domains ranging from law enforcement to national security, offender monitoring to the exoneration of the falsely accused, applicant selection, counterterrorism, and on to the validation of the claims of faithful spouses and fishing contests winners. EDA is clearly an important part of the past and current practice of polygraphy. We hope that this manual will be of benefit to the profession by removing some of the mystery from this highly useful measure.

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