7 The Electrodermal System

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PROLOGUE: OVERVIEW

Electrodermal activity (EDA) has been one of the most widely used – some might add "abused" – response systems in the history of psychophysiology. Research involving EDA has been reported in practically all psychology, psychiatry, and psychophysiology research journals. The wide range of journals in which EDA research is published reflects the fact that EDA measures have been applied to a wide variety of questions ranging from basic research examining attention, information processing, and emotion, to more applied clinical research examining predictors and/or correlates of normal and abnormal behavior. The application of EDA measures to a wide variety of issues is due in large part to its relative ease of measurement and quantification combined with its sensitivity to psychological states and processes.

The purpose of this chapter is to provide a tutorial overview of EDA for interested students, researchers, and practitioners who are not specialists in this particular system. We begin with a historical orientation and then discuss the physical, inferential, psychological, and social aspects of EDA.

HISTORICAL BACKGROUND

The discovery of electrodermal activity. The study of psychological effects on the electrical changes in human skin began over 100 years ago in the laboratory of Jean Charcot, the French neurologist famous for his work on hysteria and hypnosis. Vigouroux (1879, 1888), a collaborator of Charcot, measured tonic skin resistance levels from various patient groups as a clinical diagnostic sign. In the same laboratory, Féré (1888) found that by passing a small electrical current across two electrodes placed on the surface of the skin one could measure momentary decreases in skin resistance in response to a variety of stimuli (visual, auditory, gustatory, olfactory, etc.). The basic phenomenon discovered by Féré is that the skin momentarily becomes a better conductor of electricity when external stimuli are presented. Shortly thereafter, the Russian physiologist Tarchanoff (1890) reported that one could measure changes in electrical potential between two electrodes placed on the skin without applying an external current (see Neumann & Blanton, 1970, and Bloch, 1993, for interesting details regarding these initial discoveries). Hence, Féré and Tarchanoff are said to have discovered the two basic methods of recording electrodermal activity in use today. Recording the skin resistance response (or its reciprocal, the skin conductance response) relies on the passage of an external current across the skin and hence is referred to as the *exosomatic* method, whereas recording the skin potential response does not involve an external current and hence is referred to as the *endosomatic* method. The present chapter will focus on the exosomatic method of recording *skin conductance level* (SCL) and *skin conductance response* (SCR) because this clearly is the method of choice among contemporary researchers (Fowles et al., 1981).

Issues in the history of EDA research. Several issues identified in this early research have been sources of considerable speculation and investigation throughout the history of research with this response system. One set of such issues concerns the mechanisms and functions of EDA. In terms of peripheral mechanisms, Vigouroux proposed what became known as the "vascular theory" of EDA (Neumann & Blanton, 1970). The vascular theory associated changes in skin resistance with changes in blood flow. Tarchanoff favored a "secretory theory," which related EDA to sweat gland activity. This theory was supported later by Darrow (1927), who measured EDA and sweat secretion simultaneously and found the two measures to be closely related, although the phasic SCR would begin about one s before moisture would appear on the surface of the skin. Thus, it was concluded that activity of the sweat glands, not sweat on the skin per se, was critical for EDA. (Other lines of evidence indicating that sweat glands are the major contributors to EDA have been reviewed by Fowles, 1986, pp. 74–75.) It was generally known at the time that palmar sweat glands are innervated by the sympathetic chain of the autonomic nervous system, so EDA was said to reflect

sympathetic activation. In terms of more central physiological mechanisms, work by early investigators such as Wang and Richter indicated that EDA was complexly determined by both subcortical and cortical areas (for a review of this early research, see Darrow, 1937). Darrow also proposed that "the function of the secretory activity of the palms is primarily to provide a pliable adhesive surface facilitating tactual acuity and grip on objects" (1937, p. 641).

Issues surrounding the proper methods of recording and quantifying EDA also have been important in the history of this response system. Lykken and Venables (1971) noted that EDA has continued to provide useful data "in spite of being frequently abused by measurement techniques which range from the arbitrary to the positively weird" (p. 656). In fact, we would date the beginning of the modern era of EDA research to the early 1970s when Lykken and Venables proposed standardized techniques of recording skin conductance and standardized units of measurement. This was followed shortly by an edited book (Prokasy & Raskin, 1973) devoted entirely to EDA which contained several useful review chapters, including a particularly outstanding chapter by Venables and Christie (1973). Published around the same time were several other excellent reviews (Edelberg, 1972a; Fowles, 1974; Grings 1974). More recent reviews can be found in books by Boucsein (1992) and by Roy et al. (1993), as well as in individual chapters by Andreassi (2000), Fowles (1986), Hugdahl (1995), and Stern, Ray, and Quigley (2001).

Another issue of central importance concerns the psychological significance of EDA. From the beginning, this response system has been closely linked with the psychological concepts of emotion, arousal, and attention. Carl Jung added EDA measurements to his word-association experiments in order to objectively measure the emotional aspects of "hidden complexes." An American friend joined Jung in these experiments and enthusiastically reported that, "Every stimulus accompanied by an emotion produced a deviation of the galvanometer to a degree in direct proportion to the liveliness and actuality of the emotion aroused" (Peterson, 1907, cited by Neumann & Blanton, 1970, p. 470). About half a century later, when the concept of emotion was less in favor, Woodworth and Schlosberg (1954) devoted most of one entire chapter of their classic textbook in experimental psychology to EDA, which they described as "perhaps the most widely used index of activation" (p. 137). They supported this indexing relationship by noting that tonic SCL is generally low during sleep and high in activated states such as rage or mental work. The authors also related phasic SCRs to attention, noting that such responses are sensitive to stimulus novelty, intensity, and significance.

Many of these issues have remained important for contemporary psychophysiologists and are discussed in the remainder of this chapter. In the next section we present a summary of the contemporary perspectives regarding the basic physiological mechanisms and proper recording techniques of EDA.

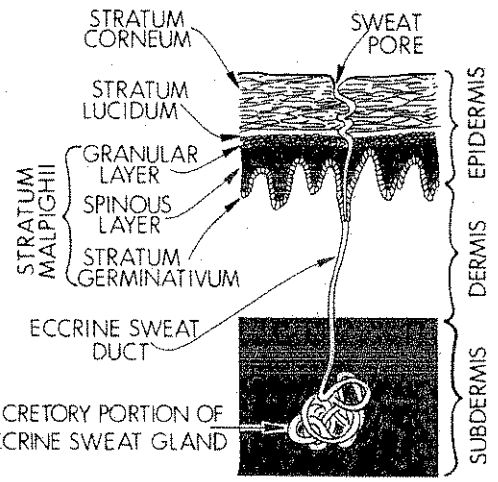

Figure 7.1. Anatomy of the eccrine sweat gland in various layers of skin. (Adapted from Hassett, 1978).

PHYSICAL CONTEXT

Anatomical and physiological basis. The skin is a selective barrier that serves the function of preventing entry of foreign matter into the body and selectively facilitating passage of materials from the bloodstream to the exterior of the body. It aids in the maintenance of water balance and of constant core body temperature, functions accomplished primarily through vasoconstriction/dilation and through variation in the production of sweat. As pointed out by Edelberg (1972a), it is not surprising that an organ with such vital and dynamic functions constantly receives signals from control centers in the brain, and he suggests that "we can listen in on such signals by taking advantage of the fact that their arrival at the skin is heralded by measurable electrical changes that we call electrodermal activity" (p. 368).

There are two forms of sweat glands in the human body: the apocrine, which have been less studied, and the eccrine, which have been of primary interest to psychophysiologists. The primary function of most eccrine sweat glands is thermoregulation. However, those located on the palmar and plantar surfaces are thought to be more related to grasping behavior than to evaporative cooling (Edelberg, 1972a) and they have been suggested to be more responsive to psychologically significant stimuli than to thermal stimuli. Although all eccrine glands are believed to be involved in psychological sweating, such sweating is usually most evident in these areas primarily because of the high gland density (Shields et al., 1987). The measurement of EDA by psychophysiologists is primarily concerned with psychologically induced sweat gland activity.

Figure 7.1 shows the basic peripheral mechanisms involved in the production of EDA. The extreme outer layer

of the skin, the stratum corneum or horny layer, consists of a layer of dead cells that serves to protect the internal organs. Below the stratum corneum lies the stratum lucidum, and just below that is the stratum Malpighii. The eccrine sweat gland itself consists of a coiled compact body that is the secretory portion of the gland, and the sweat duct, the long tube which is the excretory portion of the gland. The sweat duct remains relatively straight in its path through the stratum Malpighii and stratum lucidum, it then spirals through the stratum corneum and opens on the surface of the skin as a small pore (Edelberg, 1972a).

Many models have been suggested to explain how these peripheral mechanisms relate to the electrical activity of the skin and to the transient increases in skin conductance elicited by stimuli. Edelberg (1993) concluded that one can account for the variety of electrodermal phenomena, including changes in tonic SCL and phasic SCR amplitude, with a model based entirely on the sweat glands.

To understand how electrodermal activity is related to the sweat glands, it is useful to think of the sweat ducts (the long tubular portion of the gland that opens onto the skin surface) as a set of variable resistors wired in parallel. Columns of sweat will rise in the ducts in varying amounts and in varying numbers of sweat glands, depending on the degree of activation of the sympathetic nervous system. As sweat fills the ducts, there is a more conductive path through the relatively resistant corneum. The higher the sweat rises, the lower the resistance in that variable resistor. Changes in the level of sweat in the ducts change the values of the variable resistors, and yield observable changes in EDA.

Historically, both the sympathetic and parasympathetic divisions of the autonomic nervous system (ANS) were considered possible mediators of EDA. This is partially because the neurotransmitter involved in the mediation of eccrine sweat gland activity is acetylcholine, which is generally a parasympathetic neurotransmitter, rather than norepinepherine, the neurotransmitter typically associated with peripheral sympathetic activation (Venables & Christie, 1980). It is now generally agreed that human sweat glands have predominantly sympathetic cholinergic innervation from sudomotor fibers originating in the sympathetic chain, although some adrenergic fibers also exist in close proximity (Shields et al., 1987). Convincing evidence for the sympathetic control of EDA has been provided by studies that have measured sympathetic action potentials in peripheral nerves while simultaneously recording EDA. The results have shown that within normal ranges of ambient room temperature and thermoregulatory states of subjects, there is a high correlation between bursts of sympathetic nerve activity and SCRs (Wallin, 1981).

Excitatory and inhibitory influences on the sympathetic nervous system are distributed in various parts of the brain and therefore the neural mechanisms and pathways involved in the central control of EDA are numerous and complex. Boucsein (1992, pp. 30–36) followed the suggestions of Edelberg (1972a) in describing at least two and possibly three relatively independent pathways that lead to the production of SCRs (see Figure 7.2). The *first* and highest level of central EDA control involves contralateral cortical and basal ganglion influences (Sequeira & Roy, 1993). One cortical pathway involves excitatory control by the premotor cortex (Brodmann area 6) descending through the pyramidal tract, and another involves both excitatory and inhibitory influences originating in the frontal cortex. The *second* level of EDA control involves ipsilateral influences from the hypothalamus and limbic system (Sequeira & Roy, 1993). There is considerable evidence of an excitatory hypothalamic descending control of EDA. Limbic influences are complicated, but there is evidence of excitatory influences from the amygdala and inhibitory effects originating from the hippocampus. The *third* and lowest level mechanism is in the reticular formation in the brainstem (see Roy, Sequeira, & Delerm, 1993). Activation of the reticular formation by direct electrical stimulation or sensory stimulation evokes skin potential responses in cats, and presumably skin conductance responses in humans. An inhibitory EDA system has also been located in the bulbar level of the reticular formation.

Most of the evidence regarding the central pathways that control EDA described above was derived from animal studies, usually cats (e.g., Wang, 1964; Roy et al., 1993). More recently however, knowledge of the central control of human EDA, particularly EDA associated with attention and emotional processes, has increased dramatically with advances in neuroimaging technology. Using this technology, two strategies have been used to investigate the neural substrates of EDA: examination of EDA patterns in patients with delineated focal brain lesions (e.g., Asahina et al., 2003; Bechara et al., 1999; Tranel & Damasio, 1994; see review by Tranel, 2000), and examination of the relationship between patterns of brain activation and simultaneously recorded EDA (e.g., Critchley et al., 2000; Fredrikson et al., 1998; Nagai et al., 2004; Patterson, Ungerleider, & Bandettini, 2002; Williams et al., 2000).

Although there is not perfect overlap in the brain areas implicated across these studies, some consistent patterns have emerged. For example, activation of brain areas involved in evaluating stimulus significance, particularly the ventromedial prefrontal cortex, right inferior parietal region, and anterior cingulate, has been found to be associated with elicitation of SCRs. In addition, when the stimulus has emotional significance, the amygdala and orbitofrontal cortex, in addition to the areas mentioned above, are involved. Thermoregulatory sweating is controlled by the hypothalamus, which also integrates patterns of sympathetic activity in emotion, in conjunction with limbic structures.

Physical recording basis. As briefly described earlier, EDA is measured by passing a small current through a pair of

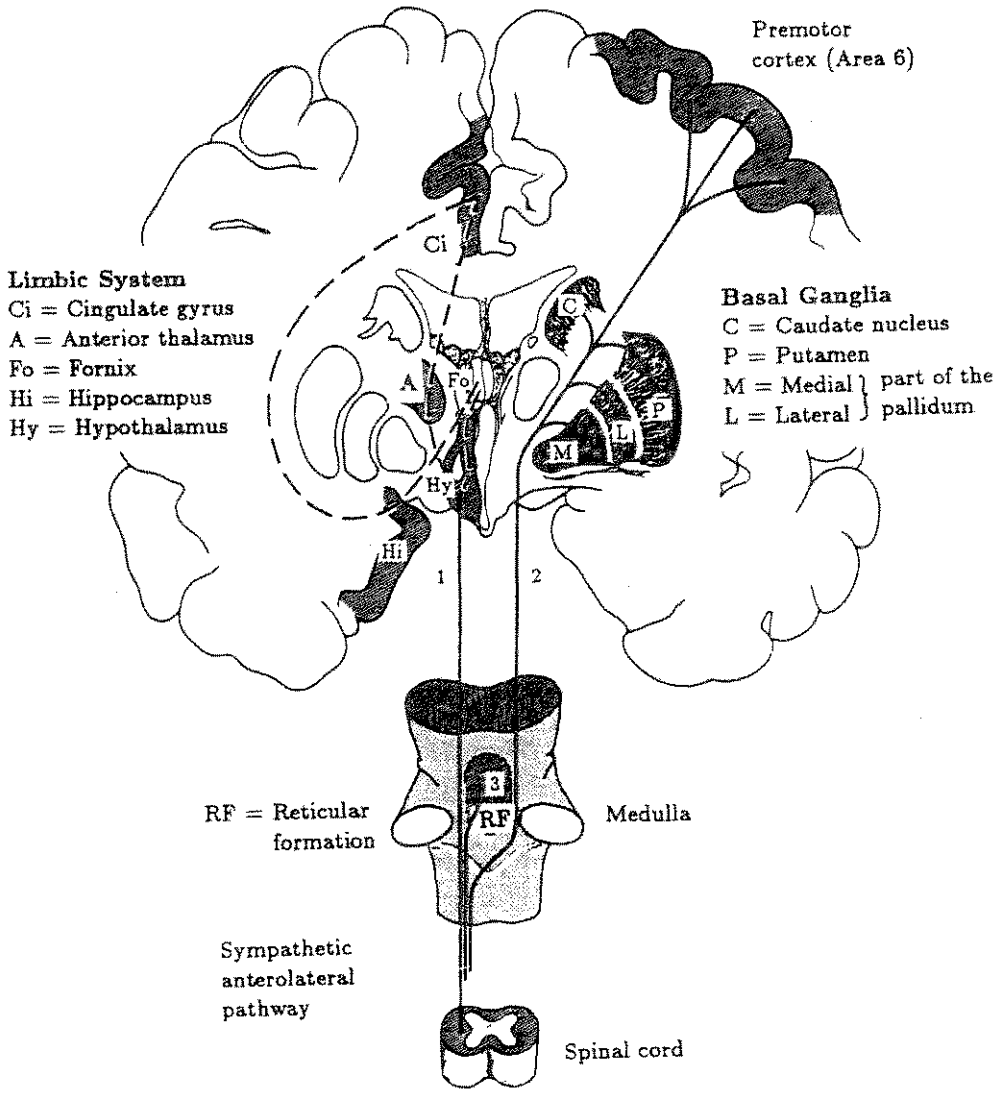

Figure 7.2. Central nervous system determiners of EDA in humans (From Boucsein, 1992).

electrodes placed on the surface of the skin. The principle invoked in the measurement of skin resistance or conductance is that of Ohm's law, which states that skin resistance (R) is equal to the voltage (V) applied between two electrodes placed on the skin surface, divided by the current (I) being passed through the skin. This law can be expressed as $R = V/I$. If the current is held constant then one can measure the voltage between the electrodes, which will vary directly with *skin resistance*. Alternatively, if the voltage is held constant, then one can measure the current flow, which will vary directly with the reciprocal of skin resistance, *skin conductance*. Conductance is expressed in units of Siemens and measures of skin conductance are expressed in units of microSiemens (μS).

Lykken and Venables (1971) argued strongly for the direct measurement of skin conductance with a constant-voltage system rather than measuring skin resistance with a constant current system. A description of constant voltage circuits that allow the direct measurement of skin conductance can be found in Lykken and Venables as well as in Fowles et al. (1981), and most of the physiological recording systems currently on the market include constant voltage systems for the direct recording of skin conductance.

EDA recording systems. Older recording systems, in operation 10 or more years ago, output EDA to a paper record in analog form. Most recording systems today are computer-based systems in which the analog skin conductance signal is digitized and stored on a computer. With such systems, a researcher must select which time points the computer will sample the EDA. Historically, this sampling window has been a few seconds following each presentation of an experimental stimulus. In these cases, EDA at all other time points is lost. Fortunately, with expanding computing capability, it is now generally feasible to sample EDA continuously, to allow an experimenter to flag critical events with a keypress or programmed signal, and to provide a continuous printout of an experimental session. In choosing an EDA recording system one must consider

computing capabilities and software issues. For example, some manufacturers offer software packages for the acquisition of EDA, some offer software for the quantification of EDA, and some offer both (a listing of major commercial systems available for the recording and quantification of EDA is available at: *http://www.psychophys.com/company.html*).

In addition to selecting an EDA recording system, special consideration must be given to the choice of recording electrodes, electrode paste, electrode placement, and general environmental considerations. Silver-silver chloride cup electrodes are the type most typically used in skin conductance recording because they minimize the development of bias potentials and polarization. These electrodes can be easily attached to the recording site through the use of double-sided adhesive collars which also serve the purpose of helping to control the size of the skin area that comes in contact with the electrode paste, an important parameter because it is the contact area, not the size of the electrode, that affects the conductance values.

The electrode paste is the conductive medium between the electrodes and the skin. Probably the most important concern in choosing an electrode paste is that it preserve the electrical properties of the response system of interest. Because the measurement of EDA involves a small current passed through the skin, the electrode paste interacts with the tissue over which it is placed. For this reason, the use of a paste which closely resembles sweat in its salinity is recommended (Venables & Christie, 1980). Instructions for making such paste are given in Fowles et al. (1981, p. 235) and Grey and Smith (1984, p. 553). Satisfactory paste is also available commercially. Commercial EKG or EEG gels should not be used because they usually contain near saturation levels of NaCl and have been shown to significantly inflate measures of skin conductance level (Grey & Smith, 1984).

Skin conductance is recorded using two electrodes, both placed on active sites (bipolar recording); hence it does not matter in which direction the current flows between the two electrodes. Skin conductance recordings are typically taken from locations on the palms of the hands, with several acceptable placements. The most common electrode placements are the thenar eminences of the palms, and the volar surface of the medial or distal phalanges of the fingers (see Figure 7.3). It should be noted that although electrodermal activity can be measured from any of these sites, the values obtained are not necessarily comparable. Scerbo et al. (1992) made a direct comparison of EDA recorded from the distal and medial phalange sites simultaneously and found that both the elicited SCR amplitude and SCL were significantly higher from the distal recording site. The greater level of reactivity at the distal site was found to be directly related to a larger number of active sweat glands at that location (Freedman et al., 1994). Therefore, the distal phalange site is recommended unless there are specific reasons for not using the distal site (e.g., recording from children whose fingertips may be too small for stable electrode attachment, presence of cuts or heavy calluses on the fingertips, etc.).

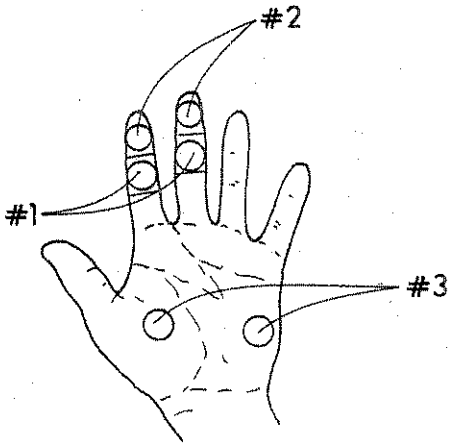

Figure 7.3. Three electrode placements for recording electrodermal activity. Placement #1 involves volar surfaces on medial phalanges, placement #2 involves volar surfaces of distal phalanges, and placement #3 involves thenar and hypothenar eminences of palms.

Another recording issue concerns the hand from which to record. Many laboratories use the nondominant hand because it is less likely to have cuts or calluses, and because it leaves the dominant hand free to perform a manual task. However, this begs the question of whether there are significant laterality differences in EDA. Although differences between left and right hand EDA recordings have been reported, the differences reported across studies are often in opposite directions and the interpretations have been ambiguous (see review of early literature by Hugdahl, 1984). It is tempting to speculate that the prior conflicting findings may be because of lack of clear distinctions between emotional and nonemotional tasks (Hugdahl, 1995). EDA in emotional tasks is presumably controlled primarily by the ipsilateral limbic system, whereas EDA in non-emotional tasks may be controlled by the contralateral system (see Figure 7.2). Although research in this area continues (e.g., Brand et al., 2002; 2004; Esen & Esen, 2002; Naveteur et al., 1998; Polagaeva, Egorov, & Pirogov, 1997; Schulter & Papousek, 1998), evidence linking EDA asymmetries to specific patterns of lateralized brain activation is still inconclusive. Taken together, the current literature suggests that sensitive indices of handedness should be included in any study examining bilateral EDA (Schulter & Papousek, 1998), but provides no definitive evidence that EDA recorded from one hand gives consistently different results with respect to the effects of experimental variables than that recorded from the other hand.

Because it is critical in EDA recording that the electrical properties of the response system be preserved, the electrode sites should not receive any special preparation such as cleaning with alcohol or abrasion, which might reduce the natural resistive/conductive properties of the skin. However, because a fall in conductance has been

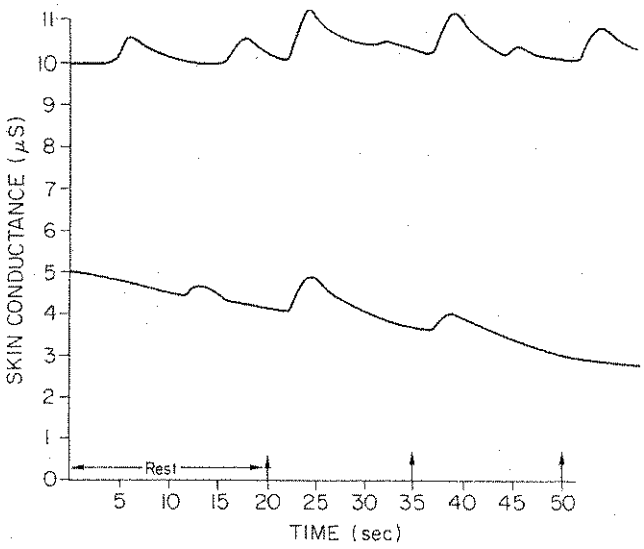

Figure 7.4. Two hypothetical skin conductance recordings during 20 s of rest followed by three repetitions of a simple discrete stimulus. Arrows represent the presentation of a stimulus (From Dawson & Nuechterlein, 1984).

noted following the use of soap and water (Venables & Christie, 1973), and because the length of time since the last wash will be variable across subjects when they arrive at the laboratory, these authors recommended that subjects be asked to wash their hands with a nonabrasive soap prior to having the electrodes attached and that the skin be kept clean and dry.

Ambient temperature and time of day are two environmental factors that should be controlled (e.g., Hot et al., 1999; Venables & Mitchell, 1996). Because EDA is influenced by hydration of the corneum, SCL tends to rise with increases in ambient temperature in the normal room temperature range. Boucsein (1992) recommends a room temperature of 23°C. Likewise, room humidity should be kept as constant as possible. Because diurnal effects may influence EDA, this variable also should be controlled across experimental conditions.

INFERENTIAL CONTEXT

Quantification procedures. Figure 7.4 shows tracings of two hypothetical skin conductance recordings during a 20 s rest period followed by three presentations of a simple discrete stimulus (e.g., a mild tone). Several important aspects of EDA can be seen in Figure 7.4. First, it can be seen that tonic SCL begins at 10 μS in the upper tracing and at 5 μS in the lower tracing. Although tonic SCL can vary widely between different subjects and within the same subject in different psychological states, the typical range is between 2 μS and 20 μS with the types of apparatus and procedures described here. Computing the log of SCL can significantly reduce skew and kurtosis in the SCL data and is recommended by Venables and Christie (1980).

It can also be seen in the lower tracing of Figure 7.4 that the SCL drifts downward from 5 μS to nearly 4 μS during the rest period. It is common for SCL to gradually decrease while subjects are at rest, rapidly increase when novel stimulation is introduced, and then gradually decrease again after the stimulus is repeated.

Phasic SCRs are only a small fraction of the SCL and have been likened to small waves superimposed on the tidal drifts in SCL (Lykken & Venables, 1971). If the SCR occurs in the absence of an identifiable stimulus, as shown during the rest phase of Figure 7.4, it is referred to as a "spontaneous" or "nonspecific" SCR (NS-SCR). The most widely used measure of NS-SCR activity is their rate per minute, which typically is between 1 and 3/min while the subject is at rest. However, responses can be elicited by deep breaths and bodily movements, so unless these also are recorded, it is impossible to say which responses are truly NS-SCRs.

Presentation of a novel, unexpected, significant, or aversive stimulus will likely elicit an SCR referred to as a "specific" SCR. With the exception of responses elicited by aversive stimuli, these SCRs are generally considered components of the orienting response (OR). As is also the case with NS-SCRs, one must decide on a minimum amplitude change in conductance to count as an elicited SCR. Minimum values between .01 and .05 μS are generally used. Another decision regarding scoring of specific SCRs concerns the latency window during which time a response will be assumed to be elicited by the stimulus. Based on frequency distributions of response latencies to simple stimuli, it is common to use a 1–3 s or 1–4 s latency window. Hence, any SCR that begins between 1 and 3, or between 1 and 4 s, following stimulus onset is considered to be elicited by that stimulus. It is important to select reasonably short latency windows, perhaps even shorter than 1–3 s, so as to reduce the likelihood that NS-SCRs will be counted as elicited SCRs (Levinson, Edelberg, & Bridger, 1984).

An important advance in EDA research during the past decade or two is the development of computerized scoring programs. Scoring software is available from the manufacturers of several EDA recording systems, and customized software or shareware is frequently used as well. One example of shareware is SCRGAUGE by Peter Kohlisch, available in Boucsein (1992). Another shareware with a long history is SCORIT 1980 (Strayer & Williams, 1982), which is a revision of SCORIT (Prokasy, 1974). Interested readers can contact Dr. William C. Williams (*BWilliams@EWU.edu*) for an updated revised version of SCORIT 1980.

Having decided on a minimum response amplitude and a latency window in which a response will be considered a specific stimulus-elicited SCR, one can measure several aspects of the elicited SCR besides its mere occurrence and frequency. Definitions and typical values of the major EDA component measures are given in Table 7.1 and shown graphically in Figure 7.5. The most commonly reported measure is the size of the SCR, which is quantified as the amount of increase in conductance measured from the

Table 7.1. Electrodermal measures, definitions, and typical values

Measure	Definition	Typical Values
Skin conductance level (SCL)	Tonic level of electrical conductivity of skin	2–20 μS
Change in SCL	Gradual changes in SCL measured at two or more points in time	1–3 μS
Frequency of NS-SCRs	Number of SCRs in absence of identifiable eliciting stimulus	1–3 per min
SCR amplitude	Phasic increase in conductance shortly following stimulus onset	0.1–1.0 μS
SCR latency	Temporal interval between stimulus onset and SCR initiation	1–3 s
SCR rise time	Temporal interval between SCR initiation and SCR peak	1–3 s
SCR half recovery time	Temporal interval between SCR peak and point of 50% recovery of SCR amplitude	2–10 s
SCR habitation (trials to habituation)	Number of stimulus presentations before two or three trials with no response	2–8 stimulus presentations
SCR habituation (slope)	Rate of change of ER-SCR amplitude	0.01–0.5 μS per trial

Key: SCL, skin conductance level; SCR, skin conductance response; NS-SCR, nonspecific skin conductance response.

onset of the response to its peak. The size of an elicited SCR typically ranges between .1 and 1.0 μS. The values in Table 7.1 are representative of healthy young adults. Readers interested in the effects of individual differences in age, gender, and ethnicity should consult Boucsein (1992). Although effects of these variables on EDA have been documented and linked to differences in skin physiology, the effects appear to interact with the nature of the eliciting stimuli (e.g., emotional or neutral), recording environment (e.g., season, time of day, etc.), and recording methodology (constant current or constant voltage) (Boucsein, 1992; Venables & Mitchell, 1996). In general, we advise that these individual differences be controlled across experimental conditions.

When a stimulus is repeated several times and an average size of the SCR is to be calculated, one may choose to compute mean SCR amplitude or magnitude. *Magnitude* refers to the mean value computed across all stimulus presentations including those without a measurable response, whereas *amplitude* is the mean value computed across only those trials on which a measurable (nonzero) response occurred (Humphreys, 1943). The magnitude measure is the most commonly used but Prokasy and Kumpfer (1973) argue against its use because it confounds frequency and amplitude, which do not always covary. A magnitude measure can create the impression that the response size is changing when, in fact, it is response frequency that is changing. Hence, these authors recommend separate assessments of frequency and amplitude rather than magnitude. However, it is important to note that a complication with the amplitude measure is that the *N* used in computing average response size can vary depending on how many measurable responses a subject gives, and the data of subjects without any measurable response must be eliminated. Thus, a subject who responds on each of ten stimulus presentations with a response of .50 μS will have the same mean SCR amplitude as a subject who responds on only the first stimulus presentation with a response of .50 μS, and does not respond thereafter. We concur with Venables and Christie (1980) that there are arguments for and against both amplitude and magnitude and that although no absolute resolution is possible, it is important to keep the difference between the two measures clearly in mind. In some situations it may be reasonable to compute and compare results obtained with SCR frequency, amplitude, and magnitude.

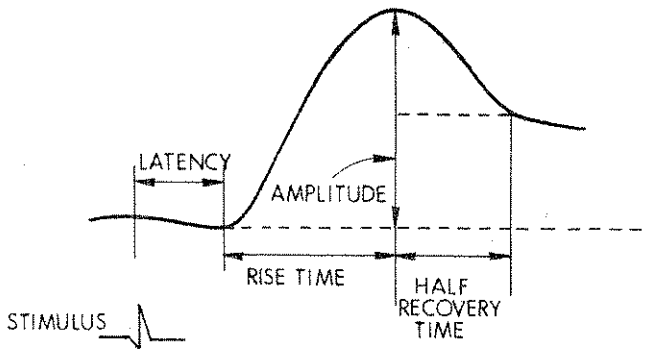

Figure 7.5. Graphical representation of principal EDA components.

Like SCL, SCR amplitude and magnitude are frequently found to be positively skewed and also leptokurtotic, so a logarithmic transformation is often used to remedy these problems. If measurements are being made of SCR magnitude, so that zero responses are included, then log of (SCR + 1.0) may be calculated, because the logarithm of zero is not defined (Venables & Christie, 1980). Another common practice is to use a square root transformation, $\sqrt{\text{SCR}}$, to normalize response amplitude data; this does not require the addition of a constant (Edelberg, 1972a). In some cases the choice of the square root or logarithmic

transformation should be guided by considerations of achieving or maintaining the homogeneity of variance across several groups (Ferguson & Takane, 1989). If skew, kurtosis, or homogeneity of variance problems do not exist in a particular set of data, no transformations need be performed.

In addition to response size, one can also measure temporal characteristics of the SCR including onset latency, rise time, and half recovery time. These temporal characteristics of the SCR waveform are not as commonly reported as magnitude, and their relationship to psychophysiological processes is not as well understood at this time. The possibility that SCR recovery time, for example, can provide information independent of other EDA measures and is uniquely responsive to specific psychophysiological processes was suggested by Edelberg (1972b), but was questioned by Bundy and Fitzgerald (1975), and remains unsettled (Fowles, 1986, pp. 84–87; Edelberg, 1993, pp. 14–15). This is not to say that SCR recovery time is without discriminating power; rather, only that its qualitatively different informational properties relative to other EDA components is an open issue.

The usual constellation of EDA components is for high SCL, frequent NS-SCRs, large SCR amplitude, short latency, short rise time, and short recovery time to cluster together. However, the correlations among the EDA components generally are not very high, usually less than .60 (Lockhart & Lieberman, 1979; Venables & Christie, 1980; Schell, Dawson, & Filion, 1988). The size and consistency of these relationships are compatible with the hypothesis that many of the EDA components may represent partially independent sources of information although, as indicated above with SCR recovery time, this is an unsettled hypothesis. The one exception to the modest relationships among EDA components is the consistently high correlation between SCR rise time and recovery time. Based on this relationship, Venables and Christie (1980) suggest that SCR rise time and half recovery time may be essentially redundant measures and, that because recovery time is not always as available as rise time (because of subsequent responses), rise time may be the preferred measure.

A problem with quantifying the SCR components occurs when the response to be scored is elicited immediately after a preceding response that has not had time to fully recover. It is customary to measure the amplitude of each response from its own individual deflection point (Grings & Lockhart, 1965; Edelberg, 1967). However, the amplitude and the temporal characteristics of the second response are distorted by being superimposed on the recovery of the first response. For example, the measurable amplitude of the second response will be smaller given its occurrence following the first response. The amount of distortion of the second response is a function of the size of the first response and the time since the first response (Grings & Schell, 1969). Although there is no perfect solution to the response interference effect when hand-scoring EDA, it can be pointed out that response frequency may be the least distorted component of the response in this situation. In addition, as mentioned earlier, one advantage of computerized scoring of EDA is the availability of more sophisticated scoring algorithms. In this regard, Lim et al. (1997) applied a multi-parameter curve-fitting algorithm to the scoring of overlapping skin conductance responses and they were able to decompose the overall response complex into meaningful components of the separate responses.

Another problem with quantifying the EDA components concerns the existence of large variability because of extraneous individual differences. Thus, whether an SCL of 8 μS is considered high, moderate, or low will depend upon that specific subject's range of SCLs. For example, one can see in Figure 7.4 that an SCL of 8 μS would be relatively low for the subject depicted in the upper tracing but would be relatively high for the subject depicted in the lower tracing. Similarly, an SCR of .5 μS may be relatively large for one person but relatively small for another. Lykken et al. (1966) proposed an interesting method to correct for this interindividual variance called range correction. The procedure involves computing the possible range for each individual subject and then expressing the subject's momentary value in terms of this range. For example, one may compute a subject's minimum SCL during a rest period and a maximum SCL while the subject blows a balloon to bursting; the subject's present SCL can then be expressed as a proportion of his/her individualized range according to the following formula: (SCL – SCLmin)/(SCLmax – SCLmin). The rationale underlying these procedures is that an individual's range of EDA is due mainly to physiological variables unrelated to psychological processes (e.g., thickness of the corneum). It is the variation within these physiological limits that is normally of psychological interest (Lykken & Venables, 1971).

Although the range correction procedure can reduce error variance and increase the power of statistical tests in some data sets, it also can be problematic in others. For example, range correction would be inappropriate in a situation where two groups being compared had different ranges (Lykken & Venables, 1971). Taking a different approach, Ben-Shakhar (1985) has recommended using within-subject standardized scores to adjust for individual differences because this transformation relies upon the mean, a more stable and reliable statistic than the maximum response. Although these techniques may be useful under some circumstances, most investigators simply compare average values of SCL and SCR across groups, or compare difference scores within a group (e.g., SCL during a task minus SCL during rest).

Another important aspect of elicited SCRs is their decline in amplitude and eventual disappearance with repetition of the eliciting stimulus (SCR habituation). Habituation is a ubiquitous and adaptive phenomenon whereby subjects become less responsive to familiar and nonsignificant stimuli. There are several methods of quantifying

habituation of the SCR (Siddle, Stephenson, & Spinks, 1983). One simple method involves counting the number of stimulus repetitions required to reach some predetermined level of habituation (e.g., two or three consecutive trials without measurable SCRs). This "trials-to-habituation" measure is useful and has been widely employed since its use by Sokolov (1963), but it is subject to considerable distortion by the occurrence of a single response. For example, whether an isolated SCR occurs on trial 3 can make the difference between a trials-to-habituation score of "0" (indicative of an atypical nonresponder) and a "3" (indicative of a typical rate of habituation).

Another common measure of habituation is based on the rate of decline of SCR magnitude across trials as assessed by a "trials" main effect or interaction effect within an analysis of variance. However, this measure does not provide information about habituation in individual subjects and moreover can be distorted by differences in initial levels of responding.

A third measure of habituation is based on the regression of SCR magnitude on the log of the trial number (Lader & Wing, 1966; Montague, 1963). The regression approach provides a slope and an intercept score (the latter reflecting initial response amplitude), which are usually highly correlated with each other. Covariance procedures have been used to remove the dependency of slope on intercept, providing what Montague (1963) has called an "absolute rate of habituation." However, this technique rests on the assumptions that slope and intercept reflect different underlying processes and that the treatment effects under investigation do not significantly affect the intercepts (Siddle et al., 1983). Use of the slope measure also assumes that subjects respond on a sufficient number of trials to compute a meaningful slope, which may not be the case for some types of subjects with mild innocuous stimuli. Nevertheless, to the extent that these assumptions can be justified, the slope measure is often preferable because: (1) unlike the analysis of variance approach, individual habituation scores can be derived, (2) unlike the trials-to-habituation measure, isolated SCRs have less of a contaminating effect, (3) unlike trials-to-habituation, the slope measure makes fuller use of the magnitude data, and (4) unlike trials-to-habituation, the slope measure can discriminate between subjects who show varying degrees of habituation but who fail to completely stop responding for two or three consecutive trials.

The temporal stability (test-retest reliability) of EDA measures such as the frequency of NS-SCRs, SCL, responsiveness to stimuli, and habituation have been fairly well investigated in normal healthy adults (see Freixa i Baque, 1983 for a discussion of early studies, and Schell et al., 2002, for a more recent review). Test-retest correlations for periods extending up to one year or more have ranged from approximately .40 to .75 for NS-SCR frequencies, from .40 to .85 for SCL, and from .30 to .80 for number of SCRs elicited by a series of repeated stimuli. Stability of temporal measures (i.e., latency, rise time, etc.) is typically lower. Schell et al. (2002) found that as measures of overall responsiveness, simple counts of the number of SCRs elicited by a series of stimuli were more reliable than trials-to-habituation measures.

ADVANTAGES AND DISADVANTAGES OF THE USE OF EDA

When one is considering use of EDA as an indicator of some psychological state or process of interest, it is well to remember that in the great majority of situations, changes in electrodermal activity do not occur in isolation. Rather, they occur as part of a complex of responses mediated by the autonomic nervous system.

Experimental treatments that have the effect of increasing SCL and/or NS-SCR rate also are expected to generally increase heart rate level and blood pressure and to produce peripheral vasoconstriction, to mention a few of the more commonly measured autonomic responses (Engel, 1960; see Grings & Dawson, 1978). The response or responses chosen for monitoring by a particular investigator should reflect considerations such as those discussed in the following section.

For some researchers, EDA may be the response system of choice because, unlike most ANS responses, it provides a relatively direct and undiluted representation of sympathetic activity. As has been pointed out above, the neural control of the eccrine sweat glands is entirely under sympathetic control. Therefore, increases in SCL or the SCR are due to increased tonic or phasic sympathetic activation. In contrast, with heart rate as with most ANS functions (pupil diameter, gastric motility, and blood pressure), a change in activity in response to stimuli of psychological significance cannot be unambiguously laid to either sympathetic or parasympathetic activity; it may be due to either one or to a combination of both. Thus, the researcher who wishes an unalloyed measure of sympathetic activity may prefer to monitor EDA, whereas the experimenter who wishes a broader picture of both sympathetic and parasympathetic activity may prefer heart rate, if constraints of instrumentation will allow only one to be recorded. Similarly, if for some reason (perhaps the use of medication with side effects on cholinergic or adrenergic systems) one wishes to monitor a response which is predominately cholinergically mediated at the periphery but which is also influenced by sympathetic activity, then EDA would be the choice.

Another advantage of measuring SCR is that its occurrence is generally quite discriminable. Thus, on a single presentation of a stimulus, one can determine by quick inspection whether or not an SCR has occurred. In contrast, the presence of a heart rate response on single stimulus presentation may be difficult to distinguish from ongoing variability in heart rate that reflects changes in muscle tonus or respiratory sinus arrhythmia.

In addition to decisions made based on neuroanatomical control and basic response characteristics, an investigator

may prefer EDA to other response systems because of the nature of the situation in which the subject is assessed. Fowles (1988) argued convincingly that heart rate is influenced primarily by activation of a neurophysiological behavioral activation system that is involved in responding during *appetitive* reward-seeking, to conditioned stimuli associated with reward, and during active avoidance. On the other hand, EDA is influenced primarily by activation of a neurophysiological behavioral *inhibition* system that is involved in responding to punishment, to passive avoidance, or to frustrative nonreward. This latter system is viewed as an anxiety system. Thus, if an investigator is studying the reaction of subjects to a situation or to discrete stimuli that elicit anxiety, but in which no active avoidance response can be made, the electrodermal system should be the physiological system that is most responsive.

For many investigators, an additional advantage of the use of EDA relative to other response systems is that of all forms of ANS activity, individual differences in EDA appear to be most reliably associated with psychopathological states. The correlates of some of these stable EDA differences between individuals are discussed in the following section.

Finally, it is important to note that, in comparison to many other psychophysiological measures, EDA is relatively inexpensive to record. After initial purchase of the recording system, expenses for each subject are trivial, involving electrode collars and paste and the occasional replacement of electrodes. Electrical shielding of the room in which the subject sits which is generally needed for noise-free recording of EEG or event related potentials is unnecessary, and the costs of using EDA as a response measure are minuscule compared to those of hemodynamic techniques such as PET scans or functional MRI. Furthermore, the techniques used to record EDA are completely harmless and risk-free, and thus they can be used with young children and in research designs that require repeated testing at short intervals of time.

There are also potential disadvantages to the use of EDA as a dependent measure. First, EDA is a relatively slow-moving response system. As mentioned previously, the latency of the elicited SCR is between 1.0 and 3.0 s, and tonic shifts in SCL produced by changes in arousal and alertness require approximately the same time to occur. Thus, an investigator who is interested in tracking very rapidly occurring processes, or stages within a complex process, may not find EDA useful. Although the SCR cannot index such rapidly occurring processes as sensory gating or stages of stimulus analysis on a real-time basis, it has been found to be correlated with real-time measures of these processes. For example, Lyytinen, Blomberg, and Näätänen (1992) observed that the parietal P3a was larger when an SCR was elicited by a novel tone than when no SCR was elicited.

Another potential disadvantage is that EDA has multiple causes; the elicited SCR is not specific to a single type of event or situation (as, for instance, the N400 ERP component appears to be specifically influenced by semantic expectancy, Kutas, 1997). However, the multiple influences on EDA may actually be as much an advantage as a disadvantage. As described throughout this chapter, EDA can be used to index a number of processes: activation, attention, and significance or affective intensity of a stimulus. In using EDA as a response measure, one must take care to control experimental conditions – that is, be sure that one is varying only one process that may influence EDA at a time. Such experimental control is essential for all attempts to draw clear inferences from results, whether one is recording EDA, electrocortical activity, or a hemodynamic measure, given the number of processes that may influence these measures as well.

Thus, like any single response system, EDA has distinct advantages and disadvantages. The ideal situation, of course, is one in which the researcher can record more than one response measure. When ANS activity is of primary interest, EDA and heart rate are probably the two most common choices: EDA for its neuroanatomical simplicity, trial-by-trial visibility, and utility as a general arousal/attention indicator and heart rate for its potential differentiation of other psychological and physiological states of interest to the researcher.

PSYCHOLOGICAL AND SOCIAL CONTEXT

In this section, we review the psychological and social factors that have been shown to influence EDA in three types of paradigm: (1) those that involve the presentation of discrete stimuli, (2) those that involve the presentation of continuous stimuli, and (3) those that involve examining the correlates of individual differences in EDA.

Effects of discrete stimuli. Properties of stimuli to which the SCR is sensitive are wide and varied: they include stimulus novelty, surprise, intensity, arousal content, and significance. It might be argued that, because EDA is sensitive to such a wide variety of stimuli, it is not a clearly interpretable measure of any particular psychological process (Landis, 1930). This view is certainly correct in the sense that it is impossible to identify an isolated SCR as an "anxiety" response, or an "anger" response, or an "attentional" response. However, the psychological meaning of an SCR becomes interpretable by taking into account the stimulus condition or experimental paradigm in which the SCR occurred. The better controlled the experimental paradigm, the more conclusive the interpretation. That is, by having only one aspect of the stimulus change across conditions (e.g., task significance) while eliminating other differences (e.g., stimulus novelty, intensity, etc.), then one can more accurately infer the psychological processes mediating the resultant SCR. As we will illustrate in the following discussion, the inference of a specific psychophysiological process requires knowledge of both a well controlled stimulus situation and a carefully measured response.

One discrete stimulus paradigm that relies on the SCR's sensitivity to stimulus significance is the so-called Guilty Knowledge Test (GKT), which is a type of detection of deception test ("lie detection"). The GKT, also sometimes referred to as a "Concealed Knowledge Test," involves recording SCRs (as well as other physiological responses) while presenting subjects with a series of multiple-choice questions (Lykken, 1959). For example, a suspect in a burglary case might be asked to answer "no" to each of the alternatives given for a question concerning details about the burglary. For each question, the correct alternative would be intermixed among other plausible alternatives. The theory behind the technique is that the correct answer to each question will be more psychologically significant to a guilty subject than will the other alternatives, whereas for the innocent subject all of the alternatives would be of equal significance. Therefore, the guilty subject is expected to respond electrodermally more to the correct alternatives, whereas the innocent subject is expected to respond randomly (Lykken, 1959). Lykken (1981) suggested that guilty subjects can be detected nearly 90% of the time and that innocent subjects can be correctly classified nearly 100% of the time with a properly constructed GKT. For a discussion of the differing views of psychophysiological techniques of detecting deception, see Iacono (Chapter 29 in this volume).

Tranel, Fowles, and Damasio (1985) developed another type of discrete stimulus paradigm with which to study the effects of significant stimuli. SCRs were recorded from normal college students while being presented a set of slides depicting faces of famous people (e.g., Ronald Reagan, Bob Hope, etc.) interspersed among a larger number of faces of unfamiliar people. Subjects were instructed simply to sit quietly and look at each slide. The results revealed that the average SCR was much larger to slides of significant faces ($M = 1.26\ \mu S$) than to the nonsignificant faces ($M = .19\ \mu S$).

Although the GKT of Lykken (1959) appears to be quite adequate to detect concealed information (and hence the guilty person), and the paradigm of Tranel et al. (1985) appears adequate to test for recognition of famous faces, one may question whether either paradigm is sufficient to demonstrate the effect of stimulus significance per se on the SCR. It may be argued that both paradigms confounded relative novelty with relative stimulus significance. If guilty subjects dichotomize items into relevant and irrelevant categories in the GKT (Ben-Shakhar, 1977), then the relevant category is presented less often than the irrelevant category and this relative novelty may contribute to the differential SCRs. Likewise, in the studies using slides of famous faces, the significant category of stimuli was presented less often than the nonsignificant category and this difference in relative novelty may have contributed to the differential SCRs. The number of presentations of relevant/significant stimuli should have been equal to that of irrelevant/nonsignificant stimuli in order to unambiguously demonstrate the effect of stimulus significance on SCRs. As mentioned earlier in this section, close control over stimulus properties (in this case, novelty and significance) is necessary in order to infer the psychological processes eliciting the SCR. Interestingly, using a modification of the GKT in which relevant and irrelevant items were presented equally often, Verschuere et al. (2004) have found evidence that responses to relevant items remain greater than to irrelevant items. These findings demonstrate the importance of stimulus significance in eliciting SCRs above and beyond novelty.

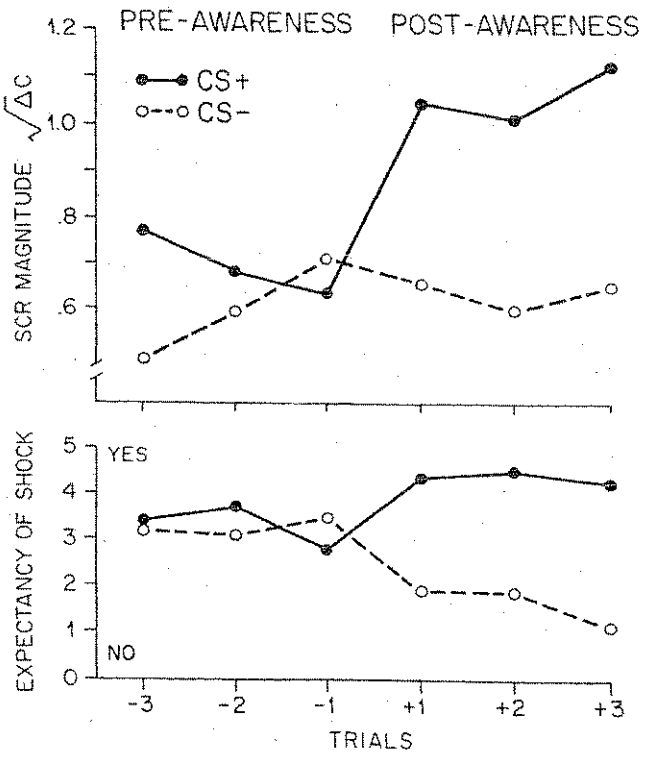

Figure 7.6. Mean SCR magnitude (top) and mean expectancy of shock (bottom) to the reinforced conditioned stimulus (CS+) and the nonreinforced conditioned stimulus (CS−) on three pre-aware and three post-aware trials (Adapted from Dawson & Biferno, 1973).

Another discrete stimulus paradigm in which EDA is commonly measured that highlights the influence of stimulus significance while controlling for stimulus novelty involves discrimination classical conditioning (Grings & Dawson, 1973). For example, Dawson and Biferno (1973) employed a discrimination classical conditioning paradigm in which college student subjects were asked to rate their expectancy of a brief electric shock (unconditioned stimulus, UCS) following each presentation of a CS+ (a conditioned stimulus regularly followed by the shock) and a CS−(a control stimulus never followed by shock). Tones of 800 Hz and 1200 Hz were presented equally often and served as the reinforced CS+ and the nonreinforced CS−, counterbalanced across subjects. Thus, on each conditioning trial, the subject's expectancy of shock and the associated SCR were recorded. The results, shown in Figure 7.6, revealed that subjects tended

to respond equally to the reinforced CS+ and to the nonreinforced CS– until they became aware of the contingency between the conditioned stimuli and the shock. There was no evidence of SCR discrimination conditioning prior to the development of awareness; however, once the subject became aware, the CS+ became more significant than the CS–, and there was an abrupt increase in the magnitude of the SCRs elicited by the CS+. Moreover, SCR discrimination conditioning fails to occur when CS-UCS pairings are embedded in distracting tasks that effectively prevent subjects from becoming aware of the critical stimulus relations (see reviews by Dawson & Schell, 1985; Lovibond & Shanks, 2001). These results suggest that awareness of the CS-UCS relation is necessary for human discrimination SCR conditioning.

The conditions under which subjects must be consciously aware of the stimulus significance in order to elicit SCR ORs is a topic of considerable research. For example, SCR discrimination conditioning has been reported to occur without subjects becoming aware of the CS-UCS relationship under special circumstances when "prepared" stimulus relationships are conditioned. The concept of "preparedness" is that certain stimulus associations (e.g., taste with nausea and snakes with pain) are more quickly, easily, and automatically learned than are others (e.g., an arbitrary tone and a shock) and are more resistant to extinction because they have been correlated in our evolutionary past (Seligman, 1970).

Öhman and his colleagues, in an interesting series of studies beginning in the 1970s, extended Seligman's concept to human autonomic conditioning, using types of CSs that have been termed biologically prepared, potentially phobic, or fear-relevant: pictures of spiders, snakes, and angry faces (see Öhman, 1992 for reviews). In the early studies of this series, Öhman and his colleagues demonstrated that SCRs conditioned with fear-relevant CSs and a shock UCS were more resistant to extinction than were SCRs conditioned with neutral CS-UCS relations (pictures of flowers or happy faces as CSs associated with shock). Such SCRs also were more resistant to cognitive manipulations such as extinction instructions informing subjects that the UCS would no longer be delivered (Hugdahl & Öhman, 1977) and were retained past the point of cognitive extinction (no greater expectancy of the UCS after the CS+ than after the CS–) following the presentation of many nonreinforced trials (Schell, Dawson, & Marinkovic, 1991).

In later studies of this series, backward masking was used to prevent awareness of the CS-UCS relation by preventing conscious recognition of the fear-relevant CSs. In this paradigm, visual CSs are presented very briefly (30 ms) and immediately followed by a masking stimulus. These procedures prevent recognition of the CSs in the vast majority of subjects on the vast majority of trials (Öhman, Dimberg, & Esteves, 1989a).

Backwardly masked angry and happy faces have been used as CSs during acquisition (Esteves et al., 1994). In one group, a masked angry face (CS+) was paired with shock, whereas in another group a masked happy face (CS+) was paired with shock. During subsequent extinction, unmasked CSs were presented and conditioned SCRs were elicited to the previously masked angry face CS+, but not to the happy face CS+. Thus, electrodermal conditioning was established "nonconsciously" to a threatening angry face, but not to a friendly smiling face. Conditioning to other masked biologically fear-relevant CSs was replicated in subsequent experiments by Öhman and Soares (1998) using pictures of snakes and spiders rather than angry faces. Studies using functional brain imaging techniques have replicated these SCR results and demonstrated the importance of the amygdala, extended regions of the amygdala complex, and sensory cortex in such conditioning (Morris, Buchel, & Dolan, 2001).

Studies of brain damaged patients also indicate that the amygdala is critical for SCR classical conditioning. For example, Bechara et al. (1995) found that a patient with selective bilateral destruction of the amygdala did show unconditioned SCRs to the unconditioned stimulus but did not show SCR conditioning to the CS, although this patient was aware of the CS-UCS relation. A different patient with bilateral hippocampi damage (but intact amygdala) showed both conditioned and unconditioned SCRs but could not describe the CS-UCS relation. All in all, contrary to the results shown in Figure 7.6, these findings indicate that SCR conditioned responses may be acquired without the subjects' awareness of the CS-UCS relation in some circumstances. The nature of these circumstances (only with biologically prepared fear-relevant stimuli or with certain types of brain damage?) is a topic of ongoing research.

SCRs elicited by discrete nonaversive stimuli are generally considered to be part of the orienting response to novel or significant stimuli. We believe that the data reviewed in this section can be interpreted within this theoretical setting. The task of subjects exposed to the GKT is to deceive or conceal knowledge, and the correct item is more relevant to this task than are incorrect alternative items. Thus, subjects orient more to the task-significant items than the task-nonsignificant items. Verschuere et al. (2004) found greater heart rate deceleration following relevant items than irrelevant items in a GKT which is consistent with the orienting hypothesis. Likewise, faces of famous people may be perceived as more significant than the faces of unfamiliar people, and the signal of an impending shock (CS+) is more significant than the signal of no shock (CS–). Thus, the results observed here are consistent with the notion that the SCR is highly sensitive to stimulus significance, even under certain conditions where the reasons for that significance may not be consciously processed.

There have been several models proposed to account for the elicitation of autonomic ORs such as the SCR (see Siddle et al., 1983, for a review). For example, an influential information processing model has been proposed by

Öhman (1979). This model distinguishes between automatic preattentive processing and controlled capacity-limited processing. Autonomic orienting is elicited when the preattentive mechanisms call for additional controlled processing. According to this model, there are two conditions under which this call is made. First, the call is made and the OR is elicited when the preattentive mechanisms fail to identify the incoming stimulus because there is no matching representation in short-term memory. Thus, the OR is sensitive to stimulus novelty. Second, the call is made and the OR is elicited when the preattentive mechanisms recognize the stimulus as significant. Thus, the OR represents a transition from automatic to controlled processing based on preliminary preattentive analysis of stimulus novelty and stimulus significance. This model allows for the possibility that the OR may be elicited without conscious awareness. Others, however, have suggested that the OR occurs when controlled processing resources are actually allocated to the processing of the stimulus, at least where fear-irrelevant stimuli are concerned (Dawson, Filion, & Schell, 1989; Öhman, 1992).

Other discrete stimuli capable of eliciting SCRs are those with either strong positive or negative affective valence. We orient to stimuli that are significant because they are either very positive or very negative in terms of the emotional response that they elicit. However, unlike responses such as the startle eyeblink, the SCR does not distinguish arousing positive stimuli from equally arousing negative stimuli. Lang, Bradley, Cuthbert, and their colleagues have developed a set of widely used pictures (the International Affective Picture System, IAPS, Lang, Bradley, & Cuthbert, 1998; see Chapter 25, this volume) that are rated for both their arousal-producing quality and valence on a strongly positive to strongly negative scale. SCRs elicited by these pictures have reliably been found to be related to the arousal dimension, with responses increasing in magnitude as arousal rating increased for both positively valenced pictures (greater for erotic pictures than for beautiful flowers) and negatively valenced pictures (greater for striking snakes than for tombstones in a cemetery) (Lang et al., 1993; Cuthbert, Bradley, & Lang, 1996).

Other affective stimuli hypothesized to evoke SCRs are those associated with internal processes involved in making decisions. Damasio (1994) proposed a "somatic marker" hypothesis, the main point of which is that decision-making is influenced by emotional somatic responses. The somatic marker hypothesis has been tested by measuring SCRs during a gambling task (Bechara et al., 1997). In this task subjects select cards from "bad" decks that can yield high immediate financial gain but large long-term losses, or from "good" decks that yield lower immediate gain but a larger long-term gain. After encountering a few losses, normal subjects, as opposed to brain damaged patients, generate SCRs in anticipation of selecting cards from the "bad" deck and begin to avoid selecting cards from that deck. These results were originally interpreted as indicating that SCRs in response to decision-making processes reflect somatic markers that help the person make advantageous decisions even before conscious knowledge of the rules of the game was available. However, more recent research suggests that, in fact, subjects may have considerable conscious understanding of the game (Maia & McClelland, 2004) and this suggests that the SCR may only indicate when a person has consciously decided to make a risky decision.

In conclusion, in this section we have described some of the discrete stimulus paradigms in which EDA is most often measured and has proven to be most useful. We have emphasized that determining the psychological meaning of any particular SCR is dependent on a well-controlled stimulus situation. In addition, we have described a theoretical model that may be used to account for the SCRs elicited in the paradigms described. Finally, these areas of research examining the SCR to discrete stimuli underscore the point made previously that one advantage of the SCR is that the response can easily be measured on individual presentations of a stimulus. Thus, one may determine whether the response to a "guilty" relevant stimulus in a group of stimuli is greater than that to "innocent" irrelevant stimuli, whether the SCR elicited by a CS+ is greater on the first trial after awareness of the CS-UCS relationship occurs than on the last trial before that awareness occurs, whether the SCR elicited by a fear-relevant CS+ is greater than the SCR elicited by a CS− on the first trial pair following extinction instructions, whether the eliciting stimulus is highly arousing due to affective valence of either a positive or negative nature, and whether arousal states that occur during decision-making guide decisions when risk is involved.

Effects of continuous stimuli. We turn now to an examination of the effects of more chronic, long-lasting stimuli or situations as opposed to the brief, discrete stimuli reviewed above. Chronic stimuli might best be thought of as modulating increases and decreases in tonic arousal. Hence, the most useful electrodermal measures in the context of continuous stimuli are SCL and frequency of NS-SCRs, because they can be measured on an ongoing basis over relatively long periods of time.

One type of continuous stimulus situation that will reliably produce increases in electrodermal activity involves the necessity of performing a task. The anticipation and performance of practically any task will increase both SCL and the frequency of NS-SCRs, at least initially. For example, Lacey et al. (1963) recorded palmar SCL during rest and during the anticipation and performance of eight different tasks. The tasks ranged from those requiring close attention to *external* stimuli, such as listening to an irregularly fluctuating loud white noise, to those requiring close attention to *internal* information processing, such as solving mental arithmetic problems. The impressive finding for present purposes was that SCL increased in each and every one of the task situations. Typically, SCL increased about one μS above resting level during anticipation and then

increased another one or two μS during performance of the task. Heart rate, unlike SCL, discriminated between tasks involving attention to external stimuli and tasks requiring attention to internal information processing.

Munro et al. (1988) observed that large increases in SCL and NS-SCR frequency were induced by a different task-significant situation. In this case, college student subjects were tested during a five-minute rest period and then during performance of a continuous vigilance task. The task stimuli consisted of a series of digits presented visually at a rapid rate of one-per-s with exposure duration of 48 ms; the subject's task was to press a button whenever the digit "0" was presented. Both the number of NS-SCRs and SCL initially increased sharply from the resting levels during this demanding task and then gradually declined as the task continued.

The finding that electrodermal activity is reliably elevated during task performance suggests that tonic EDA can be a useful index of a process related to "energy regulation" or "energy mobilization." An information processing interpretation of this finding might be that tasks require an effortful allocation of attentional resources and that this is associated with heightened autonomic activation (Jennings, 1986). A different, but not necessarily mutually exclusive, explanation would invoke the concepts of stress and affect rather than attention and effortful allocation of resources. According to this view, laboratory tasks are challenging stressors, and a reliable physiological response to stressors is increased sympathetic activation, particularly EDA arousal.

Situations in which strong emotions are elicited also increase tonic EDA arousal, as would be expected from the finding discussed above that SCR magnitude is affected by the arousal value of discrete stimuli with emotional valence. In a classic experiment, Ax (1953) created genuine states of fear and anger in his subjects by causing them to feel in danger of a high-voltage shock due to equipment malfunction or by treating them in a rude and inconsiderate fashion. SCL, number of NS-SCRs, and several other measures of sympathetic nervous system activity rose during both the fear and the anger conditions, with the patterns for fear and anger differing to some degree (SCL rose more in fear than in anger, while NS-SCRs and diastolic blood pressure rose more in anger than in fear.) More recently, Levenson, Gross, and their colleagues have used films in a number of studies to elicit emotional states, primarily disgust, lasting for a minute or more (Gross & Levenson, 1993; Gross, 1998). SCL and other measures of sympathetic activation in these studies were higher during the films than during a baseline period, and the rise in SCL was influenced by the emotional regulation strategy that subjects were instructed to use. Subjects instructed to suppress their facial display of emotion, to try to behave as though anyone observing them would not know what they were feeling, showed greater increases in SCL than subjects who simply watched the films or who were instructed to reappraise what they were seeing, to watch the film with a detached, objective, and unemotional attitude.

Social stimulation constitutes another class of continuous stimuli that generally produces increases in EDA arousal. Social situations are ones in which the concepts of stress and affect are most often invoked. For example, early research related EDA recorded during psychotherapeutic interviews to concepts such as "tension" and "anxiety" on the part of both patient and therapist (Boyd & DiMascio, 1954; Dittes, 1957). In one such study, Dittes (1957) measured the frequency of NS-SCRs of a patient during 42 hours of psychotherapy. The results of this study indicated that the frequency of NS-SCRs was inversely related to the judged permissiveness of the therapist, and Dittes concluded that EDA reflects "the anxiety of the patient, or his 'mobilization' against any cue threatening punishment by the therapist" (p. 303).

Schwartz and Shapiro (1973) reviewed several areas of social psychophysiology up to 1970, including those in which EDA was measured during social interactions. These are situations in which intense cognitive and affective reaction may occur, precipitating large changes in EDA and other physiological responses. In a series of social psychophysiological studies conducted since the Schwartz and Shapiro review, EDA was recorded during marital social interactions (Levenson & Gottman, 1983; 1985). The researchers measured SCL (in addition to heart rate, pulse transmission time, and somatic activity) from married couples while they discussed conflict-laden problem areas. It was found that couples from distressed marriages had high "physiological linkage"; that is, there were greater correlations between husbands' and wives' physiological reactions in distressed marriages than those in satisfying marriages during the discussions of problem areas. Moreover, greater physiological arousal, including higher SCL, during the interactions and during baselines was associated with a decline in marital satisfaction over the ensuing three years.

Another series of studies related the effects of stressful social interactions on EDA to relapse among schizophrenia patients. It has been well documented that patients are at increased risk for relapse if their relatives are critical, hostile, or emotionally overinvolved with them at the time of their illness (Brown, Birley, & Wing, 1972; Vaughn & Leff, 1976; Vaughn et al., 1984). The term *expressed emotion* (EE) is used to designate this continuum of affective attitudes ranging from low-EE (less critical) to high-EE (more critical) on the part of the relative.

It has been hypothesized that heightened autonomic arousal may be a mediating factor between the continued exposure to a high-EE relative and the increased risk of symptomatic relapse (Turpin, 1983). According to this notion, living with a high-EE family member produces excessive stress and autonomic hyper-arousal. Autonomic hyper-arousal has been characterized as one of several transient intermediate states that can produce deterioration in the patient's behavior, which in turn can negatively

affect people around the patient. Hence, a vicious cycle can be created whereby the increased arousal causes changes in the patient's behavior that have an aggravating effect on the social environment, which then serves to further increase autonomic arousal. Unless such a cycle is broken, (e.g., by removal from that social environment), it can lead to the return of schizophrenia symptoms and a clinical relapse (Dawson, Nuechterlein, & Liberman, 1983; Nuechterlein & Dawson, 1984).

One prediction derived from this model is that patients exposed to high-EE relatives should show heightened sympathetic arousal compared to patients exposed to low-EE relatives. The first study to test this prediction obtained rather clear confirmatory results (Tarrier et al., 1979). These investigators measured the EDA of remitted patients living in the community whose relatives' level of EE had been determined by Vaughn and Leff (1976). Patients were tested for 15 minutes without the key relative and for 15 minutes with the key relative present. The frequency of NS-SCR activity of the patients with high-EE relatives and low-EE relatives did not differ when the relative was absent from the testing room, but if the key relative was present then patients with high-EE relatives exhibited higher rates of NS-SCRs than did patients with low-EE relatives. These results indicate that the presence of high-EE and low-EE relatives have differential effects on EDA which are consistent with the hypothesis that differential autonomic arousal plays a mediating role in the differential relapse rates of the two patient groups. More complete reviews of these studies and their implications can be found in Turpin, Tarrier, and Sturgeon (1988).

Individual differences in EDA. We have discussed the utility of EDA as a dependent variable reflecting situational levels of arousal/activation or attentiveness/responsiveness to individual stimuli. In this section we consider EDA as a relatively stable trait of the individual, as an individual difference variable. Individual differences in EDA are reliably associated with behavioral differences and psychopathological states of some importance, and we will examine some of these.

Individual differences in the rate of NS-SCRs and the rate of SCR habituation have been used to define a trait called "electrodermal lability" (Mundy-Castle & McKiever, 1953; Lacey & Lacey, 1958; Crider, 1993). Electrodermal "labiles" are subjects who show high rates of NS-SCRs and/or slow SCR habituation, whereas electrodermal "stabiles" are those who show few NS-SCRs and/or fast SCR habituation. Electrodermal lability is an individual trait that has been found to be relatively reliable over time, and labiles differ from stabiles with respect to a number of psychophysiological variables, including measures of both electrodermal and cardiovascular responsiveness (Kelsey, 1991; Schell, Dawson, & Filion, 1988). In this section, we review behavioral and psychological differences associated with this individual difference in both normal and abnormal populations.

Electrodermal lability is a trait of interest in psychological research in part because many investigators have reported that labiles outperform stabiles on tasks which require sustained vigilance. When individuals perform a signal detection task that is sustained over time, deterioration across time in the accurate detection of targets is frequently observed, a phenomenon referred to as vigilance decrement (Davies & Parasuraman, 1982). Several experimenters have reported that when vigilance decrement occurs, it is more pronounced among electrodermal stabiles than among labiles. This appears to be particularly true when EDA lability is defined by differences in SCR OR habituation rate (Koelega, 1990). As time on the task goes by, labiles are apparently better able to keep attention focused on the task and to avoid a decline in performance (Crider & Augenbraun, 1975; Hastrup, 1979; Munro et al., 1987; Vossel & Rossman, 1984). With a difficult continuous performance task, Munro et al., for instance, whose study was mentioned above, found that stabiles showed a significant decrement over time in performance, whereas labiles did not. The degree of task-induced sympathetic arousal as measured by increases in NS-SCR rate was negatively correlated across subjects with performance decrement.

Researchers investigating these sorts of behavioral differences between electrodermal stabiles and labiles have concluded that lability reflects the ability to allocate information processing capacity to stimuli that are to be attended (Lacey & Lacey, 1958; Katkin, 1975; Schell et al., 1988). As Katkin (1975, p. 172) concluded, "electrodermal activity is a personality variable that reflects individual differences in higher central processes involved in attending to and processing information." Viewing electrodermal lability in this way suggests that labiles should differ from stabiles in a variety of information processing tasks. Consistent with this view, EDA labile children have been found to generally outperform stabiles on a variety of tasks that require perceptual speed and vigilance (Sakai, Baker, & Dawson, 1992).

In addition to the differences between stabiles and labiles in the normal population, reliable abnormalities in electrodermal lability are associated with diagnosable psychopathology. We will next summarize EDA abnormalities reported in schizophrenia and psychopathy. A more general discussion of psychophysiological abnormalities in these and other psychopathologies can be found in Hicks, Keller, and Miller (Chapter 28, this volume).

In general two types of electrodermal abnormalities have been reported in different subgroups of patients with schizophrenia. First, between 40% and 50% of schizophrenia patients fail to show any SCR orienting responses to mild innocuous tones (termed "nonresponders"), compared to approximately 10% nonresponders in the normal population (see reviews by Bernstein et al., 1982; Dawson & Nuechterlein, 1984; Iacono, Ficken, & Beiser, 1993; Öhman, 1981). The high proportion of electrodermal non-responders in schizophrenia has been a reliable

finding across studies. For example, Bernstein et al. (1982) examined a series of 14 related studies in which samples of American, British, and German schizophrenia patients and normal controls were tested using a common methodology and response scoring criteria. The consistent finding was that approximately 50% of the patients were non-responders, compared to only 5 to 10% of controls. (More recent data reported and reviewed by Venables and Mitchell (1996) suggest the percentage of SCR nonresponders in normal groups may be closer to 25%.)

The second electrodermal abnormality, found in the "responder" subgroup of patients, is the presence of higher than normal levels of tonic arousal, indicated by high SCLs and a high frequency of NS-SCRS (Dawson & Nuechterlein, 1984; Dawson, Nuechterlein, & Schell 1992a; Öhman, 1981). In effect, the nonresponder group is characterized by hyporesponsivity to stimuli whereas the responder group is characterized by tonic hyperarousal. Both types of abnormalities have been found to be reliable across time. For example, in a group of 56 chronic schizophrenia patients classified as nonresponders on an initial test, 87% remained nonresponders two weeks later and 91% were nonresponders four weeks later (Spohn et al., 1989). In a group of 29 schizophrenia nonresponder outpatients, 62% remained nonresponders one year later (Schell et al., 2002). The tonic measures of SCL and NS-SCRs also remained relatively stable over a one-year period in the schizophrenia outpatients (test-retest rs = .43 and .53 respectively). The latter test-retest correlations, although significant, are in the lower end of the range of correlations found over similar time intervals with normal subjects that were reviewed earlier, possibly because of fluctuating symptoms among the patients.

The hope associated with the identification of responder and nonresponder EDA subgroups is that it will identify meaningful subgroups in terms of different symptomatic types of schizophrenia or different prognoses, or that one or both abnormalities might constitute a vulnerability marker for schizophrenia. Unfortunately, the results relating EDA abnormalities with current symptoms, future prognosis, and vulnerability have not always been consistent. As we point out later, the reasons for these inconsistencies may have to do with different populations of patients and control comparison groups.

Nonresponder and responder subgroups of patients have been reported by some investigators to show different symptomatology at the time of testing, with responders generally displaying more symptoms of excitement, anxiety, manic behavior, and belligerence, whereas nonresponders tend to show more emotional withdrawal, conceptual disorganization, and negative symptoms (e.g., Bernstein et al., 1981; Straube, 1979; Fuentes et al., 1993). Furthermore, SCR hypo-responsivity has been related to a more severe form of illness (Katsanis & Iacono, 1994), poor premorbid adjustment (Öhman et al., 1989), and more psychiatric symptoms overall (positive and negative) (Green, Nuechterlein, & Satz, 1989; Kim et al., 1993). Other investigators, however, have found the hyper-aroused responders to display the greater level of overall symptomatology (Brekke et al., 1997; Dawson et al., 1992b).

Abnormally elevated EDA arousal also has been found particularly during periods of psychotic symptomatology, compared to the same patients during periods of remission (Dawson et al., 1994) (see Figure 7.7). Moreover, heightened EDA arousal has been found to occur within a few weeks prior to an impending psychotic relapse, compared to control periods of stable remission within the same patients (Hazlett et al., 1997). This finding is consistent with a theoretical model that hypothesizes that heightened sympathetic activation is associated with a "transient intermediate state" that precedes psychotic episodes in vulnerable individuals (Nuechterlein & Dawson, 1984). According to this theoretical model, not all such intermediate states will necessarily be followed by psychotic exacerbation or relapse. Rather, these states constitute periods of heightened vulnerability with an increased risk of relapse, with the actual occurrence of relapses or exacerbation being influenced by environmental stressors.

Results regarding prediction of outcome also have been somewhat inconsistent. The predominant finding is that EDA hyperarousal is associated with poor short-term symptomatic prognosis (Brekke, Raine, & Thomson, 1995; Frith et al., 1979; Zahn, Carpenter, & McGlashan, 1981; Dawson et al., 1992b; see review by Dawson & Schell, 2002). However, a minority of studies have reported that EDA hyporesponsivity, not hyperarousal, is associated with poor prognosis. The typical procedure in these short-term studies was to relate EDA recorded during rest and simple orienting tasks from schizophrenia patients initially while in symptomatic states and then relate the EDA measures to subsequent persistence of the symptoms weeks or months later. In a longer-term study (Tarrier & Barrowclough, 1989), the number of NS-SCRs and the regression slopes of SCL measured during interactions with relatives at the time the patients were hospitalized were found to be related to symptomatic relapse over the next two years. The direction of the effect, greater frequency of NS-SCRs and greater rise in SCL among the patients who later relapsed, is consistent with the notion that high EDA arousal is predictive of prognosis. These results are consistent with the hypothesis that patients at high risk of relapse have a predisposition to autonomic hyperarousal to certain environmental or social stimuli.

The studies of prognosis reviewed above relied primarily upon measures of psychotic symptoms or hospital readmission. However, there are some studies that have measured prognosis as functional outcome, such as holding a job or having friends, instead of psychotic symptoms. Öhman et al. (1989b) reported that skin conductance nonresponding and lower levels of tonic EDA activity taken at the beginning of a follow-up period predicted poor social and employment outcome over a two-year period in a subgroup of male schizophrenia patients. Their outcome criteria combined the employment and social-contact outcome

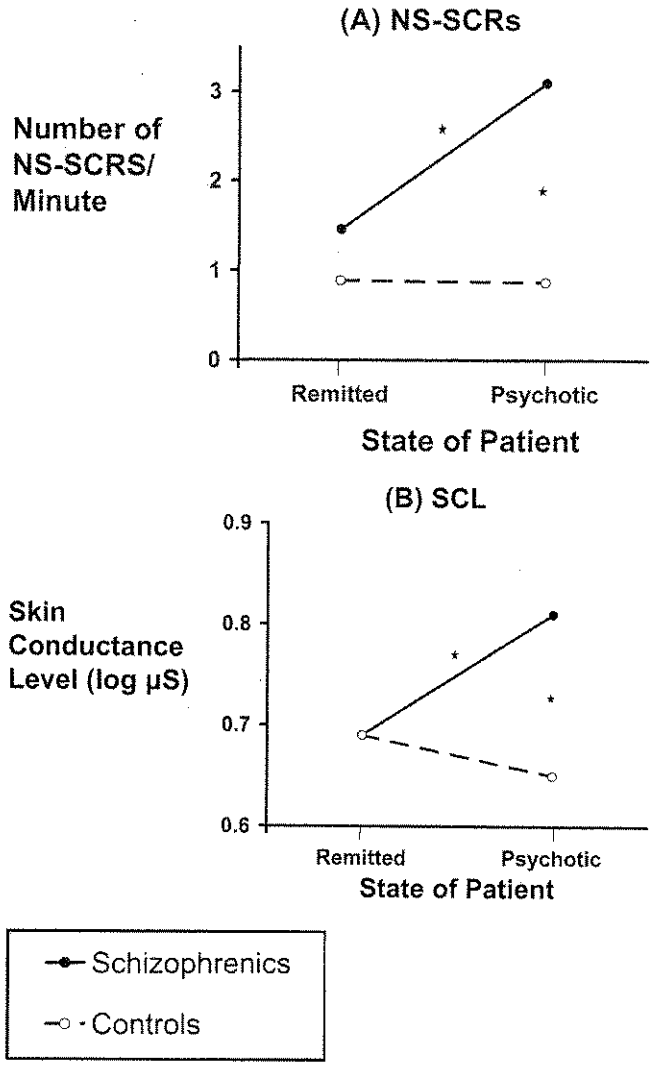

Figure 7.7. (A) Mean number of nonspecific SCRs per minute and (B) mean log SCL obtained from normal controls and patients with schizophrenia when the patients were in remitted and psychotic states. Asterisks indicate significant differences (Adapted from Dawson et al., 1994).

criteria developed by Strauss and Carpenter (1974) into one outcome index. To have a "good" outcome, patients had to simultaneously have at least a minimal social life (meet with friends at least once a month) and had to be employed or enrolled in school at least on a part time basis. Conversely, Wieselgren et al. (1994), using an identical methodology to that used by Öhman et al. (1989b), reported an opposite relation for female schizophrenia patients, with high tonic electrodermal activity predicting poor social and work outcome. More recently Schell et al. (2005) used the same measure of outcome and reported results consistent with Wieselgren et al. That is, high SCL and NS-SCRs (as well as number of SCR ORs) were associated with poor social and occupational outcome and negative symptoms measured one year later. Moreover, this was true for both males and females. These results suggest that hyperarousal and autonomic hyper-reactivity to the environment may interfere with fragile cognitive processing mechanisms in ways that exacerbate vulnerabilities in the areas of social competence and coping. These exacerbated cognitive and social deficits may then create a vicious cycle by feedback to the social environment with eventual symptomatic relapse (Dawson, Nuechterlein, & Liberman, 1983; Nuechterlein & Dawson, 1984).

Schell et al. (2005) also raised the possibility that both EDA abnormalities in patients with schizophrenia (nonresponsiveness and hyperarousal) may predict poor outcome. Whether a particular study finds nonresponders or responders to have the poorer outcome may depend upon whether the sample as a whole is more or less responsive or aroused than normal. Many of the studies reviewed above did not include comparison of patients to normal controls, instead selecting their EDA subgroups based solely on the distribution within the patient group. However, interesting differences are present among those that did report comparisons to normal. For example, Öhman et al. (1989), who reported poorer functional outcome among nonresponders, had a sample of patients who were much more likely to be nonresponders and to have lower SCL than normal controls. However, Wieselgren et al. (1994) and Schell et al. (2005), both of whom reported poor outcome associated with the hyperaroused responders, had groups of patients who did not differ from normal on SCR responsivity but did as a whole have higher than normal EDA arousal. Thus, Öhman et al.'s more abnormal non-responders had the poorer outcome, whereas Wieselgren et al.'s and Schell et al.'s more abnormal hyper-aroused responders had the poorer outcome. It may be that either abnormality, hyporesponsivity or hyperarousal with respect to controls, is associated with poor outcome. Hyporesponsiveness may be associated with generally limited cognitive processing capacity, whereas hyperarousal may act to interfere with efficient processing as described above.

Finally, the issue of vulnerability to schizophrenia has been addressed in some EDA studies, again not always with consistent results, by examining first degree relatives of schizophrenia patients, usually the children of schizophrenia patients, who are not manifesting schizophrenic symtomatology. The most common finding in the early research using this methodology was abnormal hyperarousal and/or hyper-reactivity to aversive stimuli in the offspring of schizophrenia patients (see reviews by Dawson & Nuechterlein, 1984; Öhman, 1981). Subsequent research has generally supported this finding. For example, Hollister et al. (1994) found that the young offspring of schizophrenic patients have higher than normal frequency of NS-SCRs, and those who later developed schizophrenia tended to have the highest level of NS-SCRs. Iacono, Ficken, and Beiser (1999) also found a higher than normal rate of NS-SCRs in the responder first-degree relatives of patients with schizophrenia. However, the latter study reported the same abnormality in first degree relatives of patients with major depressive illness, a finding that suggests that electrodermal hyper-arousal may not be a vulnerability marker specific to schizophrenia.

Abnormalities in tonic EDA and SCR responsiveness have also been reported in other psychopathologies, particularly psychopathy. Psychopaths are usually characterized as low in arousal and deficient in feelings of fear and anxiety, leading to their thrill-seeking and anti-social behavior (Lykken, 1957; Quay, 1965). It would be expected that both of these abnormalities should be reflected in EDA abnormalities, in particular in lower tonic measures of arousal such as SCL and NS-SCRs, and in smaller SCRs given in response to stimuli that would be associated with fear or anxiety in normal individuals. Both such abnormalities have been reported among psychopaths.

Fowles (1993), in a review of EDA during resting conditions, concluded that lower levels of SCL were occasionally found among psychopaths, although effect sizes were small, and less evidence existed for lower NS-SCR levels. Lorber (2004), in a meta-analysis of 95 studies of EDA and HR in psychopathy, concluded that psychopaths were characterized by reduced tonic EDA at rest, although again the effect sizes were small. Clearer differences from normal controls appear in tonic EDA levels as arousal increases, as, for instance, when simple orienting stimuli are presented (Fowles, 1993). Tonic EDA differences between psychopaths and normals clearly maximize when stressful stimuli are present (Fowles, 1993).

In one very well-known study that assessed not only tonic EDA but also response to anxiety-provoking stimuli, Hare (1965) measured SCL in psychopathic and nonpsychopathic prison inmates and college student controls during rest and while they watched the numbers 1–12 presented consecutively on a memory drum at 3 s intervals. A strong electric shock was given as the number 8 was presented. Psychopathic subjects had lower SCL during rest and during the task than the other groups, and psychopathic inmates showed smaller increases in skin conductance from numbers 1 to 8 than did nonpsychopathic inmates, which was interpreted as indicating less fear elicited in the interval prior to anticipated punishment. This finding with the "count-down" procedure has been replicated several times (for reviews, see Fowles, 1993 and Lykken, 1995).

As would be expected from Hare's findings, numerous investigators have reported that psychopaths show impaired SCR conditioning with aversive UCSs (usually electric shocks) (Lykken, 1957; Hare, 1965; for a review, see Fowles, 1993). Psychopaths also exhibit abnormal SCRs to other affective stimuli. Verona et al. (2004) presented positively and negatively affectively valenced and neutral sounds (e.g., laughing baby, crying baby, clucking chicken) from the International Affective Digitized Sounds (IADS; Bradley & Lang, 1999) system to prison inmates assessed with the Psychopathy Checklist – Revised (PCL-R; Hare, 1991). The PCL-R assesses what are generally regarded as two factors of psychopathy, emotional detachment (e.g., egocentricity, shallow affect, and absence of remorse) and antisocial behavior (e.g., frequent trouble with the law, pathological lying, and substance abuse). Inmates scoring high on the emotional detachment factor showed smaller responses to both pleasant and unpleasant sounds than did those who scored low on the factor, indicating that abnormalities in emotional processes in psychopathy extend beyond the realm of fear and anxiety. An interesting study by Blair et al. (1997) presented psychopathic and nonpsychopathic prison inmates with IAPS slides from three categories: nonthreatening (e.g., a book), threatening (e.g., a very angry face), and distress (e.g., a crying child). The two groups did not differ in SCR magnitude to threatening and nonthreatening stimuli, but the psychopaths responded less to the distress cues than nonpsychopaths.

In addition to these abnormalities in EDA seen in adults diagnosed with psychopathy, lower levels of tonic EDA have been reported in adolescents who later exhibited antisocial behavior. Raine, Venables, and Williams (1990) recorded EDA, heart rate (HR), and EEG during rest and several tasks from a sample of unselected 15-year-old schoolboys, and at a 10-year follow-up identified those who during the follow-up period had committed serious criminal offenses. As adolescents, the offenders had a lower rate of resting NS-SCRs, indicating lower arousal levels. The lower resting HR and greater EEG power in low-frequency bands seen in the offender group also were consistent with lower arousal.

It is worth noting that studies of the psychophysiological correlates of psychopathy have typically used only male subjects. Little if anything is known about psychophysiological abnormalities among female psychopaths.

EPILOGUE

EDA is a sensitive peripheral index of sympathetic nervous system activity that has proven to be a useful psychophysiological tool with wide applicability. Social and behavioral scientists have found that tonic EDA is useful to investigate general states of arousal and/or alertness, and that the phasic SCR is useful to study multifaceted attentional processes, as well as individual differences in both the normal and abnormal spectrum. We believe that future research will continue to support the use of EDA in a variety of situations and stimulus conditions.

An important direction for future research involves sharpening the inferential tool characteristics of EDA itself. That is, basic research is needed to address the specific conditions under which specific EDA components reflect specific psychological and physiological processes and mechanisms. For example, under what stimulus conditions does the SCR amplitude component of the orienting response reflect automatic preattentive cognitive processes versus controlled cognitive processes? Likewise, under what test situations do tonic and phasic EDA components reflect different brain systems? We expect that the expanding use of neuroimaging techniques in cognitive and affective neuroscience will elucidate these issues, making EDA an even more interesting and valuable psychophysiological tool.

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