Autonomic Nervous System

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Changes in autonomic nervous system (ANS) activity can result from a variety of factors including physical movement, postural changes, sleeping, disease, and aging. For social and personality psychologists the value of examining the ANS may be that in many situations ANS responses can indicate shifts in emotion, motivation, attention, and preferences. Several obvious advantages of using ANS responses have been well established. For example, ANS responses are not susceptible to self-report biases often engendered in sensitive contexts in which individuals might be unwilling to report their unexpurgated feelings (Gardner, Gabriel, & Deikman, 2000; Guglielmi, 1999). Additionally, obtaining data "on-line" allows for a dynamic analysis of moment-to-moment reactions that does not require introspective responses from participants. There are, however, some advantages that are less obvious. ANS responses can temporally precede conscious awareness revealing emotional responses or preferences that participants cannot yet report (Bechara, Damasio, Tranel, & Damasio, 1997). Finally, some patterns of ANS responding may be linked to mental and physical health vulnerabilities, which would allow social and personality psychologists, along with clinical and health psychologist, to draw links between social contexts or dispositions and disease etiology and progression.

In this chapter, I describe some of the primary techniques, methodological considerations, and psychological inferences associated with measuring ANS responses. Following these descriptions, I provide examples of some research programs that have effectively used the ANS to explore questions within social and personality psychology. I also speculate on some possible domains that have not been examined that might prove to be promising. In the third part, I describe some critical design features that are relevant when examining ANS responses, and finally I conclude by describing advantages and disadvantages of these types of measures in psychological research.

**1. Measuring autonomic nervous system responses**

The autonomic nervous system is part of the peripheral nervous system, and primarily serves a regulatory function by helping the body adapt to internal and environmental demands, thereby maintaining homeostasis. There are a variety of measures that can be used to assess changes in ANS activity. Here I review three broad, but related, categories: electrodermal activity, cardiovascular activity

(e.g., heart rate variability, respiration, and cardiac output), and blood pressure responses, with a specific focus on measuring, scoring and editing, and interpreting these responses. In this section, each measure is briefly described and the general physiology of the measure is outlined, then measurement, scoring, and interpretative caveats are discussed[1].

*Electrodermal activity (EDA)*

Electrodermal activity (EDA), also known by its outdated name *galvanic skin responses* (GSR), is a fairly common measure of ANS activity, and one that has a long history in psychological research. EDA measures responses in the eccrine sweat glands, which are found widely distributed across the body, but are densely distributed in the hands and soles of the feet. The sympathetic branch of the ANS system innervates these sweat glands, but unlike most ANS responses the neurotransmitter involved in changes is acetylcholine rather than epinephrine.

EDA is commonly measured in one of two ways. The first method, *skin conductance,* uses a small current passed through the skin using a bipolar placement of sensors and the resistance to that current is measured. The reciprocal of this resistance is *skin conductance.* The second method, *skin potential,* uses no external current and is collected using a unipolar placement of sensors. In addition to these methods of assessing EDA there are two categories of data quantification that are based on how the EDA data are aggregated. When examining responses to a specific and identifiable stimulus one looks at phasic activity or the *response*. When describing electrodermal activity that is not associated with a specific stimulus onset, but rather changes in EDA over longer periods of time (i.e., minutes rather than seconds), it is appropriate to examine tonic responses or *level*. Thus, with two methods of collection and two methods of quantifying changes there are four categories of EDA data: s*kin conductance response* (*SCR*), s*kin conductance level* (*SCL*), *skin potential response* (*SPR*), and s*kin potential level* (*SPL*). Choice of method and quantification should be determined by the specific questions under investigation, which are described in more detail below.

*Preparation and recording.* To record *skin conductance* a bipolar placement of silver-silver chloride sensors are placed on the fingers, palms, or soles of the feet. If finger placement is used it is

recommended to put the sensors on adjacent fingers (2nd or 3rd fingers; or 4th or 5th fingers) because they will be innervated by the same spinal nerve (Christie, 1973) (Figure 1). Unlike SC recording, *skin potential* recording requires a unipolar placement in which one electrode is placed on an active site – typically the palm of the hand – and the other sensor is placed on an inactive site, typically the forearm, though any inactive site would work.

Preparation of the skin should include a mild washing with water and a nonabrasive soap. Use of alcohol-based hand sanitizer or anti-bacterial soap prior to sensor placement is not recommended because the soap can excessively dry out the skin resulting in lower levels of EDA and obscure sensitive changes. An electrolyte, either KCL, NaCL, or commercially available conductance cream, is then applied in a thin film on the two sensor sites and also in the wells of the sensors. Once the sensors are attached it is advised to wait several minutes (typically 5 to 15 minutes) prior to beginning the recording session. Before beginning recording one should check for sensor sensitivity. EDA responds to respiration so the participant can be instructed to take a deep breath and hold the breath for a few seconds. A good EDA signal will show a change in response (an increase if using SC and a decrease if using SP) within 2 to 3 seconds once the breath is initiated.

*Editing and quantification*. After data collection, waveforms should be inspected for movement artifact and electrical interference. Most scoring programs that are free or available for purchase will have options for editing waveforms that allow a coder to *spline,* or interpolate, the area of the waveform that is affected by an artifact. This smoothing technique typically removes the influence of artifacts through interpolation by identifying the beginning and end of areas of the waveform that contain an artifact and replacing them with an estimate derived from adjacent areas.

When quantifying EDA to examine tonic levels (SCL/SPL) the decisions for averaging the waveform are time-based, that is, averaging across a specified time period while a participant is at rest and then averaging over a similar time period when a participant is engaged in a task or activity. For example, reactivity values can be made in which one-minute of baseline data, typically the last minute or the minimum minute (when EDA reaches its nadir), are subtracted from data quantified in one-minute

intervals from a task. These new values would then represent the change in EDA from resting to a task period. Alternately, ANCOVA or regression techniques could be used in which baseline levels are added as covariates or repeated measures analyses are used to examine changes over time.

A slightly more complicated approach related to quantification is required when examining responses linked to specific stimuli (SCR/SPR). In this case, an identifiable time-locked stimulus is presented to the participant and a *trigger* or stimulus output is recorded on-line simultaneously with the EDA signal. A minimum threshold value of change needs to be determined so that a change in EDA can be identified as a *response* or not. Commonly this threshold is set at .05 μS (microsiemens). Post-processing of data then allows for an estimate of the change in EDA linked to the specific stimulus. Several measures can be determined from this response: the latency from the stimulus to the initiation of rise time; the time from the initiation of rise time to the peak amplitude; the amplitude; and the time to reach half-delta (Figure 2). Half-delta is a time-based measure determined by examining the total magnitude of amplitude increase, divided by two, and then calculating how long it took from peak of amplitude to half of the magnitude increase.

*Levels vs. responses*. The choice of collecting and or scoring data based on examining either levels or responses should be dictated by the research questions and study design. For example, when experimental designs include presentations of specific stimuli in a time-locked event-related design (e.g., affective pictures, pictures of members of different racial groups, etc) it makes sense to score data as *responses*. When a study design includes events that unfold over time and there are no specific time-locked events (e.g., social interactions, delivering speeches, non-scripted negotiations, etc.) then examining changes in EDA level from a baseline period to a task would be most appropriate. If the decision is made to examine changes in EDA level one can still examine spontaneous *responses*, but the designation of these responses would be *non-specific skin conductance responses* (NS-SCR). This measure is typically reported in number of NS-SCRs per minute, with resting or baseline averages ranging from 1 to 3 per minute. This measure could be used as a general index of anxiety or arousal as a result of some change in situational context or linked to different dispositional factors.

*Cardiovascular (CV) measures*

In simplest terms, the cardiovascular (CV) system consists of the heart and pathways (vessels) through which oxygenated blood is delivered to the periphery and deoxygenated blood returns to the heart. Psychologically, this system is responsive to affective states, motivation, attention, and reflexes. Additionally, CV responses have been commonly linked to vulnerabilities in physical and mental illness. In this section I review several methods that examine changes in the cardiac cycle: electrocardiogram, respiration, and impedance cardiography.

*Electrocardiogram (ECG).* The heart produces an electrical signal that can be measured with an electrocardiogram (ECG). A normal ECG recording is composed of various deflections referred to as P, Q, R, S, and T waves (Figure 3). Each heart cycle begins with an impulse from the sinoatrial node (not detected on the ECG wave), which results in a depolarization of the atria (P-wave). The QRS complex represents the depolarization of the ventricles and the T inflection indicates repolarization (or recovery) of the ventricles. These points in combination can be used to determine a variety of chronotropic, (i.e., time-based) measures such as the time of one complete heart cycle, known as heart period (or interbeat interval). This measure is the inverse of heart rate (beats per minute) though heart period is the preferred metric (see Bernston, Cacioppo, & Quigley, 1993).

*Preparation and recording.* ECG waveforms can be collected from several configurations of the limbs. Described below are three standard configurations in which placement results in an upward deflection of the Q-R complex:

Lead I: Electrodes are attached just above the right and left wrists on the inside of the arms. The left arm has the positively charged lead.

Lead II: Electrodes are attached on the right arm and left ankle. The ankle has the positively charged lead.

Lead III: Electrodes are attached on the left wrist and left ankle. The ankle has the positively charged lead.

Lead placements can be adjusted so that the sensors are placed on the torso rather than the limbs. For example, a modified Lead II configuration places the right lead below the sternum and the left lead on the left side of the torso below the ribcage. Torso placement might be deemed preferable over limb placement if there is anticipated movement of the limbs or for younger subjects (i.e., babies and toddlers).

Preparing the site for ECG placement can include a gentle abrasion of the skin and then applying a thin layer of conductance gel, but in many cases a clean signal can be obtained without any site preparation given the strong electrical signal of the heart. There are, however, several factors that can interfere with an ECG recording that should be anticipated. First, excessive hair, either on the ankles or chest, can make recording difficult if using adhesive disposable sensors. Shaving participants' ankles or torso might be possible, but could be problematic in some situations. Either adjusting the sensor location or using non-adhesive (i.e., band) electrodes might reduce the noise. Another potential problem is participant's skin type or changes in temperature during the course of the experiment. Skin that is especially oily or prone to sweat might require additional taping of disposable sensors and even band electrodes might slip in extreme cases. Good lab practice includes taping the sensors with medical tape, and this is especially true in summer months or for longer studies, when the risk of warmer skin temperature is greater.

*Editing and quantification: ECG and HRV.* Editing an ECG waveform is typically done off-line—that is once the session is complete. The primary concerns when editing an ECG waveform is the proper identification of the R-point and removal of artifacts that might appear to be an R-point. Another critical point on the ECG waveform is the Q-point—or the indication of the left ventricle contracting. The Q-point is critical for the calculation of pre-ejection period (PEP), which is considered to be one of the purest measures of sympathetic activation, and will be discussed below in the impedance cardiography section.

Respiration can influence heart rate/period. For example, during inspiration the influence of the vagus nerve on the heart is removed and the heart rate accelerates; during expiration, the vagus nerve is applied and heart rate decelerates. One way to examine cardiac changes from an ECG waveform, beyond

heart rate/period, is to examine heart rate variability (HRV), at its crudest level HR $_{Max}$ - HR $_{Min}$. HRV is influenced by a number of factors, but by deconstructing the variability one can isolate heart period changes due primarily to parasympathetic control, sympathetic control, or a combination of both. Of particular interest has been examining high-frequency (HF) HRV because changes in variability in this range are believed to be due primarily to control of the vagus nerve and thus primarily an index of parasympathetic control. There are several measures of HRV estimates, time-domain, frequency domain, and non-linear measures, and a full committee report by the Society for Psychophysiological Research is available for more details (Bernston, et al., 1997). Here I briefly review some of the estimates and what is needed to calculate these measures.

One of the simpler measures of HRV is based on time domain estimates, for example RMSSD (root mean square of successive differences), which is calculated as the standard deviation of the beat-to-beat intervals. A popular frequency domain technique to estimate HRV involves decomposing heart period variance into different frequency bands using Fourier transformation. For example, the HF band (high frequency band) ranges from .15 to .4 Hz (cycles per second) and is thought to represent primarily vagal influence and as such parasympathetic activity. Lower frequency bands ($< .15$) have also been identified and in these frequency domains the influence can be either sympathetic or parasympathetic.

Note that in these above examples respiration rate is not factored into the analyses, instead rate of breathing is assumed rather than measured. One commonly debated measurement issue in HRV research concerns the importance of controlling for respiration rate and depth in HRV analysis. For a thorough understanding of the complexities of this issue, see Denver, Reed, and Porges (2007) for justification that respiration frequency need not be included in estimates of RSA/HRV and Grossman and Taylor (2007) for a discussion of why respiration frequencies are important.

*Respiration*. Respiration can be measured a number of ways. One option is to use a strain gauge that measures pressure during inspiration and expiration, and rate and depth of breaths can be extracted. If you are using a single strain gauge the recommended placement is high on the torso immediately under the arms (and above the breasts). This placement will allow for measurement of upper respiration, but not

lower abdominal respiration, which may be important if the research focuses on deep breathing found in meditation or other focused breathing domains. In this case two strain gauges can be used to provide both upper and lower respiration. Another option is to use impedance cardiography, which can extract respiration rate and amplitude.

*Impedance cardiography.* Impedance cardiography is a non-invasive technique to estimate blood flow changes in the heart. This technique allows for estimates of how much blood is ejected during each heart cycle (stroke volume), and various changes in the cardiac cycle such as the timing of the aortic valves opening and closing. In combination with an ECG signal and blood pressure responses, a variety of cardiovascular changes can be assessed or derived.

Impedance cardiography requires the use of either spot or band electrodes[2] placed on the torso (Figure 4). Using an output of electrical current (ranging from 1 to 4 mAmps) to the two outer sensors, the inner sensors detect the resistance to the incoming current. This resistance to the current (or impedance) presents global blood flow in the thoracic cavity (typically referred to as $Z_0$, or basal impedance). As the blood volume increases the impedance decreases. The first derivative of the waveform, $\Delta z/\Delta t$, or the change in basal impedance over the change in time, provides a measure of the blood volume ejected from the heart on each beat.

As Figure 5 shows, the $\Delta z/\Delta t$ has several critical inflection and deflection points that are identified by either a software program or manually identified. Several of these points are critical to the identification of responses occurring in the cardiac cycle. For example, a chronotropic (time-based) measure of ventricle contractile force is *preejection period* (PEP). This is the time from the left ventricle contracting (Q-point on the ECG wave) to the aortic valve opening (B-point on the $\Delta z/\Delta t$ waveform). Stroke volume, the amount of blood ejected from the heart on any given cardiac cycle, is a volume based measure that requires the identification of the B-point and X-point on the $\Delta z/\Delta t$ waveform to determine the time when blood is being emptied at the aorta, along with the maximum point of the $\Delta z/\Delta t$ waveform on the given cardiac cycle labeled $Z$[3] in Figure 5.

Stroke volume provides an estimate of the amount of blood ejected at each beat, however in terms of an overall indication of how much blood is being pumped through the heart in any given minute, *cardiac output* (CO) is the preferred measure. Cardiac output is simply the product of SV and HR (SV x HR/1000). The metric for stroke volume is in milliliters, so the product is divided by 1000 to report CO in liters/min. Because CO is a combination of both heart speed and blood volume processed in the heart, it is believed to be a measure of cardiac efficiency.

When using impedance cardiography in a laboratory setting it is important to inform your participants to wear comfortable, two-piece clothing to the experiment. As the bands (or spots) require placement on the torso, directly on the skin, participants are required to lift their shirt to expose their torso. Additionally, placement of the neck sensors might be impeded by clothing that is snug on the neck. In my lab, we keep extra shirts and pants for participants who arrive in clothing that would make attachment of the bands difficult.

*Editing and quantification.* Probably one of the greatest challenges for researchers interested in impedance cardiography is the editing and summarizing of the data. First, there are some important choices to be made regarding how the data are summarized for editing. One option uses ensembled waveform averages. This method determines the composite or average waveform across some specified time period (typically between 30 s and 5 minutes). By "averaging" the waveforms over time random noise and movement are removed and a more representative cardiac cycle can be obtained. Another option is to determine blood volume changes on a cycle-to-cycle basis (see SPR committee guideline paper, Sherwood, et al., 1990).

In addition to how the data are averaged, there are also several formulas that can be used to estimate stoke volume. The Kubicek equation estimates SV from the derivative of the impedance signal and blood resistivity:

$$SV = \rho \ \times \ L^2 / Z_0^2 \ \times \ \Delta Z / \Delta t_{max} \times LVET$$

Where: $\rho$ = 135 (blood resistivity)

L = distance between electrodes

$$\Delta Z / \Delta t_{max} = \text{peak amplitude of } \Delta Z / \Delta t$$

$$LVET = \text{left ventricle ejection time (time in ms between B and X)}$$

More recently, other equations have been offered that might be superior to Kubicek. For example, the Sramek-Bernstein estimates SV from the volume of electrically participating tissue scaled according to body surface:

$$SV = \delta \, (VEPT) / Z_0 \quad x \quad \Delta Z / \Delta t_{max} \quad x \, LVET$$

Where: $\delta \, (VEPT) = \text{weight}_{max} / \text{weight}_{ideal} \quad x \quad (0.17H)^3 / 4.25$

Participant's height, weight, and ideal weight are needed

Regardless of the equation used, one of the most critical decisions when scoring impedance data is accurately identifying the *B* point on the $\Delta z/\Delta t$ waveform. Though tremendously time and labor intensive the technique that assures most accuracy is manual detection of the *B* point. Specifically *B* should be placed at the beginning of the longest uphill slope before the Z-point (Figure 5). Algorithms have been developed to assist in detecting the B point, such as placing the *B* point at 56% of the distance between Q and Z (see Berntson, Quigley, & Lozano, 2007), but in our own examination of this method we find that the program does not consistently mark the *B* point where we could visually confirm the *B* point (Koslov & Mendes, 2008). Importantly, the variability in accuracy changes based on whether the data were from a baseline period (where accuracy tends to be higher) than when the participants are engaged in a stressful task (e.g., mental arithmetic in the presence of stoic evaluators).

*Blood pressure*

Blood pressure, measured in millimeters of mercury pressure (mmHg), refers to the amount of pressure on the vessel walls during the cardiac cycle. Distinctions are made between systolic blood pressure (SBP) and diastolic blood pressure (DBP), which represent peak pressure compared to lowest pressure in the arteries, respectively. Though correlated, these measures may provide unique information and are thus typically both presented. For example, during stressful or emotionally provocative situations increases in SBP compared to DBP have been identified as part of an adaptive defense patterning (see Brownley et al., 2000). SBP responses have also been linked specifically to effort expenditure (Wright &

Kirby, 2001). Health consequences have also been identified as resulting from increases in SBP and not necessarily DBP. For example, Chobanian, et al. (2003) reported that elevated SBP, and not necessarily DBP, predicts the development of coronary heart disease.

Although SBP and DBP are often presented separately, one will also find instances in which researchers combine the two in some meaningful way. For example, pulse pressure (PP) is calculated by subtracting DBP from SBP (PP= SBP – DBP). At rest, average pulse pressure is approximately 40 mmHg. During exercise SBP typically increases more so than DBP. Extremes in PP in both directions can indicate abnormalities. When PP is too high this is likely due to artery stiffness, leaky aortic valves, or hyperthyroidism and has been linked to cardiovascular complication (Blacher, et al. 2000). Low PP values, typically influenced by low stroke volume, can indicate abnormalities such as congestive heart failure.

Another type of averaging is mean arterial pressure (MAP), which is calculated as a type of average (though not an exact mathematical average because DBP is weighted more given its longer time course within a given cardiac cycle): MAP $\approx$ [(2 x DBP) + SBP] / 3. MAP is often used in combination with CO to determine *total peripheral resistance* (TPR), using the formula: TPR = (MAP / CO) x 80. Changes in TPR can be construed as an estimate of the amount of constriction versus dilation occurring in the blood vessels – specifically the arterioles. When the arterioles constrict less blood can flow to the periphery and this is indicated by an increase in TPR. In contrast, when arterioles expand, or vasodilate, this allows more blood flow and is indicated by decreases in TPR.

BP can be obtained from various places on the body including the brachial artery (upper arm), radial artery (wrist), or at the finger. It is important to point out, however, that as the distance from the heart is increased the accuracy of blood pressure changes is reduced. BP measurements can be obtained using a variety of techniques. One option is the auscultatory method, which consists of temporally stopping blood flow at the brachial artery and listening for Kortokoff sounds indicating blood flow in the arteries—the pressure when blood first begins to flow is systolic blood pressure and the pressure when

blood flow sounds stop is diastolic blood pressure. A trained professional uses a sphygmomanometer and stethoscope to obtain BP using this technique.

However, in many cases psychologists want to obtain BP in a less labor intensive way that minimizes the self-consciousness that may arise from having one's BP measured. Digital BP machines are relatively inexpensive and fairly accurate measures of BP levels (though not as precise as a trained professional using a sphygmomanometer). Again, these BP machines typically require occluding the brachial artery every time a BP measurement is desired. This is not difficult, but could potentially distract participants from the experimental situation. A potential solution for obtaining BP responses over time, that is only minimally invasive, is with a continual or continuous BP monitor. *Continual* monitors are so designated because BP responses are estimated over some given number of cardiac cycles (e.g., BP over 15 cardiac cycles). *Continuous* BP machines have the additional advantage of obtaining BP responses on every cardiac cycle. Commercially available machines are manufactured by Colin Medical Instruments (San Antonio, Texas) and Mindware Technologies (Gahanna, OH).

Many continual or continuous BP machines use either oscillometric or tonometric technology. Oscillometric technology initially inflates a cuff over the brachial artery and then deflates until the point at which the systolic pressure can be measured, and then keeps a constant cuff pressure. The technology and algorithms used for these machines are proprietary so there is some concern about comparing results across laboratories. Tonometric technology consists of BP measurement from the radial (wrist) artery, and uses a sweep technique, which applies a varying force on the artery. This technology can be very sensitive to movement and sensor positioning relative to the heart. Manufacturers recommend putting the arm in a sling so as to position the sensor at heart height and limit movement. For social and personality psychologists who often aim for strong ecological validity, restraining the arm can be problematic. However, from my lab's own use of this technology, movement is the greatest problem. Fashioning a cradle that will keep the arm and wrist stable throughout the experiment is imperative to obtaining good measurements. Some of the more expensive machines also include an additional brachial cuff BP device

to allow for on-line comparisons from the two sites and can signal the wrist cuff to re-position if the brachial BP responses differ from BP measured at the radial artery.

## 2. ANS responses in social and personality psychology

Social and personality research using ANS responses is plentiful. Here I review some selected research, which is not meant to be exhaustive and is influenced by my own research interests in emotion, stress, motivation, attitudes, and intergroup relations. For ease I organized the sections based on the physiological measurement used rather than the psychological construct under examination.

*Electrodermal responses*

As previously described, changes in EDA can index general arousal, thus the use of these measures at first blush may seem limited. However, both classic and contemporary uses of these measures show compelling data obtained by looking at electrodermal activity. Indeed, using peripheral measures in the domains of emotion, motivation, and attention has provided important empirical evidence for social and personality psychologists.

For example, skin conductance has been used in the context of emotional disclosure. Pennebaker and colleagues (Pennebaker, Hughes, & O'Heeron, 1987) examined changes in SCL while participants disclosed traumatic events from their lives. When participants were classified as high disclosures, talking about traumatic events decreased SCL relative to those classified as low disclosures. This finding has been used as a possible explanation of why there are physical and mental health benefits of confession; high disclosures showed lower sympathetic activation than low disclosers.

While getting something traumatic off your chest may be beneficial, forcing yourself to feel good might be detrimental. Wegner and colleagues (Wegner, Broome, & Blumberg, 1997) instructed participants to either relax or not while answering questions that were believed to index intelligence (a high cognitive load condition) or answer the same questions that were described as test items (a low cognitive load condition). For participants in the high cognitive load condition instructions to relax resulted in higher SCL than those not instructed to relax. These findings nicely demonstrate the potentially ironic effects of *trying* to relax, which resulted in greater sympathetic activation.

Not surprisingly, ANS responses in general, and EDA activity in particular, are often used in research examining biases and race relations because of the difficulty in obtaining unexpurgated self-reported responses. Recently, changes in skin conductance level were used to examine threatening gender environments based on the imbalance of males to females (Murphy, Steele, & Gross, 2007). In this research, male and female participants viewed one of two videos that presented either a gender-balanced group of students or a gender-unbalanced (mostly white males) group of students in the domain of a math and engineering science camp. Changes in SCL from a baseline period to watching the videos were computed. The findings were that women showed greater increases in SCL when watching the gender unbalanced video than watching the gender balanced video, and male participants did not differ in their SCL responses as function of the gender composition of the video. The authors concluded that the gender imbalance was especially threatening for women.

In these examples, EDA was used as a general measure of arousal or anxiety. However, by limiting the context one can increase the inference of EDA changes. For example, in fear conditioning paradigms an electric shock or other aversive stimulus is paired with some unconditioned stimulus while skin conductance responses are measured. In learning phases, the shock or other aversive stimulus is repeatedly linked in time with the unconditioned stimulus. Later the shock is removed and SCRs are examined upon exposure to the unconditioned stimulus. The critical examination is the length of extinction – or how long it takes for participants to no longer show a SCR to the unconditioned stimulus once the aversive element is removed. An exceptionally creative adaptation of this design is found in a Science article by Olsson, Ebert, Banaji, & Phelps (2005). In this study, researchers paired electric shock with ingroup and outgroup male faces. They argued that individuals might be evolutionarily "prepared" to fear outgroup members and because of this, extinction of the fear response would take longer when the shock was paired with outgroup faces than when the shock was paired with ingroup faces. Indeed, when shocks were paired with outgroup faces compared to ingroup faces SCRs persisted longer and were of greater magnitude in the extinction phase. In this example, SCRs could be interpreted as fear responses because the context was constrained to a fear eliciting (shock) situation.

SC changes may index emotional responses even prior to the conscious awareness of that emotion. An elegant example of the possibility that physiology may provide information regarding emotional and motivational responses before conscious awareness is provided by Bechara and colleagues (Bechara, et al., 1997 cf. Maia & McClleland). These investigators measured SC changes while participants learned decision rules for a card task. Although self-reported indications related to "hunches" regarding decks that were associated with more gain than loss cards developed by trial 50 for control participants (i.e., non-patient), SC changes in anticipation to the loss decks occurred typically by the 10th trial, which preceded conscious awareness by approximately 40 trials. That is, SCRs suggested an intuition of an impending loss prior to participants' conscious awareness of the intuitions they were developing.

*Heart rate variability*

Of growing interest to social and personality psychologists are measures capitalizing on the variability of the cardiac cycle. Initially, heart rate variability was believed to be a measurement artifact or nuisance, but further exploration into spontaneous changes in the timing of the heart cycle proved to be psychologically and physiologically meaningful. Though there are still disagreements on the specifics related to measurement, quantification, and psychological meaningfulness of vagal tone and cardiac vagal reactivity (see *Biological Psychology, 2007, vol 74*), these measures might prove to be especially important for social and personality psychologists interested in emotion and/or mental effort.

Though most work has focused on resting/baseline RSA (a type of HF heart rate variability) and its links to dispositions and responses to social and emotional situations, there is also a growing literature on vagal reactivity – focusing on RSA changes – and vagal rebound. Vagal rebound is the extent to which RSA responses return to or even over-shoot baseline levels after some suppression of the vagal brake. Below I outline some literature exploring these various components of HRV.

One theory that has received much attention in terms of the inferences one can draw from heart rate variability is Porges' polyvagal theory (e.g., Porges, 2007). In this theory, Porges argues that vagal regulation stemming from the nucleus ambiguous and enervation from cranial nerve X acts on the vagus

nerve to modulate heart period. The polyvagal theory further specifies that primates uniquely have vagal nerve modulation (but see Grossman & Taylor, 2007), which has evolved as part of the social engagement system. One of the primary postulates of polyvagal theory is that social factors (affiliation, social engagement) or personality factors (affliative, bonding, compassion) can modulate vagal activity. Specifically, Porges argues that higher RSA (high cardiac vagal tone) can be used as an index of adaptive emotional regulation and responsiveness to the social environment. Similarly, cardiac vagal reactivity might also index appropriate social engagement in that increased vagal reactivity during a task might be associated with calmness, equanimity, and a lack of distress.

Adding some complexity to these effects, however, is the nature of the social context. Indeed, in highly stressful situations or tasks that require some amount of mental attention or effort then one should expect a withdrawal of the vagal brake (resulting in lower RSA) to indicate greater attentional control and effort. Indeed, cognitive psychophysiologists have used decreases in RSA as an index of attention or mental effort (Tattersall & Hockey, 1995). In one study, relying on this type of interpretation for HRV reactivity, Croizet, et al (2004) examined changes in RSA during a stereotype threat paradigm. They found that participants assigned to receive a stereotype threat prime had a greater decrease in RSA and poorer performance than those in the control condition and that RSA changes mediated the relationship from the condition to the performance effects.

Applications of cardiac vagal tone and vagal reactivity are increasing in personality and social psychology. Some applications have focused on the extent to which dispositional emotional styles are linked with cardiac vagal tone (Demaree & Everhart, 2004; Sloan, et al., 2001). For example, do individuals with greater hostile tendencies have lower cardiac vagal tone? In an examination of this question, researchers found that those higher in hostility tend to have lower cardiac vagal tone at baseline, during an emotional induction task, and at recovery than those lower in hostile tendencies (Demaree & Everhart, 2004; Sloan, et al., 2001).

Recently, RSA has been examined as a possible mediator for why implicit goal setting might result in improved performance. In previous studies, participants who exaggerated reports of their GPA

tended to improve more than those who did not exaggerate (Willard & Gramzow &, 2008). Was exaggeration a form of implicit goal setting or was exaggeration simply a form of anxious repression? We examined RSA reactivity as a way to differentiate anxious orientation while exaggerating from motivated goal setting (Gramzow, Willard, & Mendes, 2008). In this study participants first reported their GPA and course grades in private and then met with an experimenter to review their academic history. During this interview participant's ECG and respiration was recorded and RSA responses were calculated. We found that the more participants exaggerated their GPA the greater the increase in RSA from baseline to the interview, suggesting that participants who exaggerated their GPA were not necessarily anxious about their exaggerated standards. Additionally, those who had greater increases in RSA when discussing their GPA tended to improve their GPA in a subsequent semester. Converging evidence from nonverbal behavior coded during the interview suggested that exaggerators appeared composed rather than anxious supporting the interpretation that higher RSA while discussing one's GPA was associated with equanimity rather than anxiety.

*Impedance cardiography*

Cardiovascular responses have been used extensively in the areas of motivation, emotion, and stress. Interests in these measures are further fueled by the possibility that certain patterns or response profiles of CV responses repeatedly experienced over time might be linked to health outcomes. Early work linking type A personality and coronary heart disease examined CV responses as one of the likely mechanisms through which physical health was affected. Specifically, it was theorized that excessive CV responses would create tears in endothelial lining resulting in greater calcifications and plaque build-up that could possibly initiate ischemic events or strokes. Primarily, CV responses in this context included heart rate (heart period) and blood pressure responses.

A combination of cardiovascular and blood pressure responses is used in research attempting to index challenge and threat states. Though not without its critics (Wright & Kirby, 2003; see also Blascovich, et al., 2003), this theory attempts to differentiate motivational states using various CV measures, such as PEP, cardiac output, and total peripheral resistance. This theory argues that in

*motivated performance situations,* those that are active rather than passive and require some cognitive or behavioral responses, CV responses produce distinct profiled reactions that can differentiate motivational states related to approach/activational versus defeat/inhibitional (Mendes, Major, McCoy, & Blascovich, 2008). Early work on this theory showed that task appraisals that showed greater resources relative to demands were associated with greater cardiac responses (shorter PEP [indicating greater ventricle contractility], increased HR and CO, and decreases in vascular resistance—lower TPR). This pattern of CV reactivity was believed to be a marker of psychological states of challenge. In contrast, appraisals that showed greater perceived demands relative to resources to cope were associated with comparatively less CO and higher TPR (Tomaka, et al,. 1993). These responses were thought to index threat states. To test for the possible bi-directionality of these responses, these physiological states were engendered with non-psychological events, specifically exercise (challenge) or cold pressor (threat), to determine if appraisals associated with challenge and threat would follow from the physiological responses (Tomaka, Blascovich, Kibler, & Ernst, 1997). Results showed that although appraisals preceded CV responses as described above the relationship was not invariant. That is, physiological responses engendered in non-psychological ways did not influence subsequent appraisals.

Challenge and threat theory has been used in a variety of social and personality domains. In the social domain, these indexes have been explored to examine responses within a dyadic social interaction when one member of the dyad is stigmatized in some way. Stigmas were operationalized as physical stigmas (e.g., birthmarks), stigmas resulting from group membership (e.g., race/ethnicity), or socially constructed stigmas (e.g., accents, SES). Across more than a dozen studies, participants who interacted with stigmatized partners were more likely to exhibit threat (i.e., lower CO and higher TPR) than those interacting with non-stigmatized partners. If the results were found only with physiological responses they would have still been intriguing, but in many cases the physiological responses also correlated with other automatic or less consciously controlled responses such as cognitive performance, emotional states, and non-verbal behavior such as freezing, orientation away from the partner, and closed posture (Mendes, et al, 2008; Mendes, Blascovich, Hunter, Lickel, & Jost, 2007; Mendes, Blascovich, Lickel, & Hunter,

2002). Also of interest was the lack of correlations between participants' CV responses and their self-reported appraisals and partner ratings. In contrast with the CV responses, self-reported partner ratings showed a preference for stigmatized compared to non-stigmatized partners, suggesting that deliberate and consciously controlled measures might be more vulnerable to attempts to correct for racial bias (Blascovich, Mendes, & Seery, 2002; Mendes & Koslov, in preparation).

In the personality domain, these measures have been used to assess individual's reactions to stressful situations. For example, individuals who score higher on belief in a just world scales (e.g., hard work is rewarded) tend to exhibit greater increases in cardiac and decreases in TPR during stressful tasks than those who score lower on these scales who exhibited lower CO and higher TPR – consistent with threat profiles (Tomaka & Blascovich, 1994). Self-perceptions in the form of level and stability of self-esteem have been explored with these methods as well (Seery, et al., 2004). For participants with high and stable self-esteem, positive performance feedback resulted in more challenge responses than those with high and unstable self-esteem.

Loneliness also appears to result in these patterns of CO and TPR (Cacioppo et al., 2002; Hawkley, et al., 2003). Cacioppo and colleagues have shown in various settings that individuals reporting higher levels of loneliness are more likely to show lower CO and higher TPR than individuals reporting lower levels of loneliness. This effect has been found in both lab based settings in response to social evaluation, and field studies using ambulatory impedance and blood pressure devices. In the field study, due to lack of ability in determining whether individuals were actually in a *motivated performance situations*, the authors interpreted these profiles as indicating passive versus active coping styles (Sherwood, Dolan, & Light, 1990), with lonely individuals adopting more passive coping styles within the context of their day.

*Blood pressure*

Social psychologists have used blood pressure to index several psychological states including stress, threat, and effort. Much evidence has been accumulated by Wright and colleagues (see Wright & Kirby, 2001 for a review) supporting their theory of effort mobilization. In this extension of Brehm's

motivational intensity analysis, it has been empirically demonstrated that participants' effort increases monotonically with difficulty until the task is perceived as too difficult and then effort is withdrawn. Furthermore, ability is also a critical factor and when individuals have lower levels of ability effort is withdrawn at lower levels of difficulty. In this model, Wright typically uses SBP as a measure of effort. Although HR and DBP may also follow similar patterns as SBP, SBP is thought to be more closely aligned with effort given its tighter relationship to the sympathetic component of the cardiac cycle (systole).

**3. Experimental design considerations**

Prior to incorporating ANS responses into ones methodological toolbox there are several considerations that are reviewed here. These considerations include the level of inference one can draw, knowledge of the complex relationship between the sympathetic and parasympathetic nervous systems, how health and aging can influence responses, and individual and situational stereotypy.

*Establishing inference*. It is critical to begin with the first major obstacle of any psychophysiologist, which is determining the level of psychological inference we can attribute to any physiological response. Inference, in this context, refers to the extent to which an observed physiological response or constellation of responses indicates the presence, absence, or intensity of a psychological state. Here, I summarize the main points of psychological inference and what social and personality psychologists should and should not expect from incorporating ANS responses into their methodological toolbox.

When interpreting physiological responses in terms of what the changes might reflect psychologically it is useful to evoke the taxonomy of physiological responses outlined by Cacioppo, Tassinary, and Berntson (2000). In this conceptualization the level of inference is determined by the generality of the context in which the response occurs and the specificity of the physiological response in relation to the psychological state. The context distinction focuses on whether the context is free and unconstrained (context-independent) or constrained (context-dependent). That is, does one expect that only in a specific context a psychological states would correlate with a physiological response

(constrained) or in any context would the psychological-physiological relationship emerge (unconstrained)?

The specificity dimension refers to the relationship between psychology and physiology. Do many psychological states relate to a physiological response or do the psychology and physiology share a one-to-one relationship? For example, there are many psychological states that are thought to bring about an increase in skin conductance – arousal, attention, fear, anxiety—which would be an example of a many-to-one relationship. In contrast, the relationship between negative affect and potentiated startle responses is thought to reflect a one-to-one relationship or an *invariant* relationship. When individuals are experiencing negative emotions, either elicited incidentally or evoked via images, an auditory or visual probe is presented which potentiates the startle response as evidenced by increased eye-blink magnitude and shortened latency to blink.

By combining these dimensions of context and specificity various levels of psychophysiological relationships emerge. When the context is constrained many-to one- relationships are referred to as *outcomes* whereas in the same constrained context one-to-one relationships are referred to as *markers*. In the unconstrained context many-to-one relationships are called *concomitants* and one-to-one relationships are referred to as *invariants*. Knowledge of the level of inference is imperative when interpreting the psychological meaning of any physiological response.

An additional obstacle related to determining inference is what is the "gold standard" by which we evaluate whether a physiological response is indexing the psychological state of interest? In a somewhat tautological argument, the inferences of physiological responses are often determined by their relationship to a self-reported psychological state. Following the confirmation of the established relationship, some psychophysiologists then will conclude that their physiological responses are revealing responses that are closer to the true and valid experience of the respondent, ignoring that self-reports are often used to establish inference in the first place. Determining psychophysiological inference should be a dynamic process that includes testing and validating relationships between psychology and physiology and examining the predictive validity of physiological responses to behavior, performance, and health.

Most importantly, however, one should not infer that physiological responses *are* the psychological construct.

*Autonomic space.* A second critical factor when examining ANS responses is an understanding of how the sympathetic and parasympathetic branches of ANS interact and influence each other. In a seminal paper, Berntson, Cacioppo, and Quigley (1991) outline the importance of considering the complexity of how the two branches are related to each other. The idea that the sympathetic and parasympathetic branches are reciprocally related (as sympathetic activation increases parasympathetic activity decreases) is deemed to be overly-simplistic. Instead it is more accurate to construe these systems as complementary and complexly interactive. For example, increases in sympathetic activation can be associated with decreases in parasympathetic responses; however, this is not exclusively the case. Instead, the systems can be reciprocal, co-activated, or de-coupled. An understanding of these relationships can protect against inaccurate conclusions when observing one system in the absence of the other. For example, increases in heart rate may be incorrectly interpreted as reflecting an increase in sympathetic activation when instead heart rate increases are due to parasympathetic withdrawal or a combination of both branches.

*Design considerations.* There are several critical design considerations that influence choice of ANS measure, how the data are collected and quantified, and, most critically, how the data are interpreted. When incorporating ANS measures in your experiment one of the first decisions to make is the context in which you are collecting ANS responses. As described earlier, many of the inferences that can be drawn from the physiological responses are context bound. For example, though the SCR that Olsson, et al., used in the fear conditioning paradigm are broadly recognized as indexing a fear response, SCR are by no means universally accepted as indexing fear responses. Indeed, SCRs can result from strong positive emotion, anxiety, deception, attention, and other psychological factors that are certainly distinct from fear. So it is important to know if a physiological response is believed to be context bound or context free. As the context is more constrained the inference level is likely to increase, though there is little empirical data on this topic.

One of the critical context distinctions when examining ANS responses is the extent to which the participant is engaged in an active versus passive task (Obrist, 1981). Active tasks are ones in which some response is required by participants as opposed to passive tasks that are simply situations in which participants experience some event without having to necessarily respond in some instrumental way. This distinction is critical because in many cases ANS changes are functional and changes in ANS are due to the required needs of a task rather than the psychological change brought on by the situation. For example, giving a speech requires modulation of respiration to produce vocal tones and often postural changes occur to allow for projection in vocalization, which can influence ANS responses that have nothing to do with stress, emotion, or motivation. In addition, many ANS patterning or profiles are thought to index psychological states from active situations and not passive ones. Challenge and threat for example are thought to occur only in active situations and not passive ones. So watching a scary movie might be terrifying, as would be giving a talk to a room filled with people who you knew disagreed with you, but only in the latter case would the ANS responses yield a pattern associated with threat.

*Individual response stereotypy and health of participants.* Recruiting participants for psychophysiology studies poses some challenges. Depending on the response of interest there might be some health conditions that should be considered and screened. Of course, when interest is in either cardiovascular responses or heart rate variability people with heart conditions, pacemakers, or cardiac altering prescriptions (like beta-blockers) should be excluded. This is probably true of doctor-diagnosed arrhythmias, though in the ten years that I have been running participants (resulting in over 3,000 participants) the few times that participants claimed to have an arrhythmia we did not detect any abnormalities on the ECG waveform. Instead, in a small number of cases when participants claimed to not have arrhythmia, we have noted ECG abnormalities, such as bradycardia and premature ventricle contractions. What to do when an arrhythmia is detected is actually a matter of debate (see Stern, Ray, & Quigley, 2003). One perspective is that as non-medical professionals informing participants that there might be some abnormalities in their ECG and causing undue distress only to be proven wrong when the person does have a medical screening would outweigh the risk of occasionally being correct. The other

perspective is that abnormalities can be detected with ECG waveforms and that an informed opinion

could be beneficial to participants so one should inform. Decisions to report should be guided by your

local IRB and the quality of one's knowledge of ECG abnormalities. For several years, I received advice

from a cardiovascular surgeon when I was concerned about possible cardiac abnormalities. Forging a

relationship with a medical professional might be a critical if your IRB or funding agency wants you to

report abnormalities that are detected to participants. Importantly, though, undergraduate research

assistants with limited experience and graduate students just starting should not make these decisions, and

your lab should have some plan for how to deal with these possible situations.

      For social psychologists another potential source of difficulties with participants is individual

response stereotypy or the idea that for some individuals, regardless of the situation, ANS response will

not be modulated by the situation. For example, some individuals are thought to be chronic

vasoconstrictors and regardless of the situation will show constriction rather than dilation in their arteries

and arterioles in any change from homeostasis. There is considerable disagreement in the literature

regarding the percentage of individuals who respond without psychological modulation, but it is

something that could add error and reduce the ability to detect differences based on the experimental

manipulation. Certainly older participants are more likely to have sluggish responses and tend to have

more individual response stereotypy than have modifiable responses. Similarly, overweight individuals

also might show less psychological modulation.

      *Situational stereotypy*. Parallel with the idea that some individuals respond in similar ways

without the influence of the social setting, some situations are thought to bring about similar responses

without individual modulation. One of the most obvious situations is the startle reflex in which sound or

visual presentations occur at such high decibels or lumens that the blink reflex occurs for everyone. At

lower levels of sound, for example, psychological modulation can occur, so only at intense levels is the

startle response universal.

      *Knowledge of systems*. The most common question I hear, when one is considering incorporating

psychophysiology into their methodological toolbox, is "how much physiology do I need to know" and

there is really only answer to this question, "as much as possible." Understanding the biological systems will no doubt inform your questions, your choice of context, and probably most importantly your interpretations of the data. The good news is that obtaining training in biological systems and specifically the ANS is easier than you think. Biology departments often have terrific courses to learn anatomy and physiology. Auditing a medical school class on the cardiovascular system can provide invaluable information. Joining and attending conferences like Society for Psychophysiology Research (SPR) and American Psychosomatic Society can immerse you into a world that does not consider the ANS a mere tool to use to unearth research questions related to social and personality questions, but instead this system *is* their research question. How the body responds to stress, emotion, temperature changes, age etc., are some of the critical questions. Indeed, one might not want to brazenly claim that you are merely interested in the measure as a mere method to reveal answers related to your research questions. Examining the ANS and its complexities regarding how it changes based on psychological states, age, and disease is a worthy pursuit it its own right and provides important foundational work for social and personality psychologists whose interest in the system might be merely methodological.

  *Data editing*. Though one can find many software programs that can edit, score, and ensemble one's data with a push of the button, I strongly advocate for either designing your own software or manual scoring whenever possible. Putting trust in any software program, even those designed by researchers at the top of the field, is a leap of trust that one might not want to make when considering the multiple problems that might arise during data collection. Also, there is nothing quite like editing data to appreciate how the system reacts to stimuli, stressors, or events. In addition, after reviewing over a dozen software programs to score impedance waveforms, for example, I have yet to see a program that can consistently detect one of the critical inflection points on the dz/dt waveform – the B point. Under- or over-estimating this point can dramatically change stroke volume and cardiac output measures.

  We have established several guidelines in my lab to determine the quality of the data while scoring. One guiding rationale is *physiological plausibility*. Each measure has a range of responses that are plausible given the physiological marker. In addition to plausibility of any single measure there is also

plausibility given a constellation of multiple, but related measures. Table 1 shows plausible ranges of PEP, HR and LVET (left ventricle ejection time – time from the aortic valve opening to the time that it closes). These relationships demonstrate that when the heart is beating faster, we expect decrease in PEP and LVET. These ranges are not presented as the only possible ranges that could occur, but rather general guidelines to determine if the data are typical or not. When scoring or examining data one should be aware of general ranges in which these measures are related to each other.

*Future Directions*

One of greatest advantages of ANS recording that has likely been underutilized is examining the dynamic nature of changes in ANS responses as a result of moment to moment changes in experience. In many cases psychophysiologists spend a great amount of time and effort reducing their data to a reasonable number of time epochs and critical responses. However, statistical techniques like hierarchical linear modeling (HLM) and time series analyses allow researchers to model temporal changes in a more finely grained fashion than ever before (Vallacher, Read & Nowak, 2002). An additional benefit of these on-line responses is that they do not require a conscious assessment of what one is thinking or feeling. Thus, responses can be viewed as relatively automatic and less consciously controlled than on-line subjective reports obtained with rating dials.

ANS responses are not limited to lab-based designs. Advances in ambulatory monitoring allow for responses collected continually throughout a person's daily life and coordinated with experience sampling techniques. Ambulatory monitoring of ANS responses presents infinite possibilities for social and personality psychologists, not to mention those who intersect with public health, clinical science, and organizational behavior. The possibilities are endless and limited only by researchers' finances, imagination, and knowledge. I am hopeful that this chapter has offered at least some initial inspiration for the latter two limits.

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Footnotes

1. Given the scope of this chapter the underlying structure and function of the various systems will be greatly over-simplified. References are provided to point the reader to reviews that are essential for a thorough understanding of the physiological responses that are reviewed here.

2. The use of band versus spot electrodes is an ongoing debate among psychophysiologists. For experimenter ease and participant comfort, spot electrodes might be preferable and appear to reliably estimate stroke volume while subjects are at rest.  However, band electrodes appear to more accurately reflect changes in cardiac output during stress/challenge conditions because of detection of changes in the thoracic cavity that may be missed by spot electrodes (see Bronwley, Hurwitz, & Schneiderman, 2000).

3. The Z point is sometimes identified as the C-point.

Table 1. Plausibility of physiological ranges: HR, PEP, and LVET

| HR (bpm) | PEP (ms) | LVET (ms) |
|---|---|---|
| 40-60 | 100-140 | 300-450 |
| 60-80 | 90-130 | 250-400 |
| 80-120 | 80-120 | 250-350 |
| 100-120 | 70-100 | 200-300 |
| 120 + | <80 | 180-300 |

Figures Captions

1. Placement of bipolar and unipolar leads for measurement of *EDA*

2. Skin conductance response

3. ECG waveform

4. Impedance cardiography and placement of band sensors
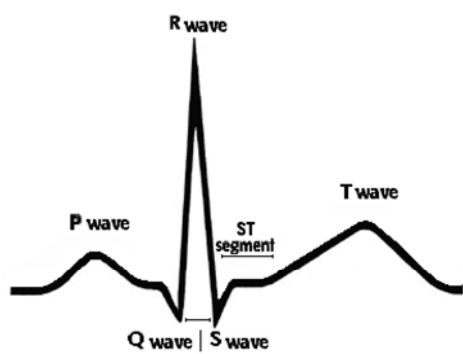
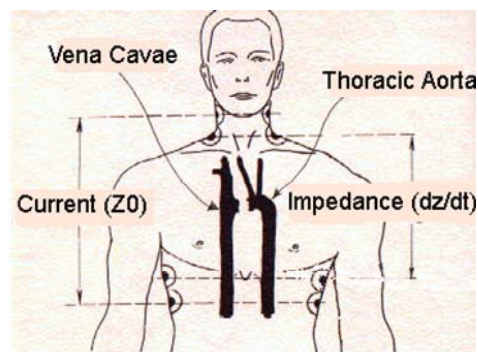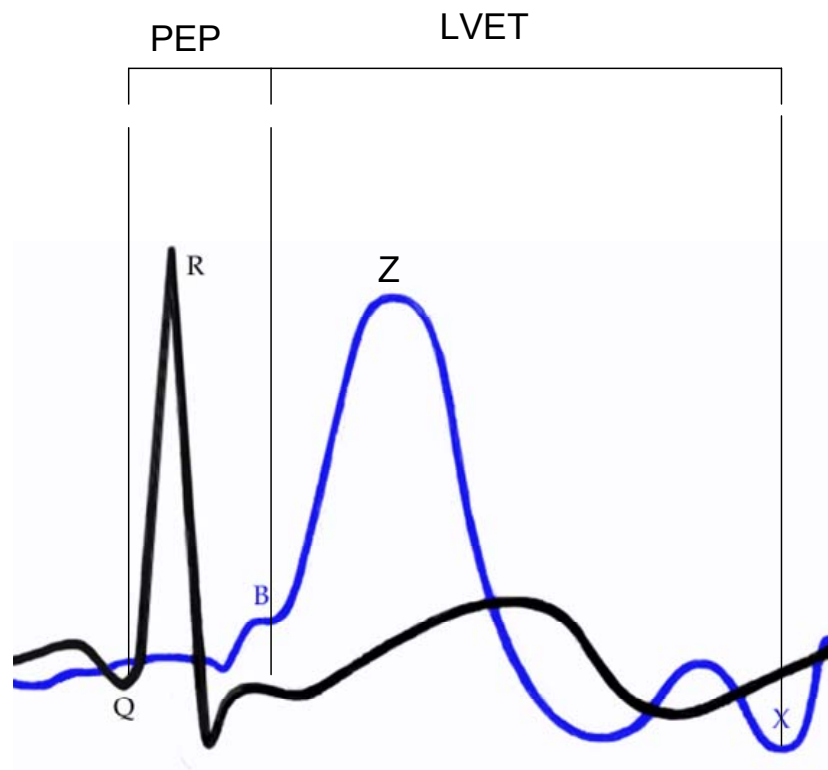5. Dz/Dt and ECG waveforms needed to score PEP, LVET, and SV
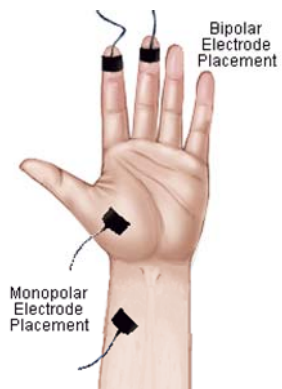
Figure 1
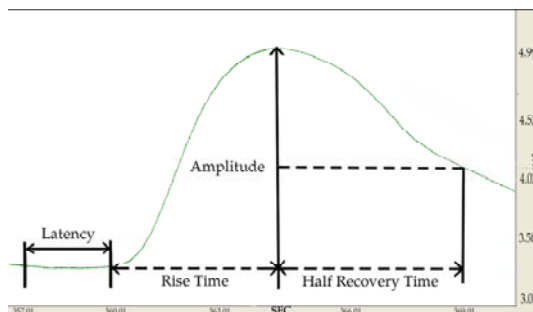


Figure 2



Figure 3



Figure 4

Figure 5