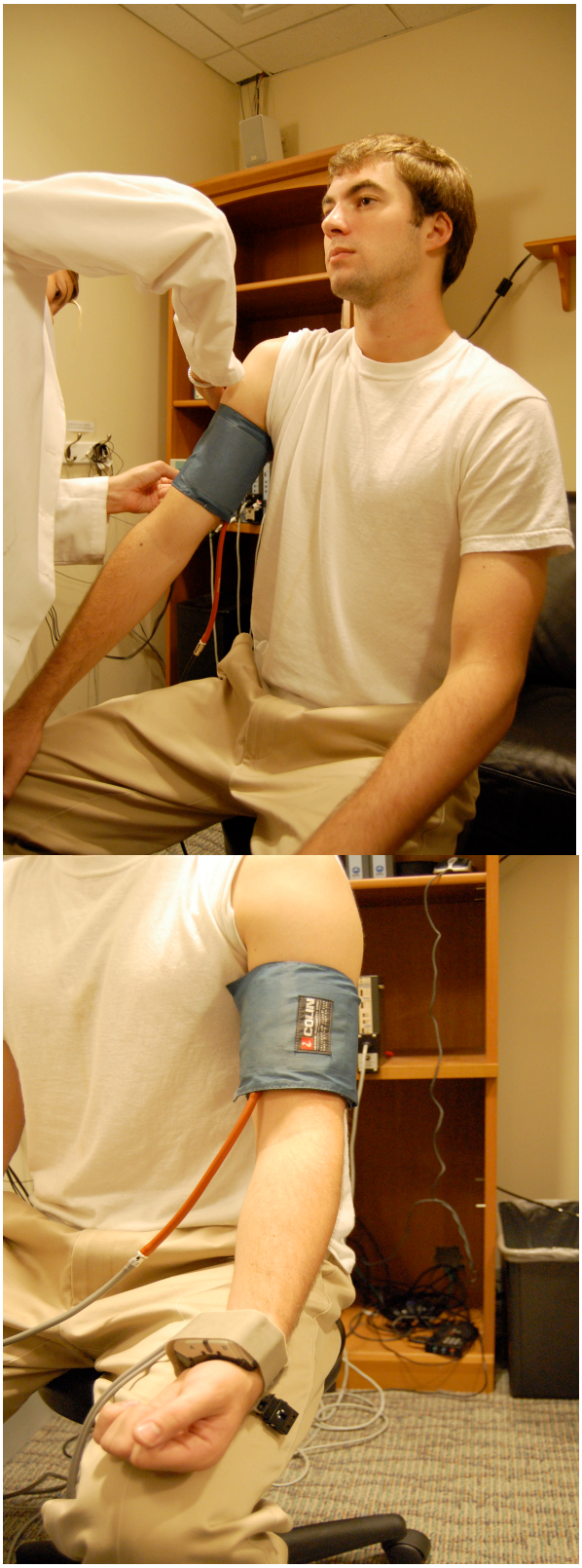
Measuring blood pressure. Blood pressure values can be obtained from sensors placed on various parts of the body including the brachial artery (upper arm), radial artery (wrist), or at the finger. It is important to point out, however, that as the distance from the heart is increased the accuracy of blood pressure changes can be reduced. Blood pressure measurements can be obtained using a variety of techniques, here we review four methods for obtaining blood pressure responses.



The first option is the auscultatory method, which consists of temporally stopping blood flow at the brachial artery and listening for sounds ("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, one that minimizes the self-consciousness that may arise from having one's BP measured. Digital BP machines are relatively inexpensive and fairly accurate (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. In Figure to the left the participant is wearing a Colin blood pressure cuff that can be adjusted to take as many as one BP reading per minute. The advantages of this method are that the BP readings are highly valid and reliable. The disadvantage is that the participant's arm is "squeezed" every time – stopping arterial blood flow. Repeated assessments with this technique could artificially elevate blood pressure and/or distract the participant from the study at hand.

The other three options allow the researcher to collect blood pressure *continuously* throughout an experiment. Commercially available machines are manufactured and/or distributed by Biopac (Goleta, CA), Colin

Medical Instruments (San Antonio, Texas), and Mindware Technologies (Gahanna, OH). In the Figure below the participant is wearing both a blood pressure machine that uses tonometric technology and an arm cuff for calibration.

Tonometric technology consists of BP measurement from the radial (wrist) artery, and uses a sweep technique, which applies 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 ecological validity, restraining the arm can be problematic. 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.

The third option is the oscillimetric method. 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 and these machines are the most difficult to locate commercially.

The fourth option is the volume-clamp (or Peñaz) method. This method uses a combination of a clamp at a peripheral site, typically the finger, held at a constant volume and a photoplethysmograph to measure blood volume. Blood pressure is estimated by measuring the amount of pressure change in the cuff that is required to keep the volume in the artery at a stable level. The most widely used machine using this technology is the Finapres, which is no longer available for purchase, but is still found in many labs. New machines using this technology can be purchased from Portapres, Finometer, and Biopac.

Applications of blood pressure responses. 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. 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).

PERIPHERAL PHYSIOLOGICAL MEASURES: Skin conductance

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. Electrodermal activity is a measure of eccrine sweat glands secretions, which are found widely distributed across the body, but are densely distributed in the palms of 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.

Electrodermal activity is commonly measured in one of two ways. The first method, *skin conductance,* uses a small current passed through the skin via a bipolar (i.e., dual) 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.

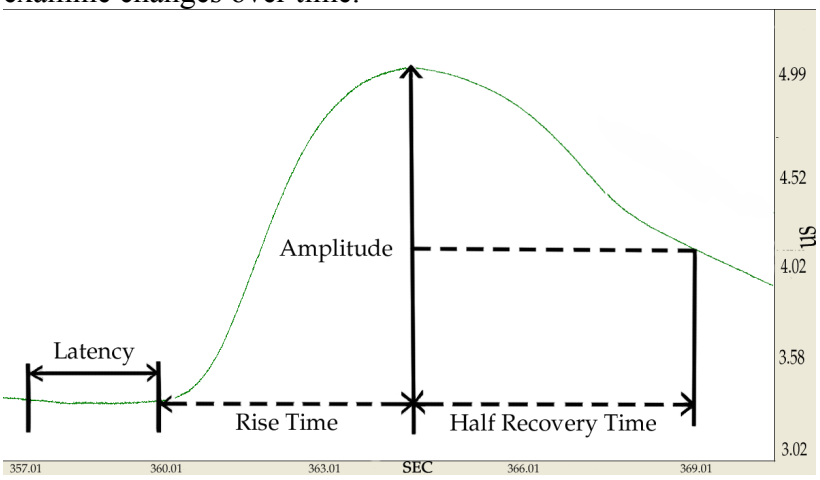
Preparation and recording. To record *skin conductance,* a bipolar placement of silver-silver chloride sensors are placed on the fingers, palms, or soles of the feet. If finger placement is used it is recommended that the sensors be placed on adjacent fingers (2^{nd} or 3^{rd} fingers; or 4^{th} or 5^{th} fingers) because they will be innervated by the same spinal nerve (Venables & Christie, 1973). Unlike skin conductance 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 includes washing with a mild, nonabrasive soap. Use of alcohol-based hand sanitizer or anti-bacterial soap prior to sensor placement is not recommended because the chemicals in them may 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 advisable to wait several minutes (typically 5 to 15 minutes) prior to beginning the recording session. Before beginning recording one should check for sensor sensitivity. Electrodermal activity responds to respiration so the participant can be instructed to take a deep breath and hold his or her breath for a few seconds. A good connection will be indicated by an increases in SC within 2 to 3 seconds once the breath is initiated.

Editing and quantification. After data collection, electrodermal waveforms should be inspected for movement artifact and electrical interference. Most scoring programs (free or ones available for purchase) 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 calculated 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 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. This threshold can be set at a variety of ranges, but typically the level is set between .1 and 1.0 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. 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, attention, arousal, or linked to different dispositional or clinical factors.

DATA EDITING

There are many software programs that are free or available to purchase. However, the most critical feature of any scoring program is the person who is *scoring* or processing the data. Many software programs have algorithms to find various points on the waveform or to identify artifacts, but some visual inspection is typically required.

The major concerns of data editing are the reliability and validity of the editing. To increase reliability of data editing, a subsample of data should always be re-scored by a different person to determine consistency. For some measures, which involve less editing or fewer "gray"

areas in judgment, one should expect near perfect reliability – for example, IBI, RSA, blood pressure responses, skin conductance responses. For other measures in which there is some subjective judgment, like at what point does the B inflection occur on the $\Delta z/\Delta t$ wave, one should look for very high reliability, but not necessarily perfect reliability. We can achieve reliability of different data editors with $\alpha > .95$ for measures such as PEP, SV/CO, LVET. Research assistants who are very conscientious and patient and who have good pattern detection skills make the best data editors.

Of course just because a group of research assistants are reliable does not mean that they are producing valid data. We suggest several guidelines to determine the quality of the data while scoring with a focus on the validity of the measures. 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 relations 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.

DESIGNING STUDIES

One never wants to be in a position in which he or she designs their research questions around their methodology, but as is the case with all methodologies there are some constraints depending on the measures targeted. The good news is that there are many options within electrophysiological recordings to get around some of the constraints that many methods do not enjoy yet – for example, as of this writing fMRI still has to be conducted while supine in a large magnet. Here we review issues related to designing experiments and how the method can be adapted to the question at hand.

Timing. Researchers need to determine whether their study is *time-based* or *event-based*. Simply, the difference between these options is that in a time-based design, the unit of measurement for ANS responses is a time window (30 sec, 1 minute, 5 minutes, etc.), whereas for an event-based design the unit of measurement is triggered by an event and then the length of the event can be defined by either the total length of the event or some pre-specified time window. Time-based studies require the experimenter to determine *a pri*ori the length of the experiment – how long is baseline, different tasks, and a recovery period. Once this is determined a time-based study will then obtain physiological data in *bins*, which means a pre-specified time period for which ANS responses are collected and labeled. For example, five minutes of rest at the beginning of a study would require the experimenter to obtain a five-minute bin of data. One could still break down the bins into smaller units to score the data, for example 30 seconds or 1 minute, but the smallest collection bin would set the largest time unit for scoring.

Event-based designs collect ANS responses based on a *trigger* that indicates the beginning of a phase of the experiment. In these designs, physiological data tends to be collected continuously throughout the experimenter with no bins identified. Instead, computer generated triggers are inserted into the acquisition software that is collecting the physiological data (or an experimenter might manual insert triggers with a key press at certain events). When collecting data for an event-based experiment to score or average the data for a specific event requires both

the trigger that initiated the event and either a second trigger that indicates the end of the event or a known time interval that indicates the length of the event (e.g., 33 seconds from the initiation trigger).

Study context. There are several critical design considerations that influence choice of ANS measures, how the data are collected and quantified, and, most critically, how the data are interpreted. When incorporating ANS measures in experiments, one of the first decisions necessary involves the context in which ANS responses are collected. As described earlier, many of the inferences that can be drawn from the physiological responses are context bound. In fear conditioning studies, for example, SCRs are often used as the primary measure of *fear* (e.g., Olsson, Ebert, Banaji, & Phelps, 2005). However, SCRs 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 patterns or profiles are thought to index psychological states from active situations and not passive ones. Challenge and threat motivational states, for example, are thought to occur only in active situations (Blascovich & Tomaka, 1996) 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 validated pattern associated with threat.

Participants' health. Recruiting participants for psychophysiology studies poses some challenges. Depending on the response of interest, there might be some health conditions that should be considered exclusionary. Of course, when interest is in either cardiovascular responses or heart rate variability people with heart conditions, abnormalities, pacemakers, or cardiac altering prescriptions (like beta-blockers) should be excluded.

There may be occasions when an abnormality is detected on the ECG, and what to do when this is detected is actually a matter of debate (see Stern, Ray, & Quigley, 2003). One perspective is the fact that non-medical professionals informing participants that there might be some abnormalities in their ECG can cause undue distress if proven wrong. 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, we received advice from a cardiovascular surgeon when concerned about possible cardiac abnormalities. Forging a relationship with a medical professional might be critical if an 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, but the lab should have some plan for how to deal with these possible situations.

Individual response stereotypy. 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 as predicted 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 response 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.

FUTURE DIRECTIONS

One of great advantages of ANS recording that has 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' imagination, knowledge and resources.

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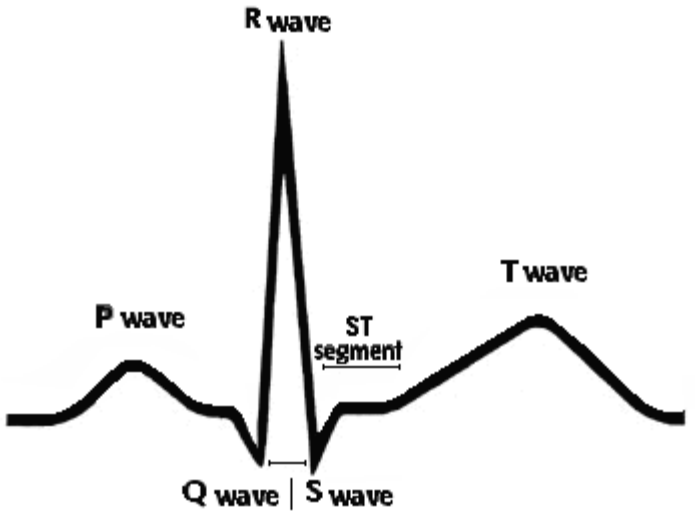
Footnotes

1. 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).

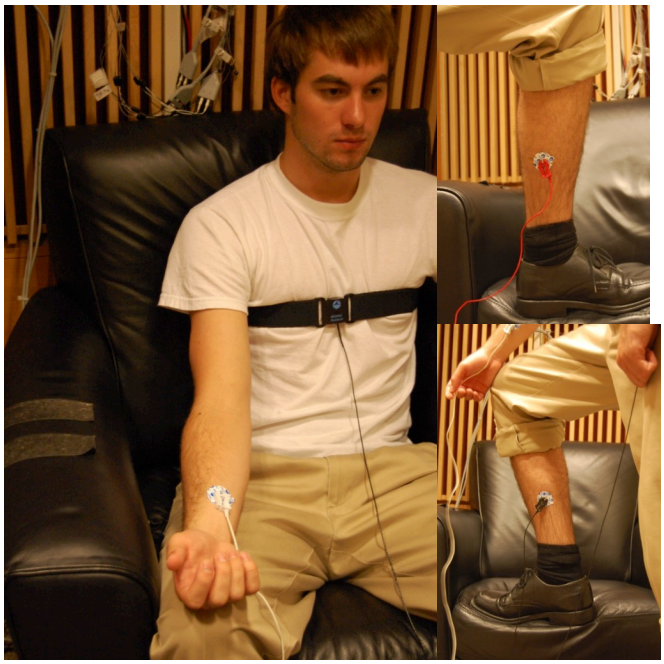
2. The Z point is sometimes identified as the C-point.

Table 2. Plausibility of physiological ranges: HR, PEP, and LVET

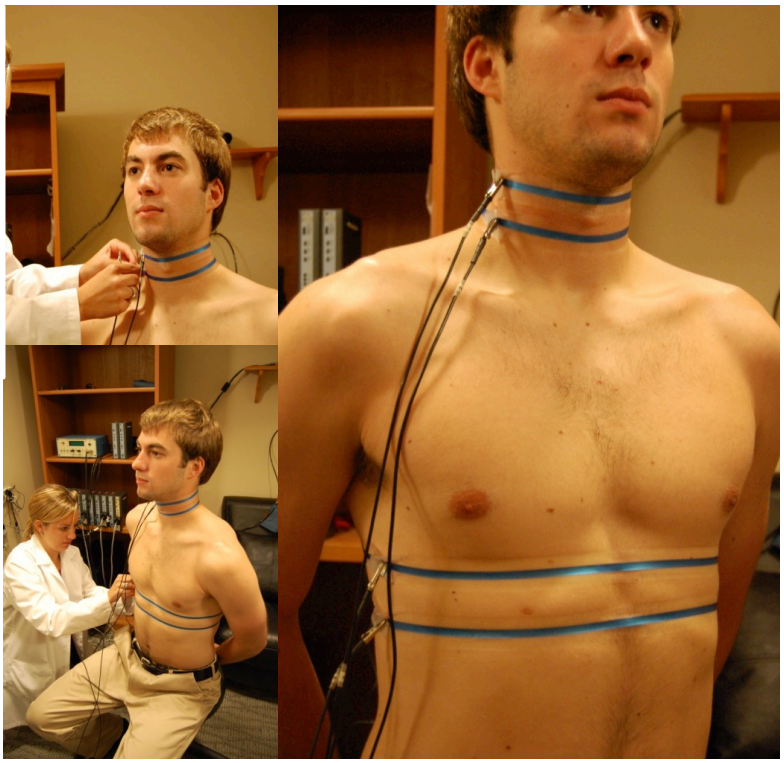
HR (bpm)	PEP (ms)	LVET (ms)
40-60	100-140	300-450
60-80	90-130	250-400
80-100	80-120	250-350
100-120	70-100	200-300
120 +	<80	180-300



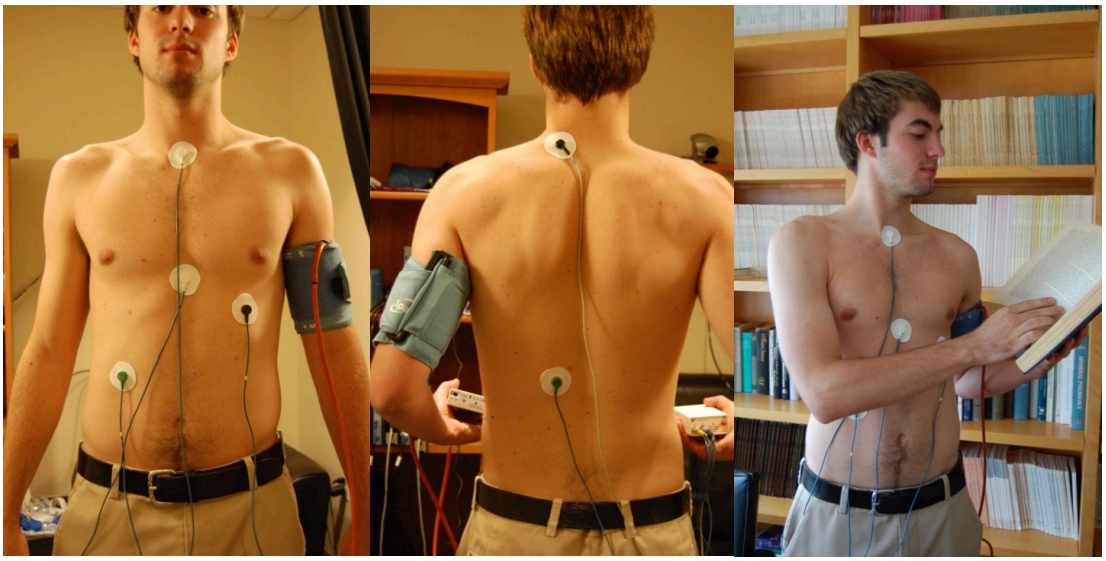
ECG waveform



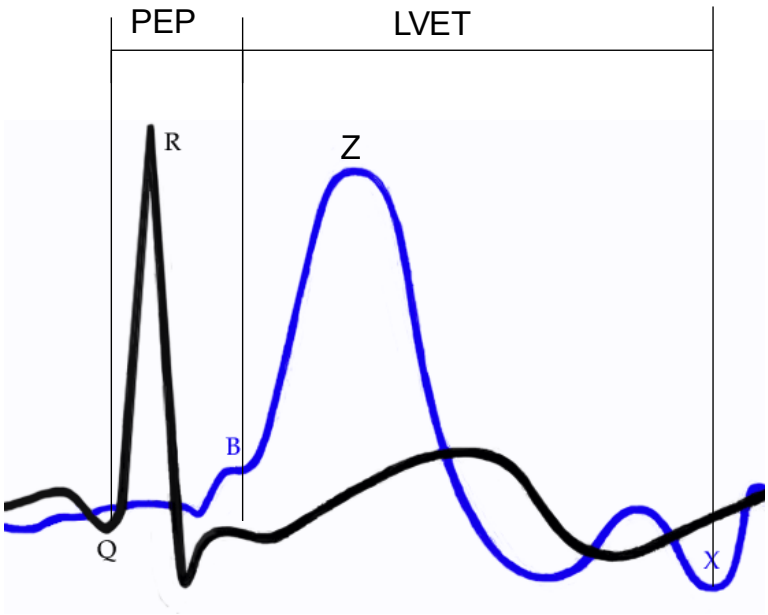
Standard lean II configuration for electrocardiograph (ECG) with respiration band



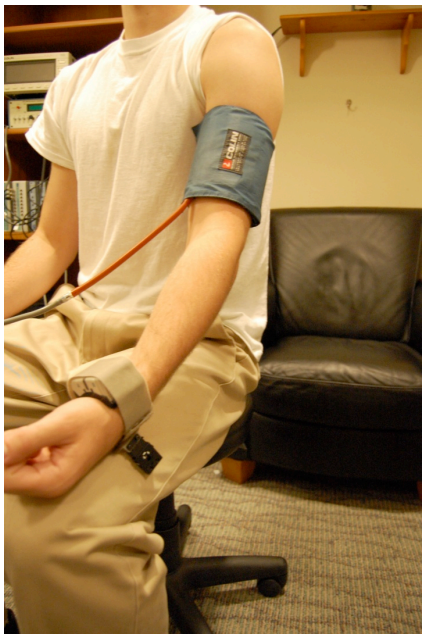
Band electrode placement for impedance cardiography



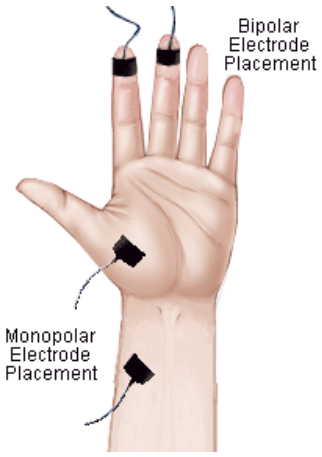
Spot electrode placement for impedance cardiography and electrocardiography



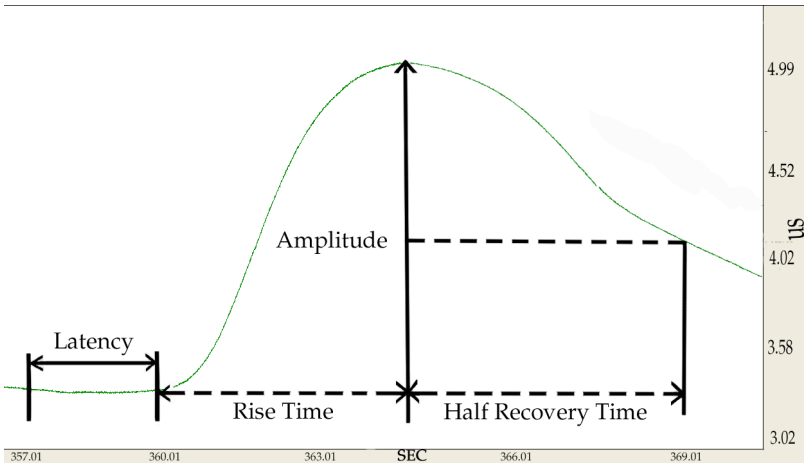
Ensembled Δz/Δt and ECG waveforms



Blood pressure device over radial and brachial arteries



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



Skin conductance response