Practical Polygraph: Understanding and Managing the Vasomotor Photoelectric Plethysmograph

by Mark Handler[1] [2] and Raymond Nelson[3]

The term "plethysmograph" is derived from the Greek term "plethymos" which means "an enlargement" or "fullness" and so the plethysmograph is a device for measuring and recording such changes. Examples of plethysmographs could include both the cardio cuff sensor and respiration sensors – because both of these respond to changes in circumference pressure. More often when referring to the plethysmograph, polygraph

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2 There are no financial or proprietary interests associated with this publication. The views and opinions expressed herein are those of the authors, and not necessarily those of LIC, APA, or Converus Inc.

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examiners are referring to a vasomotor sensor, in the form of a photoelectric plethysmograph (PLE)[4]. The PLE is used to record relative changes in pulse-wave blood-pulse volume in the tiny capillaries in the skin of the fingertips. This is what we are interested in for polygraph purposes – fingertip pulse volume or vasomotor activity[5]. The PLE sensor allows us to record and extract information about relative changes in blood-pulse volume in the body segment where the sensor is attached. Fingertip blood-pulse volume, or vasomotor activity, can be measured as the distance between diastolic and systolic peaks in the PLE pulse waveform[6]. Evaluation of the PLE data is a matter of observing and comparing the diagnostic changes in the PLE data in response to different test stimuli.

Wherezitgo? (where to attach the PLE sensor)

The PLE sensor can be attached to any of the digits of the left or right hand. All that is necessary is that the sensor can be easily positioned and that usable data is easily obtained. We recommend placing the PLE on the middle finger or the thumb to start as these have the larger arterioles compared to other fingertips. Try a different fingertip location if the tracing is not easily adjustable to 2-4 chart divisions.

Howzitwork? (tech stuff)

The photoelectric plethysmograph (PPG) uses a light source and a photosensitive cell to measure changes in light that is reflected or passed through the tissue segment where the sensor is placed. The light produced by the source is in the infrared range (7000 to 9500 Angstroms[7] or 700 to 950 nanometers[8]). Light waves in the infrared frequency ranges are scattered or reflected by red blood cells – which is why these cells appear red to our eyes – and the amount of light that reaches the photo-sensitive

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4 Plethysmograph sensors are also when testing sexual arousal, using a sensor designed to record small changes in penile tumescence that occur in response to test stimuli. An acronym for the penile plethysmograph is PPG, and for this reason we will use the acronym PLE in this document – mainly to avoid any potential confusion about the location of the sensor placement on the examinee during polygraph testing. In the medical field, the photoelectric plethysmograph is referred to as a PPG. The PLE sensor should be attached only to the fingertips during polygraph testing.

5 Other uses of the photoelectric sensor include monitoring pulse rate and respiration rate in medical settings.

6 For more information refer to Handler, M. & Krapohl, D. (2007). The use and benefits of the photoelectric plethysmograph in polygraph testing. Polygraph, 36(1), 18-27.

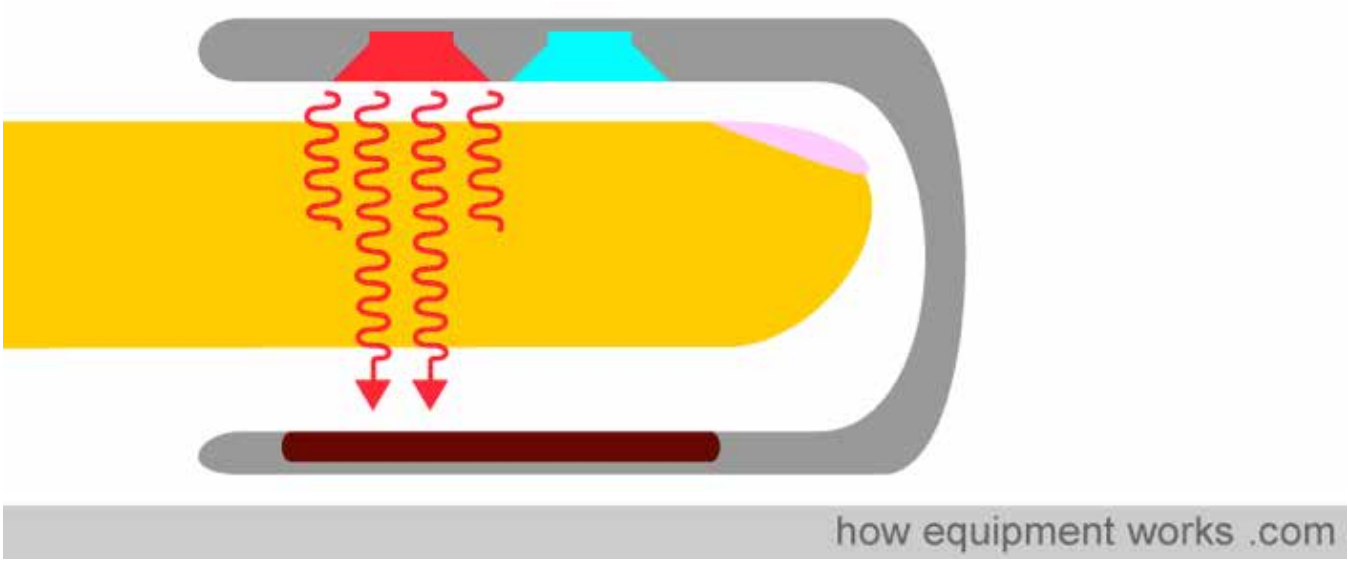
7 One angstrom = one hundred-millionth of a centimeter, or 10–10 meter. Angstroms are used to express wavelengths and interatomic distances.

8 One nanometer (nm) = one billionth of a meter, such that 7000 angstroms = 700 nanometers.

cell is related to the amount of blood through which it passes before reaching the sensor.

The photo sensor can be placed on the same skin surface as the light source, in which case we are observing changes in the amount of light that is reflected back is measured. Alternatively, the photo sensor may be placed on a skin surface opposite from the light source in which case we would observe changes in the amount of light that is transmitted through the tissues to the photo the sensor. Figure 1 shows the amount of light making it to the sensor depends on how much light is absorbed or scattered. How much of the light that makes it to the sensor depends on how much is lost as a function of the distance the light has to travel to reach the sensor and on the concentration of light absorbing material.

Figure 1. Illustration of light waves in the PLE sensor. (Reprinted and used with permission from How Equipment Works.com.) http://www.howequipmentworks.com/physics/respi_measurements/oxygen/oximeter/pulse_oximeter.html)



Whyzitwork? (Physiology)

Arteries and smaller arterioles carry oxygenated blood away from the heart to serve the body tissues. Arteries are large vessels that consist of mostly of collagen and elastin fibers along with a smaller amount of smooth muscle[9]. Blood vessels branch off and become progressively smaller as blood travels further from the heart, and the smaller diameter vessels in the periphery have a higher concentration of smooth muscle than the larger diameter vessels closer to the heart. Small arteries called arterioles play an important part

in managing systemic blood pressure. The arterioles maintain their diameter based on the amount of sympathetic innervation they are receiving at any given time. They receive a constant sympathetic innervation that is sometimes referred to as vasomotor tone.

Because innervation causes muscles (including smooth muscle) to contract, vasodilatation is achieved by a reduction in sympathetic innervation. Conversely, vasoconstriction results from sympathetic nervous system activation of the smooth muscles in the arterioles. It is for these reasons that vasoconstriction or vasomotor activity can be exploited as a proxy for increases in activity in the sympathetic division of the autonomic nervous system[10].

Hemoglobin (Hb) in our blood absorbs light and the amount of light absorbed is proportional to the concentration of Hb in the blood vessel. Other substances also absorb light, but those substances are consistent during polygraph testing. The major source of variation in light absorption during polygraph testing is the amount of blood and Hb present in the tiny vessels in the skin, and these changes are knows to be related to increases and decreases in sympathetic innervation. As the vessels constrict, there is less blood present, so there is less hemoglobin to absorb the light.

In Figure 3, one blood vessel has a low Hb concentration and the other blood vessel has a high Hb concentration. Each single Hb absorbs some of the light, so more light is absorbed when there is more Hb per unit area[11]. By measuring how much light reaches the light detector, the PLE sensor can be used to calculate how much light has been absorbed. When there is more Hb in the finger, more of the light is absorbed and less light reaches the photo sensor. Changes in the local volume of Hb at the PLE sensor site are a function of vasoconstriction,

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9 Smooth muscle is non-striated muscle for which the fibers are not highly ordered resulting in contractions and relaxation changes that are less directionally focused than skeletal muscle, and are also different than cardiac muscle. The physical activity of many internal organs is a function of smooth muscle.

10 Similar to the information from the other polygraph sensors, vasomotor activity is not itself synonymous with sympathetic activity or with deception. In comparison, skin conductance and resistance are also not synonymous with either sympathetic activity or deception, nor are they synonymous with sweating. Instead these are a proxy for (i.e., they approximate) sympathetic activity. Sympathetic activity is also not synonymous with deception but has been found to be correlated with differences in deception and truth-telling. Scientific tests are intended to quantify phenomena that cannot be easily subject to physical measurement and do so by exploiting the statistical relationships (i.e., correlation) between the obtainable data as a proxy for the phenomena of interest.

11 This property is described in a law in physics called "Beer's Law" which states that the amount of light absorbed is proportional to the concentration of the light absorbing substance.

which is a function of sympathetic innervation. See figures 2 and 3.

Figure 2. Two examples of hemoglobin concentration. (Reprinted and used with permission from How Equipment Works.com.)
http://www.howequipmentworks.com/physics/respi_measurements/oxygen/oximeter/pulse_oximeter.html

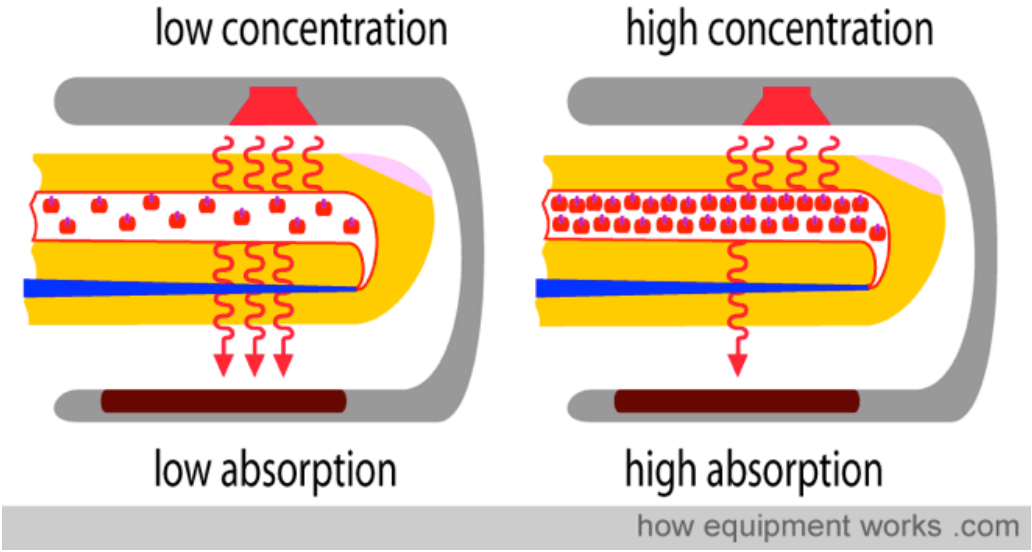
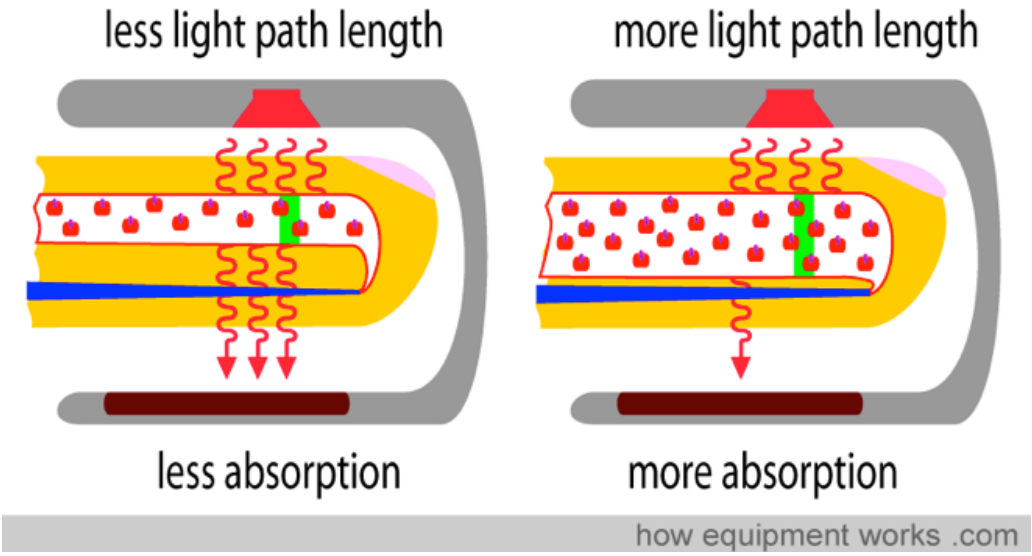


Figure 3. Varying Hb concentration as a function of vasoconstriction. (Reprinted and used with permission from How Equipment Works.com.)

http://www.howequipmentworks.com/physics/respi_measurements/oxygen/oximeter/pulse_oximeter.html



Whatzitmean? (Feature extraction and scoring)

Because vasoconstriction is a function of sympathetic innervation, the feature of interest to polygraph examiners is the constriction or reduction of fingertip blood-pulse volume. A reduction of fingertip blood-pulse volume is an indication of sympathetic innervation, for which changes can be compared according to the analytic theory of the polygraph test[12]. Vasoconstriction can be observed in the PLE data as a reduction of the distance between the diastolic and systolic peaks in the PLE waveform, when comparing the data after stimulus onset to the data prior to stimulus onset.

Figure 4 shows an acquaintance test with the PLE and other sensor data, along with visual guides to assist in the identification of the diagnostic information for feature extraction. Researchers have shown the optimal response period, between pre-stimulus and post-stimulus blood-pulse volume differences, to occur between 5 seconds and 10 seconds after stimulus onset . To more easily assist in the extraction and comparison of observed vasoconstrictions the vasomotor pulse amplitude is also shown for the 3-second period prior to stimulus onset. Reaction features in Figure 4 have been rank ordered, and it can be seen that the vasoconstriction at question 3K is a greater change in physiological activity compared to the other responses.

Although some information can be obtained from the PLE data using visual feature extraction alone, more diagnostic information can be obtained through the use of computer algorithms. Computers can be used to highlight the reaction feature and increase the reliability and precision of visual feature extraction. They can just as easily be used to fully automate the feature extraction process. The goals of a scientific test such as the polygraph test or other forensic test is to achieve a professional opinion that is supported by analysis of the test data. The practical goals are twofold:

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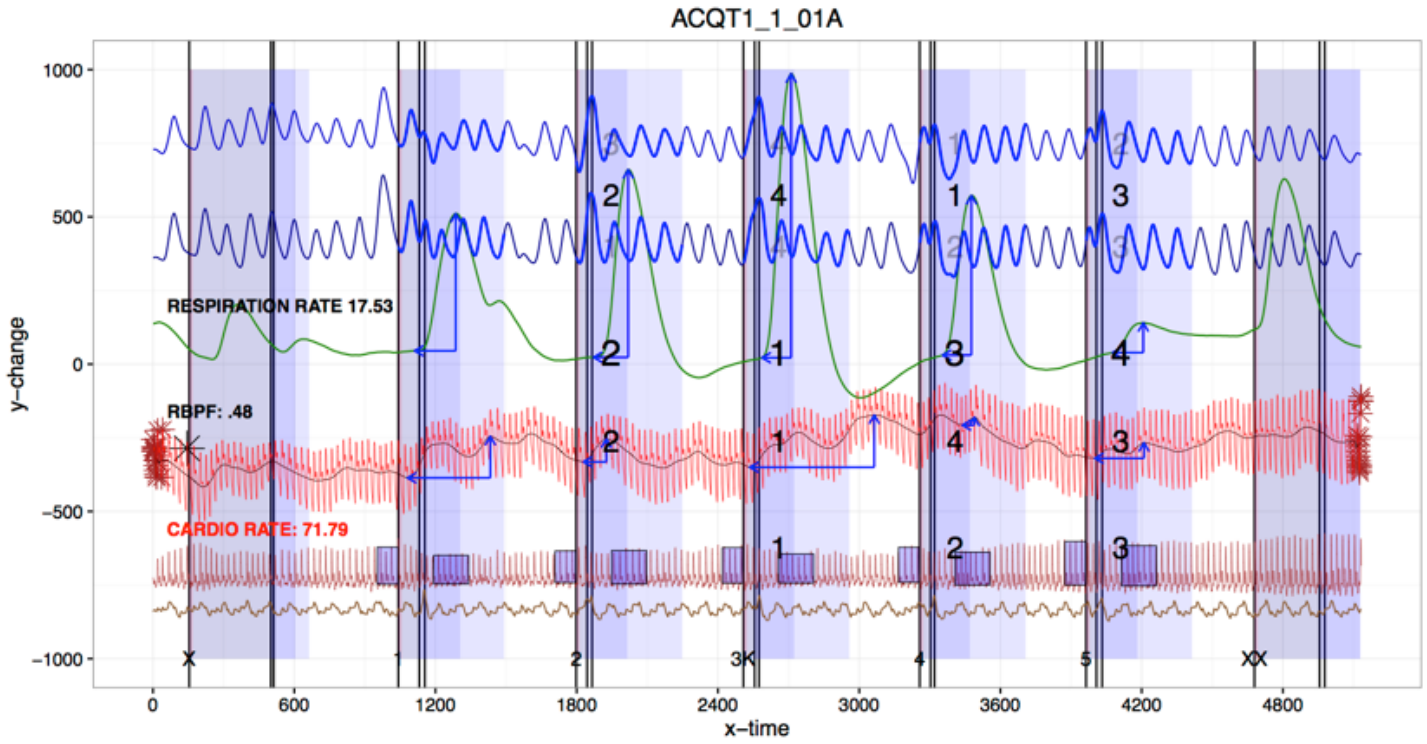
12 The analytic theory of the polygraph test holds that greater changes in physiological activity are loaded at different types of test stimuli as a function of deception or truth-telling in response to the relevant target stimuli. For more information refer to Nelson, R. (2016). Scientific (analytic) theory of polygraph testing. APA Magazine, 49(5), 69-82.

13 For more information refer to Podlesny, J. A. & Raskin, D. C. (1978). Effectiveness of techniques and physiological measures in the detection of deception. Psychophysiology, 15, 344-359.

Figure 4. Acquaintance test with feature extraction for PLE and other sensors.



1) achieve a conclusion or classification, and 2) calculate and communicate a realistic estimate of the level of confidence or margin of uncertainty associated with that conclusion – the probability or likelihood or odds that a conclusion is correct or incorrect (or the likelihood that a conclusion was based on test data that occurred due to random chance). The addition of more data can help to achieve the first objective only as long as the additional data are valid and do not co-vary with other data to such a degree that it distorts or disrupts the stability and effectiveness of the analysis model.

Until recent years many field practitioners gave little thought or attention to the second objective – quantification of the probabilistic confidence and uncertainty associated with the test result. Traditional polygraph analysis methods – those developed prior to the use of computers – relied on cut scores that were selected either arbitrarily or heuristically, though without attention to the calculation of statistical confidence or uncertainty estimates for individual exams. Polygraph error estimation, at that time, was limited to the analysis of test performance with groups or samples of cases.

The trend in forensic science in recent decades has been towards the

increased use of computers and analysis models designed to compute statistical confidence and error estimates for individual cases in addition to the study of test precision and error rates for groups such as a population or research sample. Although statistical reference tables have been published for the array of polygraph techniques in use today[14], most available reference tables do not include the PLE sensor. Computer algorithms may or may not make use of PLE data, and it should be the role of algorithm developers and vendors to provide information on this.

Inclusion of the PLE sensor data in manual analytic decision models, developed without the PLE, may have the potential to distort or overload the reference distributions or likelihood functions by adding information that is not accounted for in the statistical calculations. For example ESS tables and most other published reference data do not include the PLE sensor. Until such time as reference tables or likelihood functions become published and available it will be important to remain aware that the inclusion of the PLE sensor will mean that our calculations of the test error statistic – in the form of a p-value that can also be thought of as either the *area* under the normal distribution or the *cumulative distribution function* (i.e., the sum of all probabilities up to and including the test error statistic) – can be expected to be a biased estimate. This is acceptable only inasmuch as we expect the estimate to be biased towards the overestimation, and not the underestimation, of decision errors.

It will be important for researchers, developers and technology vendors to continue to advance the state of polygraph science. At such time published knowledge and information are able to mathematically and statistically account for the added PLE data, continued use of reference table and likelihood functions developed without the PLE data will become more scientifically and ethically questionable.

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14 Refer to Nelson R. & Handler, M. (2015). Statistical reference distributions for comparison question polygraphs. Polygraph, 41(1), 91-114.

15 Nelson, R., Handler, M., Shaw, P., Gougler, M., Blalock, B., Russell, C., Cushman, B. & Oelrich, M. (2011). Using the Empirical Scoring System. Polygraph, 40, 67-78.