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Multinomial Reference Distributions for the Empirical Scoring System[1]

Raymond Nelson[2]

Abstract

Scoring and interpretation of CQT data has progressed from subjective visual interpretation to the use of structured feature extraction methods and analytic models that make use of statistical decision methods. Empirical reference distributions are now available for a variety of comparison question polygraph test formats and numerical scoring methods. However, no previously published description could be found for a theoretical reference distribution for CQT scores. Theoretical reference distributions are an important aspect of all areas of science because, as the name suggests, they depend fundamentally on a coherent and practical understanding of the underlying theoretical basis such that it can be expressed mathematically. Theoretical distributions are calculated from facts or assumptions that are subject to logical mathematical proof. Theoretical distributions can be used to make inferences about empirical data, and can also be useful as a likelihood function for Bayesian analysis. An advantage of the theoretical distribution and a Bayesian approach is that the replacement or addition of evaluation features and recording sensors can be a simple matter when naïve assumptions are made. Multinomial reference distributions for CQT scores are calculated under the null-hypothesis to the analytic theory of the polygraph and the CQT, and the results from closed-form calculations were compared graphically to a Monte Carlo simulation. A description of the calculation of the multinomial reference distributions is provided for replication and for readers who wish to develop their understanding of, and intuition for, multinomial distributions. Reference tables for random discrete uniform multinomial distributions for the variety of CQT formats are provided in appendices.

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Introduction

A combinatoric[3] solution is described herein for the computation of multinomial[4] statistical reference distributions[5] for empirical scoring system[6] (ESS) scores for comparison question test (CQT) data. Availability of a theoretical referenced distribution for the CQT can help to advance the science of the polygraph and credibility assessment testing through the comparison of real-world observations with expected results as defined by a mathematical and statistical model. In addition to the availability of empirical data and empirical reference distributions, theoretical reference distributions help to understand the validity of an area of scientific theory, and can help to better understand and better interpret empirical observations and empirical data.

Use of statistical reference distributions to interpret polygraph data was first suggested by Barland (1985) who described a Gaussian-Gaussian signal discrimination model (Wickens, 1991; 2002), though this was largely unnoticed until the introduction of the Objective Scoring System (OSS; Krapohl & McManus, 1999; Krapohl, 2002) and the later Empirical Scoring System (ESS; Nelson, Krapohl & Handler, 2008; Nelson et al., 2011). Empirical reference distributions were published by Nelson and Handler (2015) for all comparison question polygraph formats for which data was included in the meta-analytic survey by the American Polygraph Association (2011). Although empirical reference distributions are becoming more widely used by polygraph field examiners in recent years, no published description exists for the calculation of a theoretical distribution for CQT scores.

Statistical reference distributions[7,8],

3 Combinatorics is an area of mathematics that involves counting the combinations of objects that can be created from a defined set of items according to certain rules or constraints. A number of textbooks, such as the one by Skiena (1990) and Chen and Koh (1992) address this topic in detail.

4 Multinomial refers to a statistical distribution of the expected frequency of possible outcomes under repeated trials when there are multiple possible outcomes for each individual trial. Applied to the polygraph context each presentation of each test stimulus and each sensor score represents an individual trial for which the outcomes maybe coded in as + - or 0. The more common binomial distribution, with two possible outcomes for each trial, is a special case of the multinomial. Detailed information can be found in mathematics texts and reference such as by Abramowitz & Stegun, (1972) and Olver, Lozier, Boisvert, & Clark (2010).

5 A distribution is a numerical and mathematical description of the range of possible values for a random variable. A random variable is a value that is unknown and can take a variety of possible values. Statistical distributions are mathematical or empirical descriptions of the range of values and the expected proportion or probability of observing each unique value if they occur due to random chance alone. More information can be found in statistics textbooks such as the by Evans, Hastings & Peacock. (2010) and Spiegel (1992).

6 The ESS is an evidence-based standardized protocol for the analysis of comparison question polygraph data, and is largely a derivative product of earlier research by others, including: Kircher and Raskin (1988), Raskin, Kircher, Honts and Horowitz (1988), Kircher, Krisjianssen, Gardner and Webb (2005), Krapohl and McManus (1999), and Senter and Dollins, (2003).

7 A statistical distribution is a set of numbers that can represent a phenomenon of interest (e.g., height, weight or polygraph scores) for which the data are non-deterministic or imperfect and are expected to vary somewhat. Data that vary in a completely unordered or random manner will not be useful to guide our conclusions about observations of real-world phenomena. Data that vary with some degree of order can be useful if the rules and assumption that determine the form of the data distribution can be studied and proofed by statisticians and mathematicians. Statistical distributions are characterized by numerical parameters that provide all the information necessary to calculate the distribution mathematically.

8 For example: the Gaussian or normal distribution, sometimes called a bell-curve, is a commonly used theoretical distribution that is related to the standard normal or z distribution. The normal distribution characterizes a variety of naturally occurring phenomena. There are a number of other common and recognizable theoretical distributions, including the Chi squared distribution that is the sum of squared standard normal deviates, the t distribution that characterizes the distribution of small samples and which will converge towards the normal distribution for large samples, the binomial or Bernoulli distribution for discrete values that will be asymptotically normal for large sample sizes, the Poisson distribution that characterize the frequency of occurrence of time series events, the Weibull distribution that can be used to characterize the reliability of lifetime and failure events in engineering, the family of exponential-logarithmic distributions that can be used to characterize non-linear increases or decreases in events, the uniform distribution of decimal proportions between 0 and 1, and other theoretical distributions.

are said to be *theoretical* then they are calculated from basic facts and assumptions that are accepted as the product of logical and mathematical proof. This is in contrast to *empirical* distributions that are calculated from observed sampling data[9]. In practice, theoretical and empirical reference distributions are often used together[10]. Part of the usefulness of mathematical/theoretical distributions is that probability statements about the statistical significance of observed data are mathematical abstractions that may be more robust against sample group differences than empirically derived reference distributions – if the theory is valid. The multinomial distribution, a form of discrete[11] probability distribution, can be used to describe the distribution of all possible outcomes under the null-hypothesis to the analytic theory of the CQT.

Analytic theory of the CQT

The analytic theory of the polygraph has been discussed and evaluated in numerous studies and publications (Bell, Raskin, Honts & Kircher, 1999; Honts & Peterson, 1997; Honts & Raskin, 1988; Honts & Reavy, 2015; Kircher & Raskin, 1988; Kircher, Packard, Bell & Bernhardt, 2001; MacLaren & Krapohl, 2003; Nelson, 2014, 2015a, 2015b; Raskin, Honts & Kircher, 2014; Raskin, Kircher, Honts & Horowitz, 1988), and 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. During the interview phase of a polygraph examination an examinee who does not wish to make a confession will deny involvement in a behavioral issue under investigation.

During a polygraph test, changes in physiological activity are recorded using an array of recording sensors. Data from the recording sensors is subject to numerical transformation and reduction for statistical analysis. The goal of the analysis is to classify test results as deceptive or truthful based on the differential salience (Handler & Nelson, 2007; Senter, Weatherman, Krapohl & Horvath, 2010) of different types of test stimuli. The psychological basis for observed differences in physiological activity can be thought of as generally involving a combination of the mental effort necessary to conceal the truth and assert a lie, emotion related to the behavioral act or the potential consequences for the act, and conditioned responding to the descriptive stimulus as a result of involvement or experience in a behavioral act (Hander, Shaw & Gougler, 2010; Nelson, 2015a) under investigation.

Polygraph testing is neither a deterministic observation of deception or truth-telling (i.e., perfect or unchangeable and not amenable to human behavior), nor a direct physical or linear measurement of deception or truth. Scientific tests are not expected to be infallible and are fundamentally probabilistic – including when probabilistic results are reduced to categorical results for conve-

9 For example: sampling data that are normally distributed will produce a histogram of similar shape to the standard normal distribution. However, whereas a histogram is a description of available empirical sampling data, a theoretical distribution such as the standard normal distribution is a mathematical abstraction.

10 Statistical procedures often involve the study of an observed empirical distribution with reference to a theoretical statistical distribution that is a mathematical abstraction. When the empirical data conform reasonably to the shape of a theoretical distribution we can then use our mathematical knowledge of the theoretical distribution as a model to make replicable probabilistic and categorical inferences about our empirical data. When the empirical data are randomly selected or representative of the population from which the data was drawn we can begin to make inferences about the population from which the empirical sample was obtained.

11 A distribution is said to be discrete when the numerical values cannot be divided into fractions or smaller parts, when there are no meaningful values in between the nodal values that are characteristic of the data. For example: a person's height or weight can be expressed in continuous numerical values including decimals or fractions, while the number of times a person gets kicked by a horse can be expressed using only positive integers for which there is no meaningful interpretation in between each integer. Theoretical distributions are said to be continuous when the data values can be expressed using numbers than can be continuously divided into infinitely smaller and smaller parts for which there remains some useful and meaningful interpretation. For example, the uniform distribution of probabilities between 0 and 1 is a continuous distribution.

nience. Like other scientific tests, the purpose of the polygraph test is to record and analyze data as a basis for replicable calculation of the probabilistic result (American Polygraph Association, 2011, Nelson & Handler, 2012, 2015; Nelson, *et al.*, 2011). Probabilities associated with test results can refer to expected classification accuracy rates with groups or samples of exams, and can also refer to the estimated statistical error or accuracy level for a single examination.

Administration and scoring of the CQT

The CQT is administered through the use of a non-accusatory pretest interview, during which the issue under investigation is clarified and all test questions are reviewed with the examinee (American Polygraph Association, 2016; Raskin & Honts, 2002; Raskin, Honts & Kircher, 2014, Handler & Nelson, 2008), followed by the acquisition and recording of the test data in response to several iterations of a sequence of stimulus questions that includes the relevant or investigation target stimuli, comparison question stimuli (Kircher and Raskin, 1988; Bell et al., 1999; Department of Defense, 2006 Handler & Nelson, 2008; Krapohl & Shaw, 2015) and other procedural questions. A common CQT question sequence for an event specific diagnostic exam will include three relevant target questions, and three comparison questions, and will be repeated three to five times (Bell, Raskin, Honts & Kircher, 1999; Department of Defense, 2006, Handler & Nelson, 2008; Krapohl & Shaw, 2015). CQT data consist traditionally of time-series recordings from three different sensors, including the thoracic and abdominal respiration sensors, an electrodermal activity (EDA) sensor and a cardiovascular activity sensor. A vasomotor sensor, also sometimes referred to as a photoelectric-plethysmograph (PLE or PPG), can also be included. Data are transformed to numerical scores for each stimulus presentation and each recording sensor.

Physiological responses to CQT stimuli are coded using a non-parametric rubric. By convention, positive scores are assigned to CQT responses when there is a greater change in physiological activity in response to the comparison stimuli, while negative scores are assigned when there is a greater change in physiology in response to the target stimuli. Scores of zero can occur when there is no interpretable difference in response, or when there is no response to both relevant and comparison stimuli, or when the data are not interpretable due to physical activity or other data artifact (Department of Defense, 2006; Krapohl & Shaw, 2015; Nelson, Krapohl & Handler, 2008; Nelson et al., 2011). The number of scores will be determined by the number of relevant questions, the number of sensors and the number of repetitions of the question sequence.

When using the ESS, EDA scores are weighted more than the other sensor scores. This is because EDA data has been shown to be more strongly correlated with differences between deceptive and truthful examinees and contributes more information to an optimal test model than other sensor data (Ansley & Krapohl, 1999; Honts, Handler, Shaw & Gougler, 2015; Harris, Horner & McQuarrie, 2000; Kircher, Kristjansson, Gardner & Webb, 2005; Kircher and Raskin, 1988; Krapohl & McManus, 1999; Nelson, Krapohl & Handler, 2008; Podlesny & Raskin, 1978; Podlesny & Truslow, 1993; Raskin, Kircher, Honts & Horowitz, 1988). The procedure for weighting the EDA scores is simply to double all EDA integer score values. EDA scores are therefore -2, 0, and + 2 when using the ESS, whereas scores from the other sensors are -1, 0 and +1. In this way, non-parametric ESS scores are intended to approximate an optimal statistical function. This is different than other manual scoring methods for which the data from various sensors are assumed to contribute equally to the effectiveness of the classification model.

Calculation of the multinomial reference distribution

Computation of the theoretical distribution of ESS scores begins with a statement of the null hypothesis to the analytic theory of the CQT. The null-hypothesis says that physiological responses are not systematically loaded for target or comparison stimuli, and instead occur in a random manner for each of the recording sensors. Both the analytic theory and the null-hypothesis pertain to the data and distribution of scores for the individual sensors in the same manner that these pertain to the grand total and question subtotal

scores. It is expected that random data, under the null-hypothesis, will give results that are meaningless and unpredictable, and this will be observed in classification accuracy rates that will not differ from random chance. The theoretical distribution of ESS scores is multinomial because there are more than two possible scores for each sensor at stimulus presentation (referred to more generally as a *stimulus trial*): -1, 0, and +1. Under the null-hypothesis the sensor scores are not loaded in any systematic way, and are therefore uniformly or equally likely to occur[12] .

For each recording sensor, there will exist a multinomial distribution of possible sensor totals determined by the number of trials and the number of possible sensor scores for each stimulus trial. For example: the sensor distributions for an event-specific polygraph test with three relevant questions and three repetitions of the question sequence will consist of nine stimulus trials for each question for which there will be three possible sensor scores at each trial (27 sensor scores). Similarly, the sensor distribution for an event-specific polygraph examination with three repetitions of a question sequence that includes only two relevant questions will consist of six stimulus trials, again with three possible sensor scores at each trial (18 sensor scores). In the same way, the sensor distributions for an event-specific polygraph test with five repetitions of a question sequence that includes four relevant questions will consist of 20 stimulus trials with three possible sensor scores at each trial (60 sensor scores).

Some polygraph examinations are evaluated using only the question subtotal scores; in this case the number of stimulus trials for the calculation of the multinomial sensor distribution will be determined by the number of repetitions of the test question sequence. For example: the multinomial distribution for the sensor subtotal scores of a multiple-issue polygraph with three repetitions of the question sequence will be calculated from three stimulus trials regardless of the number of relevant stimuli.

Computation of the multinomial distribution for sensor totals

A complete discussion of multinomial calculations is beyond the scope of this paper. However, a worked example can be useful to illustrate the basic idea. Because transformed numerical results for all sensors can receive one of three possible values for each stimulus trial, all sensor distributions are identical under the null-hypothesis. First it is necessary to establish a coherent vocabulary to describe the various ways of summarizing the numerical scores. Table 1 shows a sample score sheet, with simulated random data, illustrating the calculation of the question subtotals, sensor subtotals, sensor totals, and grand total score[13]. There are nine different multinomial distributions that can be calculated for the sensor total scores depending on the CQT format. This is because CQT formats can consist of two, three, or four relevant questions, and can be completed with three, four, or five repetitions of the test question sequence. A multinomial sensor distributions can be calculated for the sensor subtotals, for use when polygraph decision rules make use of question subtotals.

The score sheet in Table 1 shows an exam with 9 stimulus trials (i.e., there are three repetitions of a question sequence that includes three relevant questions). There are 19,683 unique permutations[14] of the score sheet in Table 1 and 55 unique un-ordered

12 The multinomial distribution can also be calculated with weighted probability values for the possible sensor scores for each stimulus trial when there is a satisfactory basis of information to inform those probability values.

13 The term sensor subtotal refers to the sum of the repetitions of each individual relevant question for a recording sensor. Sensor total refers to the sum of all scores for all repetitions of all relevant questions for a recording sensor. The sum of the sensor subtotals will equal the sensor total. The term grand total is used to refer to the sum of all sensor scores for all repetitions of all relevant questions. Question subtotal refers to the sum of all sensor scores for all repetitions of each individual relevant question. The sum of the question subtotal scores will equal the grand total score. There is no mathematical use for the subtotals for each presentation of each stimulus, nor for the sensor subtotals for each repetition of the stimulus question sequence in calculation of the multinomial distribution of CQT scores.

combinations[15] of the number of +, -, and 0 scores. The number of unique permutation is calculated as n raised to the k power (n^k) where n is the number of different possible scores and k is the number of trials. Permutations are unique ordered sequences, and are not the same as combinations. The number of un-ordered combinations is calculated as (n+k-1)! / (k! * (n-1)!) where the "!" indicates the factorial[16]. The number of possible sensor scores for each multinomial sensor distribution is a function of the number of stimulus trials using this formula: 2*k+1, where k is the number of stimulus trials. For example, the multinomial distribution for the sensor totals with nine trials will include 19 possible values (2*9+1=19) for the sensor totals, ranging from -9 to +9 including the value 0.

14 Permutations are unique ordered sequences of the 9 scores which consist of the values +, -, and 0. Permutations are immutable, which means that the positions of the elements of a permutation are not interchangeable. In other words, the permutation (1, 2, 3) is not the same as the permutation (3, 2, 1) or (2, 1, 3) or any other order of the same values.

15 Combinations are sequences of items that are mutable, meaning that the positions of the items in the sequence can be moved without changing the value of the sequence. In other words, the combination (1, 2, 3) is the same as (3, 2, 1) because the order of the items is different though the items themselves are the same.

16 The general form of the combinatoric formula is n! / ((n-k)!*k!) for which common examples have k smaller than n. Factorial calculations can quickly become large and unwieldy making algebraic conventions useful. For example: how many unique groups of 3 persons can be made from 10 persons? Answer: 10!/(7!*3!) = (10 * 9 * 8 * 7 * 6 * 5 * 4 * 3 * 2 * 1) / ((7 * 6 * 5 * 4 * 3 * 2 * 1) * (3 * 2 *1)) = (10 * 9 * 8) / (3 * 2 * 1) = 720 / 6 = 120. The number of k trials in the polygraph context is not constrained by and can exceed the value of n. For this reason, we use a different version of the formula.

Table 1. Sample score sheet with question subtotals, grand total, sensor subtotals, and sensor totals.

Repetition 1	R1	R2	R3
Respiration	1	0	-1
EDA	0	-2	2
Cardio	1	0	0
Vasomotor	0	1	0
Repetition 2	R1	R2	R3
Respiration	0	1	0
EDA	2	0	-2
Cardio	1	0	-1
Vasomotor	-1	0	1
Repetition 3	R1	R2	R3
Respiration	-1	1	1
EDA	0	2	2
Cardio	0	-1	-1
Vasomotor	0	-1	0
Question subtotals	3	1	1
Sensor subtotals	R1	R2	R3
Respiration	0	2	0
EDA	2	0	2
Cardio	2	-1	-2
Vasomotor	-1	0	1
Sensors	Sensor totals	- blank -	
Respiration	2		
EDA	4		
Cardio	-1		
Vasomotor	0		
Grand total	5		

The number of permutations and combination differs greatly for different CQT formats. Table 2 shows the number of unique permutations, un-ordered combinations and the number of different possible sensor scores for different CQT formation. The number of unique permutations can be thought of as the total number of different arrangements of scores that could possible occur on the score sheet as shown in Table. 1. The number of permutations can become quite large. For example: the sensor totals for a polygraph test with 20 stimulus trials (i.e., five repetitions of a question sequence that includes four relevant questions) will include 51 possible values (2*20+1=41) for which there are 3,486,784,401 unique permutations and 231 un-ordered combinations. In contrast, the sensor totals for a polygraph test with 6 stimulus trials (i.e., 3 repetitions with 2 relevant questions) will included 13 possible values from -6 to +6 for which there are 729 possible permutation with 28 un-ordered combinations of the number of +, - and 0 scores. The sensor total for a single relevant question in a multiple issue exam consisting of three repetitions of the test question sequence will include seven possible values (2*3+1=7) for which there are 27 unique permutations and 10 un-ordered combinations.

Because combinations are un-ordered (i.e., the location of the scores in the score sheet is mutable or changeable), the combinations of the number of +, - and 0 scores, and resulting sensor totals, will occur more frequently than others. Returning to the example of a CQT with three repetition of a question sequence that includes three relevant questions, with the 19,683 unique permutations of the possible scores +, - and 0, there is only one way to achieve a particular sensor score of +9 because all three repetitions of all three relevant questions must produce a sensor score of +1 to achieve this sensor score. Similarly, there is only one way to achieve a sensor score of -9. However, there are 3,139 different ways to achieve a sensor score of 0.

Table 2. Unique permutations (un-ordered combinations) and [different number of scores] for sensor totals.

	2 RQs	3 RQs	4 RQs	1 RQ (subtotal)
3 repetitions	729 (28) [13]	19,683 (55) [19]	531,441 (91) [25]	27 (10) [7]
4 repetitions	6561 (45) [17]	531,441 (91) [25]	43,046,721 (153) [33]	81 (15) [9]
5 repetitions	59,049 (66) [21]	14,348,907 (136) [31]	3,486,784,401 (231) [41]	243 (21) [11]

Calculation of the multinomial distributions for CQT scores requires the enumeration of all possible permutations and combinations. With very small data sets the permutations can be enumerated manually – sometimes even mentally when the data are very tiny. The advantages of larger data sets are several, and include smaller errors of measurement, greater precision, and reduced granularity of the numerical results. It will be simpler and more expedient to work with combinations, instead of permutations, whenever possible when the datasets become larger. This is the purpose of combinatorics and multinomial calculations.

To calculate multinomial reference table for sensor scores all that is necessary is to know the number of possible scores for each trial (+1, -1, 0), the probability weights associated with each possible score (.333, .333, .333)[17], and the number of k trials that will be used (number of relevant questions * number of repetitions). In this example, the number of relevant questions is three and the number of repetitions is also three, and so the number of k trials is 9. To calculate the number of ways to achieve each score it is first necessary to enumerate all 55 possible combinations of sensor scores (i.e., how many scores of +1, -1, and 0)[18], and then sum the scores for each combination and calculate the factorial for the result. Next it will be necessary to calculate the factorial for the product of the scores for each combination. Finally, we can divide the factorials of the sums by the factorials of the products. The result will be the number of ways to achieve each combination of scores. Each of the 55 combinations of scores must be summed after multiplying the number of each possible score by the value of the score, and it will be noticed that the sums will be similar for some combinations. By summing the number of ways for all similar sums we can determine the total number of ways to achieve each of the 19 possible sensor scores.

As stated earlier, there are 12 multinomial sensor distributions needed for the ESS, including 9 distributions for the sensor totals and 3 for the sensor subtotals. These distributions will describe the number of ways to achieve each of the possible sensor scores along with the proportion of ways to achieve each score compared to the distribution. Although mathematical concepts are themselves simple, the calculate of all the ways to achieve all the possible sensor totals and sensor subtotals for all polygraph test format could become a laborious and punishing task if one attempts to do this manually. Fortunately, programmable computers and statistical software are available today, and can reduce the arduousness of these calculations for us when we know the correct formula and procedure.

The *probability mass function*[19]*(pmf)* can be calculated by taking the total number number of ways to achieve each possible sensor score and dividing that by the total number of different possible sensor scores . The *pmf* of each sensor score will be used later as the probability weight for the possible sensor scores when calculating the multinomial distribution of the combined sensor scores. Table 3 shows the multinomial sensor table for a polygraph test with three repetitions of three relevant questions, including the number of ways to achieve each possible sensor score and the probability mass function for each score.

17 These probabilities are uniform because the multinomial distribution of sensor scores is calculated under the null-hypothesis that greater changes in physiology are not systematically loaded and are instead randomly distributed, resulting in uniform probabilities for their occurrence.

18 For example: if there are nine scores of +1 then there can be zero scores of -1 or 0. If there are eight scores of +1 then there can be one score of -1 and zero scores of 0, or one score of 0 and zero scores of -1. And so on.

19 The probability mass function describes the proportion of scores at each level in the distribution and can be used to estimate the likelihood of achieving a particular score under the null hypothesis.

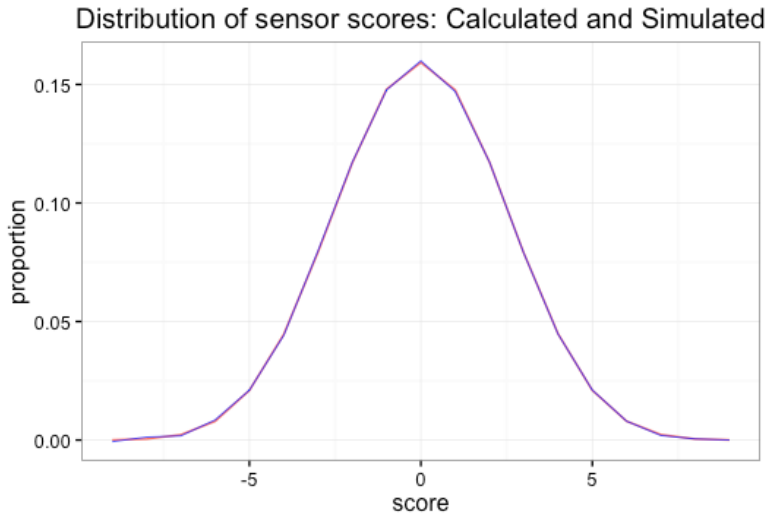
20 The probability mass function describes the proportion of scores at each level in the distribution and can be used to estimate the likelihood of achieving a particular score under the null hypothesis.

Table 3. Multinomial for one sensor total with three repetitions of three relevant questions.

score	ways	*pmf*
-9	1	.0001
-8	9	.0005
-7	45	.0023
-6	156	.0079
-5	414	.0210
-4	882	.0448
-3	1554	.0790
-2	2304	.1171
-1	2907	.1477
0	3139	.1595
1	2907	.1477
2	2304	.1171
3	1554	.0790
4	882	.0448
5	414	.0210
6	156	.0079
7	45	.0023
8	9	.0005
9	1	.0001

The *pmf* in Table 3 was compared to a simple Monte-Carlo simulation of 1 million iterations of a sample space consisting of n=9 random selections from the uniform distribution of [.333, .333, .333]. Each set or iteration of nine random selections resulted in a sum between -9 and +9, for which the results were aggregated over the 1 million iterations to determine he proportion of results that produced each of the possible integer scores between -9 and +9. Results of the comparison between the closed form multinomial calculation of this distribution and the Monte Carlo simulation are shown in Figure 1. There is virtually perfect concordance between the distributions, and differences are made visible only through the addition of a small amount of noise to one of the lines. The meaning of this is that the multinomial calculations can be considered correct because they can be verified with a simulation for which the intuition is simpler than the intuition for the combinatoric math.

Figure 1. Histogram comparing a Monte-Carlo simulation with the closed form multinomial sensor distribution for three repetitions of a sequence that includes three relevant questions.



Reference tables for sensor totals are shown in Appendices A-C for CQT formats consisting of five repetitions of question sequences including two, three and four relevant questions with three-position scoring. Appendix D shows the reference table for sensor scores for sensor *subtotals* with five repetitions of the relevant questions with three-position scoring.

Computation of the multinomial reference distribution for combined sensor scores

Because no classification can be made using an individual sensor total, the distribution of *combined sensor scores* will be of more useful to field examiners than the distribution of scores for individual sensors. The distribution of combined CQT sensor scores is the combination of the multinomial distributions of the scores for the individual sensors using the *pmf* for the sensor scores as the weighting coefficients.

One important aspect of the multinomial distribution of ESS scores is that EDA scores are weighted more than other sensor scores in attempt to approximate a more optimal statistical function than can be achieved by naïve weighting[21]. A consequence of this weighting is that sensor totals for ESS scores are immutable (i.e., scores cannot be interchanged for the sensors) and the multinomial distribution cannot be calculated using the computationally more convenient method involving un-ordered combinations of sensor scores. Instead the multinomial distribution of ESS scores must be completed using the more exhaustive method involving unique permutations. Fortunately, computers today, once they are given properly coded instructions, can perform this task easily.

The distribution of the combined sensor totals – in the form of a grand total score or question subtotal score – is also a multinomial distribution. For the distribution of combined sensor scores n is the number of possible scores that can result for each sensor (e.g., n = 19 possible scores ranging from -9 to +9 when there are three repetitions of a question sequence that includes three relevant questions) while k is the number of sensors included in the grand total or question subtotal

21 Naive in this usage (analytics and statistics) refers to an assumption, not necessarily supported by evidence, that we know nothing about the relative importance and contribution of the different sensor data to the final test result and precision of the test model.

scores (i.e.., k = 4 when using the respiration, EDA, cardio and vasomotor sensors). So, the distribution of the combined sensor totals will be determined by the number of stimulus trials and the number of sensors. The likelihood of each is expressed by the *pmf* for the sensor total (as shown in Table 3).

The *pmf* for the sensor total therefore gives us the probability weights for the calculation of the multinomial distribution for combined sensor scores. The distribution of combined sensor scores will have a range of 2*n+1 where n is the product of the number of sensors and the number of stimulus trials. Following the same example that was started earlier, the grand total score for an exam with three repetitions of a question sequence that includes three relevant questions and four recording sensors (respiration, EDA, cardio, and vasomotor) will have a range of 91 possible ESS scores. This is because the four recording sensors have a combined maximum of score of 5 for each stimulus trial, because ESS EDA scores are weighted more than the other sensor scores, and because (5*9=45) while 2*45+1=91. This multinomial distribution has 130,321 unique permutations.

Table 4 shows the multinomial distribution of ESS grand total scores for a polygraph with three repetitions of three relevant questions using the traditional array of sensors (respiration, EDA, cardio), including the range of possible scores, number of ways to achieve each score and the *pmf* for each CQT score. Also shown in Table 4 is the *cumulative distribution function*[22](*cdf*), *continuity corrected pmf*[23], along with the *odds*[24]. Finally, because point estimation is realistically less useful than interval estimation, the 5th percentile lower limit of the confidence interval was calculated for the odds using the Clopper-Pearson method[25] for the binomial (Agresti & Coull, 1998; Clopper & Pearson, 1934; Newcombe, 1998; Thulin, 2014). The lower limit of the Clopper-Pearson interval allows us to estimate the proportion of repeated experiments that can be expected to exceed a threshold if the present data are informing us correctly about reality. When used in the context of Bayesian decision-making, the Clopper-Pearson interval may be thought of as a *credible interval* that describes the level of confidence or uncertainty about a probabilistic and categorical conclusion[26,27].

22 The cumulative distribution function is the cumulative sum of the *pmf*.

23 The continuity correction is calculated by averaging all pairs of cell values. This has the effect of placing the location of the probability value in the middle of the cell instead of at the edges. This is analogous to sports betting wherein a bet is place on a point value such as 55.5 even though ½ points are never scored in reality. This allows a more straightforward discussion of the odds that the actual point score will be over or under the value.

24 Odds are always presented as relative to the value of 1 and indicate the likelihood of achieving a score of equal or more extreme value.

25 This interval estimation method was selected because it known to never have less than the nominal coverage area. In other words, the actual coverage rate for a 95% confidence interval may exceed 95% depending on the input parameters. Other interval estimation methods may have actual coverage rates that are less than nominal depending on the input.

24 Credible intervals in Bayesian analysis are analogous to confidence intervals in frequentist analysis, except that Bayesian analysis regards the criterion of interest as a probability and the data as fixed (i.e., it is the information available with which to calculate a conclusion). In contrast, frequentist confidence intervals regard the criterion as fixed (reality exist in only one form) and regards the data as a random variable for which the confidence interval describes the likelihood of obtaining the data.

25 For example: the lower limit of a Bayesian credible interval might tell us that we are 95% certain that the odds exceed a particular value.

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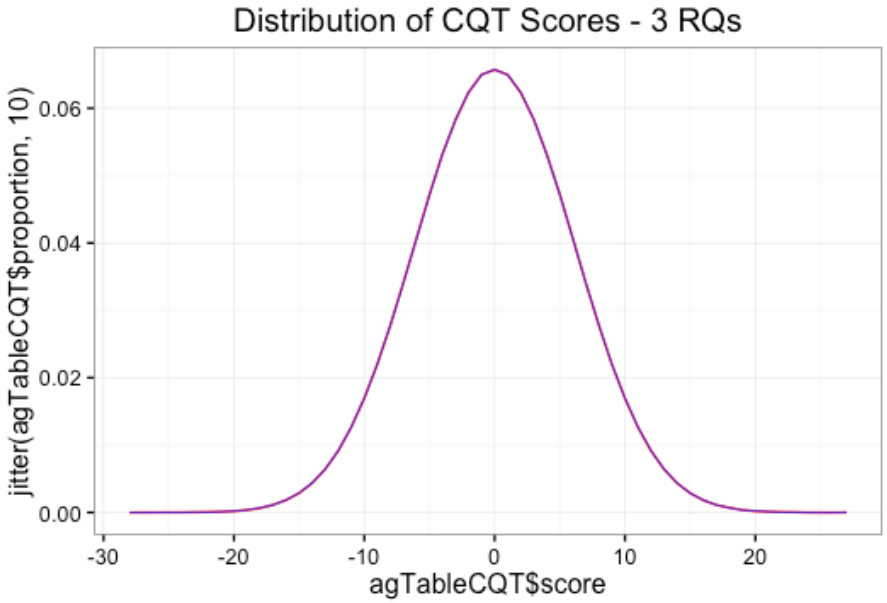
27 For example: the lower limit of a Bayesian credible interval might tell us that we are 95% certain that the odds exceed a particular value.

Table 4. Multinomial distribution of ESS grand total scores for three repetitions of a question sequenced that includes three relevant questions, with the number of ways to achieve each score, pmf, cdf, continuity-corrected cdf, odds and the 5th percentile lower limit of the Clopper-Pearson interval (extreme values are omitted).

score	ways	*pmf*	*cdf*	cdfContCor	odds	oddsLL05
-19	90	.0004	.0008	.0006	1712	11.27
-18	100	.0007	.0014	.0011	910.8	11.07
-17	108	.0011	.0025	.0020	503.7	10.73
-16	117	.0018	.0043	.0035	288.9	10.21
-15	124	.0029	.0072	.0058	171.4	9.47
-14	132	.0044	.0116	.0094	105.1	8.52
-13	138	.0064	.0179	.0148	66.37	8.45
-12	145	.0092	.0270	.0227	43.11	7.08
-11	150	.0127	.0394	.0336	28.73	6.28
-10	156	.0169	.0558	.0485	19.62	5.31
-9	160	.0220	.0771	.0681	13.69	4.35
-8	165	.0278	.1037	.0931	9.74	3.6
-7	168	.0341	.1360	.1242	7.05	2.9
-6	172	.0406	.1742	.1617	5.18	2.34
-5	174	.0471	.2181	.2057	3.86	1.87
-4	177	.0531	.2673	.2558	2.91	1.48
-3	178	.0584	.3211	.3115	2.21	1.17
-2	180	.0624	.3786	.3717	1.69	0.91
-1	180	.0649	.4386	.4350	1.3	0.71
0	181	.0658	.5000	.5000	1	0.55
1	180	.0649	.5614	.5650	1.3	0.71
2	180	.0624	.6214	.6283	1.69	0.91
3	178	.0584	.6789	.6885	2.21	1.17
4	177	.0531	.7327	.7442	2.91	1.48
5	174	.0471	.7819	.7943	3.86	1.87
6	172	.0406	.8258	.8383	5.18	2.34
7	168	.0341	.8640	.8758	7.05	2.9
8	165	.0278	.8963	.9069	9.74	3.6
9	160	.0220	.9229	.9319	13.69	4.35
10	156	.0169	.9442	.9515	19.62	5.31
11	150	.0127	.9607	.9664	28.73	6.28
12	145	.0092	.9731	.9773	43.11	7.08
13	138	.0064	.9821	.9852	66.37	8.45
14	132	.0044	.9885	.9906	105.1	8.52
15	124	.0029	.9928	.9942	171.4	9.47
16	117	.0018	.9957	.9966	288.9	10.21
17	108	.0011	.9975	.9980	503.7	10.73
18	100	.0007	.9986	.9989	910.8	11.07

The distribution shown in Table 4 was also compared a simple Monte-Carlo simulation of 1 million iterations. The Monte-Carlo simulation for ESS grand totals scores consisted of three sensor scores with a range of -9 to +9, which were sampled using the pmf from Table 3 as the sampling weighting coefficients. After multiplying the EDA scores by two, the sum for each case in the simulation was an integer between -36 to +36. Results for the 1 million simulations were aggregated for the number and proportion of iterations that produced each of the possible scores from -36 to +36. A comparison between the closed form multinomial calculation of this distribution and the Monte Carlo simulation is shown in Figure 2. There is again virtually perfect concordance between the distributions, and differences are made visible only through the addition of a small amount of noise to one of the lines.

Figure 2. Histogram comparing a Monte Carlo simulation of CQT scores with the closed form calculations of the distribution of ESS grand total scores three repetitions of a sequence that includes three relevant questions using the respiration, EDA, and cardio sensors.



Appendices I-K show the multinomial reference distributions for grand total scores of CQT question sequences that include two, three, and four relevant questions with the addition of the vasomotor sensor. Appendix L shows the multinomial reference distribution of CQT subtotal scores using the additional vasomotor sensor. These reference tables can serve as the likelihood function for naïve-Bayes classification methods, and may be of interest to those who wish the study or replicate the closed form multinomial calculation or to compare these results with simulation. Reference tables such at that shown in Table 4 and those in the appendices can be used to determine the cut-points for statistical significance prior to testing, and can also be used to the statistical values associated with a test result.

Determination of the cut-points using Table 4 is a matter of looking in the last column, for lower limit of the Clopper-Pearson interval for the odds, and then selecting the smallest value that is greater than 1 along with the largest value that is less than -1 and then looking in the first column to determine the cut-point for those odds. Table 4 shows that cut-points of +3 and -3 exceed the odds 1 and -1, meaning that scores that equal or

exceed these cutpoints are significantly likely to improve our knowledge if we begin by assuming we know nothing. Table 4 can also be used to determine the odds associated with a test score. To do this, simply locate the lest score in the left-most column and then select corresponding value from the last column for lower limit of the Clopper-Pearson interval where scores that exceed the values 1 and -1 are statistically significant at the .05 (one-tailed) level.

Reference tables such as that shown in Table 4 can reduce the need for procedurally intensive recalculation of a range of values that may be used repeatedly. For this reason, to reduce the computational workload for those who wish to study or work with the multinomial distributions for CQT scores, all ESS distributions of interest to polygraph formats in field practice use today can be calculated and saved in a series reference tables. Appendices E-G show the multinomial reference distributions for grand total scores of CQT question sequences that include two, three, and four relevant questions using the traditional array of respiration, EDA and cardio sensors. Appendix H shows the distribution of CQT subtotal scores along with multiplicity corrections[28] for two, three and four relevant questions[29] scores using the traditional sensor array. Appendices I-K show the multinomial reference distributions for grand total scores of CQT question sequences that include two, three, and four relevant questions with the addition of the vasomotor sensor. Appendix L shows the multinomial reference distribution of CQT subtotal scores with multiplicity correction for two, three and four relevant questions using the additional vasomotor sensor. These reference tables can serve as the likelihood function for naïve-Bayes classification methods, and may be of interest to those who wish the study or replicate the closed form multinomial calculation or to compare these results with simulation.

Comparison of Table 4, for three repetitions of a question sequence with three relevant questions, with the one in Appendix F, for five repetitions of a question sequence with three relevant questions, shows that although the statistical values may differ slightly the integer cutscores are identical. For this reason, the tables in Appendices E-L show only the calculations with five repetitions. Table 5 shows the ESS cutscores for statistical significance for event-specific polygraphs using the multinomial reference distributions with a one-tailed alpha = .05 for the lower limit of the Clopper-Pearson interval for both positive and negative classifications. Table 6 shows the ESS cutscores for subtotal scores of polygraphs interpreted with an assumption of independent criterion variance. Inspection of Tables 5 and 6 indicate that integer cutscores, determined by the lower limit of the Clopper-Pearson interval, are different when using the vasomotor sensor.

Table 5. ESS cutscores for grant total scores of event-specific exams using the multinomial reference distributions, using a one-tailed alpha = .05 for the lower limit of the Clopper-Pearson interval for positive and negative classifications (multiplicity-corrected subtotal cutscores in parenthesis).

	2 RQs	3 RQs	4RQs
Respiration, EDA, Cardio	+3 / -3 (-5)	+3 / -3 (-7)	+3 / -3 (-9)
Respiration, EDA, Cardio, Vasomotor	+3 / -3 (-5)	+3 / -3 (-7)	+3 / -3 (-9)

28 The multiplicity corrected odds were calculated as the exponent of the natural log of the subtotal odds divided by the number of relevant questions raised the sign value of the lowest subtotal score [exp(log(minSubtotal odds)/ numberRQs^minSubtotalSign].

29 In practice only the lowest subtotal score is used for classification though the multiplicity correction is calculated as a function of the number of relevant questions.

Table 5. ESS cutscores for subtotal scores of multiple-issue exams using the multinomial reference distributions, using a one-tailed alpha = .05 for the lower limit of the Clopper-Pearson interval without statistical correction for positive classifications and with statistical correction for negative classifications.

	2 RQs	3 RQs	4RQs
Respiration, EDA, Cardio	+2 / -3	+1 / -3	+1 / -3
Respiration, EDA, Cardio, Vasomotor	+2 / -3	+1 / -3	+1 / -3

Discussion

Counting things is an ancient human activity – perhaps the second, or third, or at least possibly among the top five of the oldest professions. Human progress and scientific progress can, in many ways, be thought of as a function of the improvements in our ability to count and quantify things. Combinatorics and multinomial calculations is simply a way to count things for which different possible combinations can exist.

To appreciate the importance of both theoretical and empirical probability distributions it is useful to remember the difference between the two. Empirical distributions are based on the observation of outcomes in a dataset for a population, sample or individual. On the other hand, theoretical probability distributions are based on a mathematical function that defines the distribution of values that could possibly occur within our theoretical understanding of the data. It will also be useful to remember that probability, in general, refers to the measurement of uncertainty and the chance of a given event occurring.

An overarching goal of science is to learn the general facts and principles about how reality and the universe works. But the volume of phenomena and data in the universe is far too great to work with, and so science often requires that we attempt to learn from sampling data. Inferential statistics and probability theory are intended to help us to determine what can be reasonably said about reality and the universe based on our analysis of the available data. In the context of the polygraph or other scientific test, statistics and probability theory is intended to help us determine what can be said about the test subject. Statistics is simply the mathematical language of science, because the goal of quantification related directly to the goal of scientific knowledge.

Inferential statistics begins by observing empirical data to determine the distribution of observed values, and ends by making reference to a theoretical distribution. Theoretical distributions are the core of statistical decision making because they allow us to make replicatable mathematical estimations about important phenomena for which we can obtain neither a physical measurement nor perfect deterministic observation. Use of the term theoretical should not be misunderstood as implying speculation or impracticality. Theoretical distributions sit at the core of inferential statistics because they allow us to make allow us to make rational and replicable estimates and predictions about any phenomena for which no deterministic solution or physical measurement can be achieved.

Slightly different interpretations may be suggested by the use of empirical and theoretical distributions. Use of empirical distributions in the original ESS involved a pragmatic assumption that the test result belonged to one of two groups if the test score satisfies a specified probability threshold that defines the boundary of statistical significance for the opposing group. There are two empirical distribution because we are seeking one of two classifications. Evaluation of CQT data using a theoretical distribution depends on a single distribution calculated under the null-hypothesis that CQT data are non-systemic or meaningless, occurring only randomly. Instead of comparing the test data to a statistical thresh-

old for the opposing classification, use of the theoretical distribution requires the comparison of the test data, and the hypothesis that the data are systematically loaded as a function of deception and truth-telling, against the null-hypothesis of random responses. An interpretation of statistical significance can be made when the test score satisfies a decision or classification boundary that can be specified in terms of a proportion or odds ratio that describes the loading of the numerical scores and physiological responses to test stimuli. Both empirical and theoretical distributions can be used in Bayesian classification and decision models.

Theoretical reference distributions for CQT scores may provide a in important and useful and generalizable probability estimate for ESS scores. Whereas empirical reference distributions depend heavily on the representativeness of a volume of available sampling data, theoretical distributions depend more directly on the validity of the operational or analytic theory – that data are loaded systematically as a function of deception or truth-telling. The value of an analytic and operational theory for the comparison question test is that answers to questions about validity rely more on observations about real-world test performance than upon understanding the exact psychological or physiological mechanism that explain why the test works – though questions about psychological and physiological constructs will remain important areas for scientific inquiry and research.

Theoretical distributions rely on the mathematical expression, and mathematical proof, of our understanding of reality, and can be compared with the practical observation of existing empirical data. Effectiveness of any interpretation of the practical categorical meaning of the theoretical probability outcomes of polygraph test results will rest on both the correctness of mathematical expressions, and the correctness of the theoretical assumption that responses to different types of test stimuli do, or do not, vary as a function of truth-telling or deception to the target questions. That non-systematic and meaningless data can be characterized by random numbers is well-proven to the point where it is accepted as axiomatic.

Summary

This project involved the calculation of theoretical reference distributions for ESS scores of CQT formats that consist of up to five repetitions of a question series that can include two, three, or four relevant questions, in addition to the calculation of the reference distributions for subtotal scores. The theoretical distribution of ESS scores for CQT data will take the form of a discrete multinomial distribution determined by the number of relevant questions, the number of repetitions of the test stimuli, and the number of physiological recording sensors. In probability theory, multinomial distributions provide the probability of observing any particular combination of items for a set of possible outcomes that are repeated multiple times.

Computation of the multinomial theoretical distribution for CQT scores begins with the calculation of the multinomial distribution of scores for the individual physiological recording sensors. The multinomial sensor distribution is a function of the number of possible outcomes for each stimulus trials. The number of stimulus presentations for individual sensors is a function of the number of relevant questions and the number of repetitions. Field practices require the use of three to five repetitions of the test questions. CQT formats for event-specific polygraphs can include two to four relevant target stimuli. Test formats that are interpreted with an assumption of independent criterion variance can also include two to four target stimuli. The distribution of CQT test scores is the multinomial distribution of the combined multinomial distributions for the array of recording sensors. Recording sensors traditionally include the respiration, EDA and cardio sensors and can also include a vasomotor sensor.

Two versions of the multinomial reference data were calculated, using the traditional array of respiration, EDA and cardio sensors, and also with the addition of a vasomotor sensor. This represents an important advancement to the polygraph test because previously published scoring algorithms and previously published empirical reference tables did not include vasomotor sensor data. The addition of new sensor data to existing testing and analysis methods is a non-trivial

endeavor.

Closed form calculations of the multinomial reference distributions were compared graphically with the results of Monte-Carlo simulation, and showed the two methods can be expected to produce virtually identical distributional results. A general description of the calculation of the multinomial reference distributions is provided for replication and for readers who wish to develop their intuition and understanding of multinomial calculations and multinomial distributions.

Theoretical distributions can be useful to make replicable frequentist inferences about empirical data, and can also be useful as a likelihood function for Bayesian analysis. Whereas empirical distributions provide a basis for probabilistic estimation that an observed test data would be produce by a member of the population represented by an empirical reference distribution, theoretical distributions can provide a basis for a likelihood function in Bayesian analysis. Bayes analysis[30] permits the inference of the cause of the data – which a more direct and intuitive conclusion about the probability that a polygraph test result was produced by a deceptive or truthful person.

The purpose of any scoring system is twofold. First it should attempt to optimize the effectiveness of the classification model and interpretation of test results[31]. Secondly, it should help to enable the computation of reasonable estimates of the probability that the classification is correct or incorrect. It is expected that any valid scoring or analytic method is supported by theoretical assumptions that can be clearly stated and expressed mathematically.

A scientific theory is an expression of our assumptions or conclusion of the universe, or some aspect of it, and tells us which aspects of our observation of the universe can be understood in a manner that is consistent with our understanding of other observations and other assumptions. The mathematical representation of a theory allows us to more reliably predict the consequences or results that can be expected to follow from the theory's assumption. An invalid theory, or rather an invalid hypothesis, will be useless. No amount of pretending will make an invalid hypothesis useful, and the only way to retain an invalid theory will be to disconnect from reality and engage or intellect in the practice of pseudoscience. If the analytic theory of the polygraph is correct, then a computational and intuitive understand of these multinomial reference distributions may be of some usefulness to both scientists and field practitioners.

An advantage of the theoretical distribution and a Bayesian approach is that the replacement or addition of evaluation features and recording sensors can be a simple matter when naïve assumptions are made. Use of theoretical distribution may also offer potential advantages such as robustness against group difference, and a simpler route towards the study and understanding of the empirical and practical value of the polygraph test result. Increasing the awareness and competence of polygraph professionals in the theory and application of theoretical reference distributions may lead to improved general understanding of the scientific meaning of polygraph test results, and may help to prevent incorrect interpretations and unrealistic expectations for deterministic perfection from probabilistic test results.

Availability of a theoretical distribution for ESS scores may help to advance the practical and empirical validity of the polygraph test by relieving concerns about the representativeness of available sampling data. This is because, unlike empirical distributions, theoretical distributions are mathematical abstractions that can be robust against some group differences as long as the basic analytic

30 Bayesian analysis requires three elements: some data, a prior probability, and a likelihood function to apply to the test data in order to update the prior probability to a posterior probability. Prior probabilities are an important aspect of Bayesian analysis, but are not addressed in this manuscript.

31 Tests can be optimized for a number of purposes, according to operational priorities and mission objectives, including: test sensitivity, test specificity, false-positive errors, false-negative errors, positive predictive value, negative predictive value, or any other metric for test precision.

theory remains valid for different groups.

Finally, this project does not include an analysis of empirical data. It is limited to the mathematical calculation and simulation of the theoretical distributions of CQT scores under the null-hypothesis to the operational or analytic theory of the polygraph test. Empirical evidence will still be required to demonstrate that classification into the criterion categories of guilt or innocence corresponds in the expected ways with differences in response to different types of test stimuli. Ultimately, the effectiveness of a classification method will always remain an empirical concern - especially when the results may play a role in human decision-making. It is hoped that the publication of this description of the multinomial reference distributions, and corresponding reference tables for CQT scores, will help to advance the polygraph profession through the development of more objective, accountable and replicable analysis models. Of course, effective field polygraph examination may still continue to be subject to constraints and requirements around the test administration. And, as always, addition research is recommended.

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Appendix A.

Multinomial Reference Distribution for Sensor Totals with 5 Repetitions of 2 Relevant Questions

score	ways	pmf
-10	1	<.0001
-9	10	.0002
-8	55	.0009
-7	210	.0036
-6	615	.0104
-5	1452	.0246
-4	2850	.0483
-3	4740	.0803
-2	6765	.1146
-1	8350	.1414
0	8953	.1516
1	8350	.1414
2	6765	.1146
3	4740	.0803
4	2850	.0483
5	1452	.0246
6	615	.0104
7	210	.0036
8	55	.0009
9	10	.0002
10	1	<.0001

Appendix B.

Multinomial Reference Distribution for Sensor Totals with 5 Repetitions of 3 Relevant Questions

score	ways	pmf
-15	1	<.0001
-14	15	<.0001
-13	120	<.0001
-12	665	<.0001
-11	2835	.0002
-10	9828	.0007
-9	28665	.0020
-8	71955	.0050
-7	157950	.0110
-6	306735	.0214
-5	531531	.0370
-4	827190	.0576
-3	1161615	.0810
-2	1477035	.1029
-1	1704510	.1188
0	1787607	.1246
1	1704510	.1188
2	1477035	.1029
3	1161615	.0810
4	827190	.0576
5	531531	.0370
6	306735	.0214
7	157950	.0110
8	71955	.0050
9	28665	.0020
10	9828	.0007
11	2835	.0002
12	665	<.0001

13	120	<.0001
14	15	<.0001
15	1	<.0001

Appendix C.

Multinomial Reference Distribution for Sensor Totals with 5 Repetitions of 4 Relevant Questions

score	ways	*pmf*
-20	1	<.0001
-19	20	<.0001
-18	210	<.0001
-17	1520	<.0001
-16	8455	<.0001
-15	38304	<.0001
-14	146490	<.0001
-13	484500	.0001
-12	1409895	.0004
-11	3656360	.0010
-10	8533660	.0024
-9	18062160	.0052
-8	34880770	.0100
-7	61757600	.0177
-6	100640340	.0289
-5	151419816	.0434
-4	210859245	.0605
-3	272290140	.0781
-2	326527350	.0936
-1	363985680	.1044
0	377379369	.1082
1	363985680	.1044
2	326527350	.0936
3	272290140	.0781
4	210859245	.0605
5	151419816	.0434
6	100640340	.0289
7	61757600	.0177
8	34880770	.0100
9	18062160	.0052
10	8533660	.0024
11	3656360	.0010
12	1409895	.0004
13	484500	.0001
14	146490	<.0001
15	38304	<.0001
16	8455	<.0001
17	1520	<.0001
18	210	<.0001
19	20	<.0001
20	1	<.0001

Appendix D.

Multinomial Reference Distribution for Sensor Subtotals with 5 Repetitions of the Question Sequence

score	ways	pmf
-5	1	.0041
-4	5	.0206
-3	15	.0617
-2	30	.1235
-1	45	.1852
0	51	.2099
1	45	.1852
2	30	.1235
3	15	.0617
4	5	.0206
5	1	.0041

Appendix E.

Multinomial Reference Distribution of ESS Grand Totals with 5 Repetitions of 2 Relevant Questions

score	ways	pmf	cdf	cdfContCor	odds	oddsLL05
-19	130	.0006*	.0014	.0011	903.2	12.29
-18	140	.0010	.0024	.0019	517.3	11.91
-17	148	.0016	.0041	.0033	305.8	11.33
-16	157	.0025	.0066	.0053	186.2	10.53
-15	164	.0038	.0103	.0085	116.7	9.51
-14	172	.0055	.0158	.0131	75.11	9.51
-13	178	.0077	.0234	.0198	49.57	8.04
-12	185	.0106	.0339	.0290	33.49	7.22
-11	190	.0142	.0477	.0415	23.13	6.18
-10	196	.0184	.0656	.0578	16.3	5.12
-9	200	.0233	.0880	.0788	11.69	4.29
-8	205	.0287	.1155	.1049	8.53	3.5
-7	208	.0345	.1482	.1367	6.32	2.82
-6	212	.0404	.1862	.1743	4.74	2.28
-5	214	.0462	.2293	.2177	3.6	1.84
-4	217	.0515	.2771	.2665	2.75	1.47
-3	218	.0561	.3290	.3202	2.12	1.16
-2	220	.0595	.3842	.3778	1.65	0.92
-1	220	.0617	.4415	.4382	1.28	0.72
0	221	.0625	.5000	.5000	1	0.57
1	220	.0617	.5585	.5618	1.28	0.72
2	220	.0595	.6158	.6222	1.65	0.92
3	218	.0561	.6710	.6798	2.12	1.16
4	217	.0515	.7229	.7335	2.75	1.47
5	214	.0462	.7707	.7823	3.6	1.84
6	212	.0404	.8138	.8257	4.74	2.28
7	208	.0345	.8518	.8633	6.32	2.82
8	205	.0287	.8845	.8951	8.53	3.5
9	200	.0233	.9120	.9212	11.69	4.29
10	196	.0184	.9344	.9422	16.3	5.12
11	190	.0142	.9523	.9586	23.13	6.18
12	185	.0106	.9661	.9710	33.49	7.22
13	178	.0077	.9766	.9802	49.57	8.04
14	172	.0055	.9842	.9869	75.11	9.51
15	164	.0038	.9897	.9915	116.7	9.51
16	157	.0025	.9934	.9947	186.2	10.53
17	148	.0016	.9959	.9967	305.8	11.33
18	140	.0010	.9976	.9981	517.3	11.91
19	130	.0006*	.9986	.9989	903.2	12.29
* extreme values ommitted						

Appendix F.

Multinomial Reference Distribution of ESS Grand Totals with 5 Repetitions of 3 Relevant Questions

score	ways	*pmf*	*cdf*	cdfContCor	odds	oddsLL05
-22	360	.0009*	.0025	.0021	483	17.34
-21	370	.0013	.0038	.0031	317.7	16.38
-20	381	.0018	.0056	.0047	212.8	15.18
-18	400	.0035	.0115	.0098	100.6	13.93
-17	408	.0047	.0162	.0139	70.88	12.03
-16	417	.0062	.0223	.0193	50.72	11.12
-15	424	.0080	.0301	.0264	36.84	9.86
-14	432	.0102	.0402	.0355	27.14	8.48
-13	438	.0128	.0526	.0471	20.25	7.15
-12	445	.0157	.0680	.0613	15.31	6.13
-11	450	.0190	.0864	.0787	11.7	5.15
-10	456	.0226	.1081	.0996	9.04	4.27
-9	460	.0264	.1335	.1242	7.05	3.57
-8	465	.0304	.1624	.1526	5.55	2.99
-7	468	.0343	.1950	.1850	4.4	2.48
-6	472	.0382	.2310	.2213	3.52	2.05
-5	474	.0418	.2703	.2613	2.83	1.69
-4	477	.0449	.3125	.3046	2.28	1.4
-3	478	.0476	.3571	.3508	1.85	1.15
-2	480	.0495	.4036	.3992	1.51	0.95
-1	480	.0508	.4515	.4492	1.23	0.77
0	481	.0512	.5000	.5000	1	0.63
1	480	.0508	.5485	.5508	1.23	0.77
2	480	.0495	.5964	.6008	1.51	0.95
3	478	.0476	.6429	.6492	1.85	1.15
4	477	.0449	.6875	.6954	2.28	1.4
5	474	.0418	.7297	.7387	2.83	1.69
6	472	.0382	.7690	.7787	3.52	2.05
7	468	.0343	.8050	.8150	4.4	2.48
8	465	.0304	.8376	.8474	5.55	2.99
9	460	.0264	.8665	.8758	7.05	3.57
10	456	.0226	.8919	.9004	9.04	4.27
11	450	.0190	.9136	.9213	11.7	5.15
12	445	.0157	.9321	.9387	15.31	6.13
13	438	.0128	.9474	.9529	20.25	7.15
14	432	.0102	.9598	.9645	27.14	8.48
15	424	.0080	.9699	.9736	36.84	9.86
16	417	.0062	.9778	.9807	50.72	11.12
17	408	.0047	.9838	.9861	70.88	12.03
18	400	.0035	.9885	.9902	100.6	13.93
19	390	.0025	.9919	.9932	145.1	13.75
20	381	.0018	.9944	.9953	212.8	15.18
21	370	.0013	.9962	.9969	317.7	16.38
22	360	.0009*	.9975	.9979	483	17.34
* extreme values omitted						

Appendix G.

Multinomial Reference Distribution of ESS Grand Totals with 5 Repetitions of 4 Relevant Questions

score	ways	pmf	cdf	cdfContCor	odds	oddsLL05
-25	684	.0009*	.0029	.0024	407.7	21.86
-24	697	.0012	.0041	.0035	286.3	20.43
-23	708	.0016	.0057	.0049	203.6	18.75
-22	720	.0022	.0078	.0068	146.6	19.36
-21	730	.0028	.0107	.0093	106.9	17.1
-20	741	.0037	.0143	.0125	78.83	16.24
-19	750	.0047	.0190	.0167	58.81	13.85
-18	760	.0059	.0248	.0221	44.36	12.46
-17	768	.0074	.0321	.0287	33.81	10.92
-16	777	.0091	.0411	.0370	26.04	9.4
-15	784	.0110	.0519	.0471	20.24	8.24
-14	792	.0132	.0649	.0592	15.88	7.08
-13	798	.0156	.0801	.0737	12.57	6.01
-12	805	.0183	.0978	.0907	10.02	5.14
-11	810	.0211	.1182	.1104	8.06	4.36
-10	816	.0240	.1413	.1330	6.52	3.71
-9	820	.0270	.1671	.1585	5.31	3.14
-8	825	.0300	.1957	.1870	4.35	2.65
-7	828	.0329	.2270	.2185	3.58	2.24
-6	832	.0356	.2608	.2527	2.96	1.9
-5	834	.0381	.2968	.2895	2.45	1.6
-4	837	.0402	.3349	.3286	2.04	1.35
-3	838	.0420	.3746	.3697	1.71	1.14
-2	840	.0433	.4157	.4123	1.43	0.96
-1	840	.0441	.4576	.4559	1.19	0.81
0	841	.0444	.5000	.5000	1	0.68
1	840	.0441	.5424	.5441	1.19	0.81
2	840	.0433	.5843	.5877	1.43	0.96
3	838	.0420	.6254	.6303	1.71	1.14
4	837	.0402	.6651	.6714	2.04	1.35
5	834	.0381	.7032	.7105	2.45	1.6
6	832	.0356	.7392	.7473	2.96	1.9
7	828	.0329	.7730	.7815	3.58	2.24
8	825	.0300	.8043	.8130	4.35	2.65
9	820	.0270	.8329	.8415	5.31	3.14
10	816	.0240	.8587	.8670	6.52	3.71
11	810	.0211	.8818	.8896	8.06	4.36
12	805	.0183	.9022	.9093	10.02	5.14
13	798	.0156	.9199	.9263	12.57	6.01
14	792	.0132	.9351	.9408	15.88	7.08
15	784	.0110	.9481	.9529	20.24	8.24
16	777	.0091	.9589	.9630	26.04	9.4
17	768	.0074	.9679	.9713	33.81	10.92
18	760	.0059	.9752	.9780	44.36	12.46
19	750	.0047	.9810	.9833	58.81	13.85
20	741	.0037	.9857	.9875	78.83	16.24
21	730	.0028	.9894	.9907	106.9	17.1
22	720	.0022	.9922	.9932	146.6	19.36
23	708	.0016	.9943	.9951	203.6	18.75
24	697	.0012	.9959	.9965	286.3	20.43
25	684	.0009*	.9971	.9976	407.7	21.86
* extreme values omitted						

Appendix H.

Multinomial Reference Distribution of ESS Subtotals with 5 Repetitions

score	ways	*pmf*	*cdf*	Cdf ContCor	odds	odds 2RQs	odds 3RQs	odds 4RQs	odds LL05	odds2RQLL05	odds3RQLL05	odds4RQLL05
-14	16	.0005*	.0007	.0005	1970	44.38	12.54	6.66	6.11	4.19	2.85	2.1
-13	20	.0011	.0018	.0013	778.5	27.9	9.2	5.28	6.01	4	2.46	1.8
-12	25	.0022	.0040	.0029	339.5	18.43	6.98	4.29	5.82	3.56	2.17	1.55
-11	30	.0042	.0082	.0062	161.1	12.69	5.44	3.56	5.46	2.87	1.84	1.35
-10	36	.0074	.0156	.0120	82.2	9.07	4.35	3.01	4.92	2.44	1.57	1.18
-9	40	.0122	.0275	.0219	44.7	6.69	3.55	2.59	4.2	2.11	1.34	1.05
-8	45	.0188	.0458	.0375	25.68	5.07	2.95	2.25	3.86	1.74	1.17	0.93
-7	48	.0272	.0719	.0607	15.48	3.94	2.49	1.98	3.23	1.47	1.02	0.83
-6	52	.0374	.1072	.0933	9.72	3.12	2.13	1.77	2.56	1.22	0.89	0.75
-5	54	.0487	.1524	.1367	6.32	2.51	1.85	1.59	2.02	1.02	0.78	0.68
-4	57	.0602	.2075	.1914	4.23	2.06	1.62	1.43	1.53	0.86	0.69	0.62
-3	58	.0710	.2717	.2571	2.89	1.7	1.42	1.3	1.15	0.72	0.61	0.56
-2	60	.0798	.3434	.3322	2.01	1.42	1.26	1.19	0.84	0.61	0.54	0.51
-1	60	.0855	.4203	.4143	1.41	1.19	1.12	1.09	0.61	0.51	0.48	0.47
0	61	.0875	.5000	.5000	1	1	1	1	0.43	0.43	0.43	0.43
1	60	.0855	.5797	.5857	1.41	2	2.83	4	0.61	0.84	1.13	1.49
2	60	.0798	.6566	.6678	2.01	4.04	8.12	16.32	0.84	1.47	2.35	3.33
3	58	.0710	.7283	.7429	2.89	8.35	24.13	69.71	1.15	2.4	3.75	4.75
4	57	.0602	.7925	.8086	4.23	17.85	75.4	318.5	1.53	3.5	4.83	5.79
5	54	.0487	.8476	.8633	6.32	39.91	252.2	1593	2.02	4.05	5.7	6.1
6	52	.0374	.8928	.9067	9.72	94.48	918.4	8927	2.56	5.05	6.04	6.16
7	48	.0272	.9281	.9393	15.48	239.6	3710	57430	3.23	5.68	6.14	6.17
8	45	.0188	.9542	.9625	25.68	659.7	16940	435200	3.86	5.99	6.17	6.18
9	40	.0122	.9725	.9781	44.7	1998	89300	3991000	4.2	6.11	6.18	6.18
10	36	.0074	.9844	.9880	82.2	6756	555300	4.57E+07	4.92	6.16	6.18	6.18
11	30	.0042	.9918	.9938	161.1	25940	4178000	6.73E+08	5.46	6.17	6.18	6.18
12	25	.0022	.9960	.9971	339.5	115300	3.91E+07	1.33E+10	5.82	6.18	6.18	6.18
13	20	.0011	.9982	.9987	778.5	606100	4.72E+08	3.67E+11	6.01	6.18	6.18	6.18
14	16	.0005*	.9993	.9995	1970	3.88E+06	7.64E+09	1.51E+13	6.11	6.18	6.18	6.18
* extreme values omitted												

Appendix I.

Multinomial Reference Distribution for ESS Grand Totals with 5 Repetitions of 2 Relevant Questions with PLE Sensor

score	ways	*pmf*	*cdf*	cdfContCor	odds	oddsLL05
-20	2481	.0008*	.0019	.0015	659.2	15.03
-19	2645	.0012	.0031	.0025	402.9	14.37
-18	2808	.0018	.0048	.0039	252.4	13.47
-17	2967	.0026	.0074	.0061	161.9	12.31
-16	3123	.0038	.0112	.0093	106.2	10.94
-15	3273	.0053	.0164	.0139	71.17	10.8
-14	3418	.0072	.0235	.0201	48.68	9.9
-13	3555	.0097	.0331	.0286	33.94	8.1
-12	3685	.0127	.0455	.0398	24.1	6.95
-11	3805	.0162	.0613	.0543	17.4	6.03
-10	3916	.0203	.0809	.0727	12.76	5.05
-9	4015	.0248	.1047	.0953	9.49	4.14
-8	4105	.0297	.1330	.1226	7.15	3.4
-7	4183	.0347	.1659	.1549	5.45	2.77
-6	4252	.0398	.2034	.1923	4.2	2.25
-5	4309	.0447	.2452	.2346	3.26	1.82
-4	4357	.0491	.2910	.2815	2.55	1.47
-3	4393	.0528	.3401	.3323	2.01	1.18
-2	4420	.0556	.3919	.3863	1.59	0.95
-1	4435	.0574	.4455	.4426	1.26	0.76
0	4441	.0580	.5000	.5000	1	0.6
1	4435	.0574	.5545	.5574	1.26	0.76
2	4420	.0556	.6081	.6137	1.59	0.95
3	4393	.0528	.6599	.6677	2.01	1.18
4	4357	.0491	.7090	.7185	2.55	1.47
5	4309	.0447	.7548	.7654	3.26	1.82
6	4252	.0398	.7966	.8077	4.2	2.25
7	4183	.0347	.8341	.8451	5.45	2.77
8	4105	.0297	.8670	.8774	7.15	3.4
9	4015	.0248	.8953	.9047	9.49	4.14
10	3916	.0203	.9191	.9273	12.76	5.05
11	3805	.0162	.9387	.9457	17.4	6.03
12	3685	.0127	.9545	.9602	24.1	6.95
13	3555	.0097	.9669	.9714	33.94	8.1
14	3418	.0072	.9765	.9799	48.68	9.9
15	3273	.0053	.9836	.9861	71.17	10.8
16	3123	.0038	.9888	.9907	106.2	10.94
17	2967	.0026	.9926	.9939	161.9	12.31
18	2808	.0018	.9952	.9961	252.4	13.47
19	2645	.0012	.9969	.9975	402.9	14.37
20	2481	.0008*	.9981	.9985	659.2	15.03
* extreme values omitted						

Appendix J.

Multinomial Reference Distribution for ESS Grand Totals with 5 Repetitions of 3 Relevant Questions with PLE Sensor

score	ways	*pmf*	*cdf*	cdfContCor	odds	oddsLL05
-24	9915	.0008*	.0023	.0019	518.7	21.4
-23	10248	.0011	.0034	.0028	352.2	20.18
-22	10572	.0015	.0048	.0041	242.7	18.69
-21	10888	.0020	.0069	.0059	169.7	16.95
-20	11193	.0027	.0096	.0082	120.4	17.25
-19	11488	.0036	.0132	.0114	86.55	14.98
-18	11770	.0047	.0179	.0156	63.05	13.98
-17	12040	.0061	.0239	.0210	46.52	12.51
-16	12295	.0077	.0316	.0280	34.75	10.89
-15	12536	.0097	.0411	.0367	26.26	9.29
-14	12760	.0119	.0527	.0475	20.06	8.05
-13	12970	.0144	.0668	.0607	15.49	6.83
-12	13163	.0172	.0835	.0765	12.07	5.74
-11	13342	.0202	.1031	.0953	9.5	4.85
-10	13504	.0235	.1257	.1172	7.53	4.06
-9	13652	.0269	.1514	.1424	6.02	3.41
-8	13783	.0303	.1803	.1710	4.85	2.85
-7	13900	.0336	.2122	.2030	3.93	2.39
-6	14000	.0369	.2471	.2383	3.2	2
-5	14086	.0398	.2847	.2766	2.62	1.67
-4	14155	.0424	.3247	.3177	2.15	1.39
-3	14210	.0446	.3667	.3611	1.77	1.16
-2	14248	.0461	.4102	.4064	1.46	0.97
-1	14272	.0471	.4548	.4529	1.21	0.8
0	14279	.0475	.5000	.5000	1	0.67
1	14272	.0471	.5452	.5471	1.21	0.8
2	14248	.0461	.5898	.5936	1.46	0.97
3	14210	.0446	.6333	.6389	1.77	1.16
4	14155	.0424	.6753	.6823	2.15	1.39
5	14086	.0398	.7153	.7234	2.62	1.67
6	14000	.0369	.7529	.7617	3.2	2
7	13900	.0336	.7878	.7970	3.93	2.39
8	13783	.0303	.8197	.8290	4.85	2.85
9	13652	.0269	.8486	.8576	6.02	3.41
10	13504	.0235	.8743	.8828	7.53	4.06
11	13342	.0202	.8969	.9047	9.5	4.85
12	13163	.0172	.9165	.9235	12.07	5.74
13	12970	.0144	.9332	.9393	15.49	6.83
14	12760	.0119	.9473	.9525	20.06	8.05
15	12536	.0097	.9590	.9633	26.26	9.29
16	12295	.0077	.9685	.9720	34.75	10.89
17	12040	.0061	.9761	.9790	46.52	12.51
18	11770	.0047	.9821	.9844	63.05	13.98
19	11488	.0036	.9868	.9886	86.55	14.98
20	11193	.0027	.9904	.9918	120.4	17.25
21	10888	.0020	.9931	.9941	169.7	16.95
22	10572	.0015	.9952	.9959	242.7	18.69
23	10248	.0011	.9966	.9972	352.2	20.18
24	9915	.0008*	.9977	.9981	518.7	21.4
* extreme values omitted						

Appendix K.

Multinomial Reference Distribution for ESS Grand Totals with 5 Repetitions of 4 Relevant Questions with PLE Sensor

score	ways	*pmf*	*cdf*	cdfContCor	odds	oddsLL05
-27	25602	.0008*	.0029	.0025	401.4	26.27
-26	26128	.0011	.0040	.0034	290	24.39
-25	26638	.0014	.0054	.0047	211.8	22.26
-24	27133	.0019	.0073	.0064	156.3	22.92
-23	27610	.0024	.0097	.0085	116.5	20.21
-22	28070	.0031	.0128	.0113	87.72	19.23
-21	28510	.0039	.0167	.0148	66.68	16.45
-20	28931	.0049	.0215	.0192	51.17	14.88
-19	29330	.0060	.0274	.0246	39.62	13.13
-18	29710	.0073	.0347	.0313	30.95	11.81
-17	30068	.0088	.0434	.0394	24.38	10.08
-16	30407	.0106	.0538	.0491	19.36	8.74
-15	30724	.0125	.0660	.0607	15.49	7.62
-14	31022	.0145	.0802	.0742	12.48	6.47
-13	31298	.0168	.0965	.0899	10.12	5.54
-12	31555	.0192	.1151	.1079	8.27	4.76
-11	31790	.0217	.1360	.1284	6.79	4.06
-10	32006	.0242	.1594	.1514	5.61	3.48
-9	32200	.0268	.1851	.1770	4.65	2.97
-8	32375	.0293	.2131	.2051	3.88	2.54
-7	32528	.0318	.2434	.2356	3.24	2.16
-6	32662	.0340	.2757	.2685	2.72	1.85
-5	32774	.0361	.3100	.3035	2.3	1.58
-4	32867	.0378	.3459	.3404	1.94	1.35
-3	32938	.0392	.3832	.3789	1.64	1.15
-2	32990	.0403	.4215	.4185	1.39	0.98
-1	33020	.0409	.4606	.4591	1.18	0.83
0	33031	.0411	.5000	.5000	1	0.71
1	33020	.0409	.5394	.5409	1.18	0.83
2	32990	.0403	.5785	.5815	1.39	0.98
3	32938	.0392	.6168	.6211	1.64	1.15
4	32867	.0378	.6541	.6596	1.94	1.35
5	32774	.0361	.6900	.6965	2.3	1.58
6	32662	.0340	.7243	.7315	2.72	1.85
7	32528	.0318	.7566	.7644	3.24	2.16
8	32375	.0293	.7869	.7949	3.88	2.54
9	32200	.0268	.8149	.8230	4.65	2.97
10	32006	.0242	.8406	.8486	5.61	3.48
11	31790	.0217	.8640	.8716	6.79	4.06
12	31555	.0192	.8849	.8921	8.27	4.76
13	31298	.0168	.9035	.9101	10.12	5.54
14	31022	.0145	.9198	.9258	12.48	6.47
15	30724	.0125	.9340	.9393	15.49	7.62
16	30407	.0106	.9462	.9509	19.36	8.74
17	30068	.0088	.9566	.9606	24.38	10.08
18	29710	.0073	.9653	.9687	30.95	11.81
19	29330	.0060	.9726	.9754	39.62	13.13
20	28931	.0049	.9785	.9808	51.17	14.88
21	28510	.0039	.9834	.9852	66.68	16.45
22	28070	.0031	.9872	.9887	87.72	19.23
23	27610	.0024	.9903	.9915	116.5	20.21
24	27133	.0019	.9927	.9936	156.3	22.92
25	26638	.0014	.9946	.9953	211.8	22.26
26	26128	.0011	.9960	.9966	290	24.39
27	25602	.0008*	.9971	.9975	401.4	26.27
* extreme values omitted						

Appendix L.

Multinomial Reference Distribution of ESS Subtotals with 5 Repetitions with PLE Sensor

score	ways	*pmf*	*cdf*	Cdf ContCor	odds	odds 2RQs	odds 3RQs	odds 4RQs	odds LL05	odds2RQLL05	odds3RQLL05	odds4RQLL05
-15	161	.0005*	.0009	.0007	1517	38.94	11.49	6.24	7.71	5.36	3.32	2.24
-14	200	.0011	.0020	.0015	682.2	26.12	8.8	5.11	7.56	4.48	2.84	1.98
-13	243	.0021	.0041	.0030	328.4	18.12	6.9	4.26	7.27	4	2.42	1.73
-12	287	.0037	.0077	.0059	168	12.96	5.52	3.6	6.79	3.44	2.07	1.51
-11	333	.0062	.0139	.0109	90.88	9.53	4.5	3.09	6.1	2.91	1.81	1.35
-10	378	.0099	.0236	.0190	51.67	7.19	3.73	2.68	5.22	2.5	1.56	1.2
-9	423	.0150	.0383	.0315	30.72	5.54	3.13	2.35	4.84	2.08	1.37	1.07
-8	465	.0216	.0592	.0500	19.01	4.36	2.67	2.09	4.11	1.76	1.19	0.96
-7	505	.0297	.0875	.0758	12.19	3.49	2.3	1.87	3.3	1.49	1.05	0.87
-6	540	.0389	.1242	.1104	8.06	2.84	2.01	1.69	2.66	1.26	0.93	0.79
-5	571	.0489	.1697	.1546	5.47	2.34	1.76	1.53	2.06	1.06	0.83	0.72
-4	595	.0588	.2236	.2087	3.79	1.95	1.56	1.4	1.58	0.9	0.74	0.66
-3	615	.0678	.2852	.2720	2.68	1.64	1.39	1.28	1.19	0.77	0.66	0.61
-2	628	.0750	.3531	.3432	1.91	1.38	1.24	1.18	0.89	0.66	0.59	0.56
-1	637	.0797	.4254	.4201	1.38	1.18	1.11	1.08	0.65	0.56	0.53	0.52
0	639	.0814	.5000	.5000	1	1	1	1	0.48	0.48	0.48	0.48
1	637	.0797	.5746	.5799	1.38	1.91	2.63	3.63	0.65	0.89	1.18	1.52
2	628	.0750	.6469	.6568	1.91	3.66	7.01	13.41	0.89	1.54	2.45	3.52
3	615	.0678	.7148	.7280	2.68	7.16	19.17	51.3	1.19	2.5	4.13	5.21
4	595	.0588	.7764	.7913	3.79	14.38	54.52	206.7	1.58	3.68	5.31	6.97
5	571	.0489	.8303	.8454	5.47	29.89	163.4	893.3	2.06	4.78	6.77	7.62
6	540	.0389	.8758	.8896	8.06	64.9	522.8	4212	2.66	5.6	7.47	7.8
7	505	.0297	.9125	.9242	12.19	148.5	1810	22060	3.3	6.68	7.73	7.84
8	465	.0216	.9408	.9500	19.01	361.4	6870	130600	4.11	7.32	7.82	7.84
9	423	.0150	.9617	.9685	30.72	943.7	28990	890600	4.84	7.64	7.84	7.85
10	378	.0099	.9764	.9810	51.67	2669	137900	7126000	5.22	7.77	7.84	7.85
11	333	.0062	.9861	.9891	90.88	8259	750600	6.82E+07	6.1	7.82	7.85	7.85
12	287	.0037	.9923	.9941	168	28240	4745000	7.97E+08	6.79	7.84	7.85	7.85
13	243	.0021	.9959	.9970	328.4	107800	3.54E+07	1.16E+10	7.27	7.84	7.85	7.85
14	200	.0011	.9980	.9985	682.2	465300	3.17E+08	2.17E+11	7.56	7.85	7.85	7.85
15	161	.0005*	.9991	.9993	1517	2.30E+06	3.49E+09	5.29E+12	7.71	7.85	7.85	7.85
* extreme values omitted												

Updated Numerical Distributions for the Empirical Scoring System with a Naïve-Bayes Classifier and a Multinomial Likelihood Function: An Accuracy Demonstration with Archival Datasets with and without the Vasomotor Sensor[1]

Raymond Nelson[2]

Abstract

Four archival samples are used to demonstrate the effectiveness of a naïve-Bayes classifier using a multinomial reference distribution for the ESS. The first archival sample was the scores from the polygraph examiner student participants in the first publication that described the development of the ESS. The second archival sample was also from an earlier publication on the ESS and involved scores from three experienced examiners. Use of previously described archival datasets permits a simple and direct comparison of the updated ESS with the original ESS. The third sample consisted of scores from one experienced evaluator who provided ESS scores for a study on the vasomotor sensor. The fourth archival sample also included vasomotor scores. Results are shown for the original ESS and for the updated version including point estimates and confidence intervals for test sensitivity, specificity, false-negative and false-positive errors along with positive-predictive value and negative-predicative value. An advantage of the updated ESS is the ability to quantify and account for the additional vasomotor sensor in the statistical model, whereas the addition of vasomotor scores to the original ESS can be expected to bias or overload the statistical estimates provided by a reference model that did not originally included vasomotor scores. Other potential advantages of the updated version include the use of a multinomial reference model and the use of Bayesian analysis. Results with the updated ESS are similar to the original ESS.

1 This project was supported and made possible by Lafayette Instrument Company where Raymond Nelson is employed as a research specialist.

2 Raymond Nelson is a research specialist with Lafayette Instrument Company, which develops and markets polygraph technologies. Mr. Nelson is a polygraph field examiner and psychotherapist with expertise in sexual offending, victimization, trauma and development in addition to other experience in testing, data analytics and statistics. Mr. Nelson is one of the developers of the OSS-3 computer scoring algorithm and has published numerous studies on the ESS and other aspects of the polygraph. Mr. Nelson serves as an expert witness in legal matters involving both polygraph and psychology/psychotherapy. Mr. Nelson is a past president, and currently elected member of the APA Board of Directors, and has helped with policy development at the state, local and national level. The views an opinion expressed herein are those of the author and not the APA or LIC.

This project is an exploration and demonstration of test effectiveness or classification accuracy rates when using a multinomial reference distribution as the likelihood function for a naïve-Bayes[3] decision model. There are two main advantages of this approach. First, use of Bayesian analysis may permits a more intuitive discussion of probabilistic test results than results from scoring methods that rely solely on frequentist statistics. Secondly, use of a theoretical reference distribution and naïve-Bayes classifier introduces a potentially straightforward way to include and account for the vasomotor sensor in the decision algorithm. Results are evaluated both with and without the vasomotor sensor.

The Empirical Scoring System (ESS; Nelson, Krapohl & Handler, 2008; Nelson et al., 2011) is an evidence-based, norm-referenced, and standardized method for the analysis of comparison question test (CQT) data. Since its introduction the ESS has become a widely used polygraph scoring method in both field practice and research. Although in existence for only a short time, it has been described as among the most studied polygraph scoring methods (Krapohl & Shaw, 2015). The core principles of the ESS were derived from earlier work on polygraph feature extraction and test data analysis by researchers at the University of Utah (Podlesny & Raskin, 1978; Podlesny & Truslow, 1993; Kircher & Raskin, 1988; Bell, Raskin, Honts & Kircher, 1999) the U.S. Department of Defense (Senter, 2003; Senter & Dollins, 2003) and others (Harris, Horner & McQuarrie, 2000).

The ESS has been implemented both manually and via computer automation with similar results (Nelson, Blalock & Handler, 2011). One of the strengths of the ESS is the ability to easily describe and account for the level of statistical significance for an examination result (Nelson & Handler, 2012; 2014). Related to this is the ability select decision rules, and alpha boundaries with the goal of optimizing test effectiveness and classification accuracy rates according to operational policies that may involve varying priorities for test sensitivity or test specificity, or the management of potential false-negative or false-positive testing errors according to operational and mission objectives.

Until this time the ESS has relied solely on empirical reference distributions for statistical calculations. Empirical reference distributions are known to converge to the population distribution when subject to numerous replications[4]. The absence of a large number of researchers and research activities in the polygraph profession has meant that the continuous and ongoing study of ESS (and other) reference distributions has been slow-paced.

A limitation of the ESS, and other polygraph scoring methods, has been the absence of theoretical reference distributions that can be calculated from facts and information – related to the basic theory of the test. Theoretical distributions are not calculated from empirical data, but from facts and information that are subject to logical and mathematical proof. Theoretical and empirical and theoretical reference distributions are often used together in field practice and research settings. For example: statistical procedures often involve the analysis of the empirical distribution of available experimental or testing data with reference to a theoretical statistical distribution such as the standard normal distribution. In fact, the standard normal distribution is a mathematical abstraction – calculated from knowledge that was available before the experimental or testing data. When the empirical data conform reasonably to the shape of the theoretical distribution we can use our math-

3 Naïve in this usage refers to our reliance on assumptions, not necessarily supported by evidence, that we have no information about the relative importance and contribution of the different sensor data to the final test result and precision of the test model. Naïve also implies reliance on a convenience assumption that data from different sensors contribute independently to effective classifications and do not covary so strongly that they are redundant or problematic. Naïve-Bayes models are simple, effective and commonly employed in analytic settings for which other machine learning methods may also be used to optimize the model parameters and effectiveness.

4 This is known as the 'law of large numbers" [see Renze, John and Weisstein, Eric W. "Law of Large Numbers." From *MathWorld*--A Wolfram Web Resource. http://mathworld.wolfram.com/LawofLargeNumbers.html for more information].

ematical knowledge of the theoretical distribution as a model to make inferences about the empirical data.

Because theoretical reference distributions are calculated mathematically from the basic theory of the test, they may help us to study and understand the basic constructs that determine a test's effectiveness. Recent research has led to the calculation of theoretical multinomial reference distributions for ESS scores with CQT data (Nelson, 2017). Theoretical distributions for CQT data are calculated under the null-hypothesis to the operational or analytic theory of the polygraph. The analytic theory has been the basis of numerous studies on polygraph validity and 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 investigation target stimuli (Bell, Raskin, Honts & Kircher, 1999; Honts & Peterson, 1997; Honts & Raskin, 1988; Honts & Reavy, 2015; Kircher & Raskin, 1988; Kircher, Packard, Bell & Bernhardt, 2001; MacLaren & Krapohl, 2003; Nelson, 2014, 2015a, 2015b; Raskin, Honts & Kircher, 2014; Raskin, Kircher, Honts & Horowitz, 1988). This has also been described in as differential salience (Senter, Weatherman, Krapohl & Horvath, 2010).

A practical consequence of the scarcity of research in polygraph has meant that vasomotor sensor data is not included in most computer algorithms including statistical reference table for the ESS. Although the vasomotor sensor data has been described in several studies (Honts, Amato & Gordon, 2000; Honts, Handler, Gougler & Shaw, 2015; Honts & Reavy, 2015; Horowitz, Kircher, Honts &Raskin, 1997; Kircher & Raskin, 1988, Kircher, Packard, Bell & Bernhardt, 2001; Kubis, 1962; Podlesny & Raskin, 1978; Rovner, 1986; Raskin & Kircher, 1990) published statistical reference data for CQT scores available at present (Nelson & Handler, 2015) includes only the traditional array of physiological recording sensors – respiration, electrodermal (EDA) and cardiovascular activity .

Field practitioners who use the vasomotor sensor do so with the knowledge that they are overloading the CQT scores relative to the published reference data, and are thereby disrupting the precision of the test results. This has been done with the assumption that the distortion of the statistical calculations is such that the actual probability is thought to be more extreme than the statistical classifier and not less extreme. It would be preferable to have the ability to actually account for the vasomotor sensor when calculating the statistical classifier.

Method

A naïve-Bayes classifier was developed for ESS scores using the multinomial reference distributions described by Nelson (2017 [in press]). Effectiveness of the naïve-Bayes classifier was calculated using a variety of test accuracy metrics, including test sensitivity, specificity, false-negative errors, false-positive errors, positive predictive value, negative predictive value, the proportion of correct classifications and inconclusive results. Results are provided in table format along with results from the original ESS.

Description of the naïve-Bayes classifier

Bayes' theorem is widely used in virtually all areas of data analysis, classification, predication and machine learning. In general, Bayesian analysis requires three elements: a likelihood function, some data, and a prior probability associated with the data. The likelihood function we used here for the Bayesian classifier is the multinomial distribution of ESS scores (Nelson 2017) under the null-hypothesis to the operational or analytic theory of the polygraph test[5]. Prior probabilities are a subject of potentially endless discussion, though for practical purposes it is not uncommon to conduct and analysis with an equal prior[6].

The naïve-Bayes algorithm was used to calculate the odds of truth or deception by us-

5 The analytic theory of the polygraph is that greater changes in physiological activity are loaded at different types of test stimuli as a function of deception and truth-telling in response to the relevant target stimuli. [Refer to Nelson (2016) for a discussion.]

ing the multinomial reference distribution as a likelihood function to update the prior probability using Bayes' theorem. Results are classified using two-stage decision rules (Senter, 2003; Senter & Dollins, 2003).

Results for this project were evaluated with two different alpha schemes: a symmetrical alpha = .05 for the lower limit of the Clopper-Pearson interval (Agresti & Coull, 1998; Clopper & Pearson, 1934; Newcombe, 1998; Thulin, 2014) for both positive and negative classifications, and also using an asymmetrical alpha scheme of .10 for negative classification and .05 for positive classifications. This was done because it can be observed in the published literature that inconclusive results may occur more frequently for criterion innocent cases than criterion guilty cases. Because two-stage rules may involve the use of subtotal scores when the grand total is not statistically significant, classifications based on subtotal make use of a multiplicity correction[7] to the odds as a function of the number of relevant questions.

Because the naïve-Bayes classifier is expressed in terms of odds, and because the threshold for significance is the lower limit of the Clopper-Pearson interval, a result is statistically significant whenever the lower limit exceeds the value 1, regardless of the alpha level Clopper-Pearson interval. For convenience and familiarity to field practitioners, numerical cutscores can also be determined as an alternative to the odds.

Numerical cutscores for the 5th percentile lower limit of the Clopper-Pearson interval for the odds were the following: grand total scores of +3 or greater were statistically significant for truth-telling, while grand total scores of -3 or lower were statistically significant for deception. The multiplicity corrected cutscore for statistical significance of subtotal scores was -7 for deceptive classifications. For the asymmetrical alpha scheme the cutscores were the following: grand total scores of +2 were statistically significant for truth-telling, while grand total scores of -3 or lower were statistically significant for deception. The multiplicity corrected cutscore for statistical significance of subtotal scores remained at -7 for deceptive classifications under the asymmetrical alpha scheme.

An advantage using the odds as the metric for the naïve-Bayes is that integer cutscores will vary as a function of the alpha level, whereas the threshold for statistical significance when using the odds and the lower limit of the Clopper-Pearson interval will always be the lower limit of 1. In other words, if the lower limits of the odds than has exceeded the value 1 then the test has added significant information to support a classification.

Sample data

Four archival datasets were obtained from previous publications. Two of the archival datasets involved the use of the traditional array of physiological recording sensors (respiration, EDA, and cardio). The other two datasets included the vasomotor sensor. Each of the archival datasets involved an equal number of guilty and innocent cases[8].

6 The prior is sometimes referred to as the prior probability distribution because it describes the probabilities associated with each element of the distribution of possible outcomes. In the case of polygraph classifications there are two classes (guilty or innocent) for which the equal prior probability distribution is [.5, .5]. The prior probability is sometimes referred to as the base-rate when there is objective information to inform the prior probability. Prior probabilities are sometimes incompletely known and incompletely objective, necessitating reliance on scientific and statistical knowledge about probability distributions to determine a prior. In addition prior probabilities are sometimes subjective.

For these reasons the more general term prior probability is preferable to the more specific term base-rate.

7 The multiplicity corrected odds were calculated as the exponent of the natural log of the subtotal odds divided by the number of relevant questions raised the sign value of the lowest subtotal score.

8 The terms *guilt* and *innocence* are used only as categorical description of the actual case status and are not intended to convey a legal judgement. These terms are differentiated from the terms *deceptive* and *truthful* which are intended to refer only to the categorical test result. It is always the case that the court is the finder of fact legal questions about culpability. The purpose results from a scientific analysis such as a polygraph other forensic procedure is not to replace the authority of the court but to provide evidence in a probabilistic and replicable manner so that the court can try the evidence and make an informed finding of fact.

Results

Experiment 1

The dataset for the first experiment was obtained from the first published study that described the scoring system that is now known as the ESS (Nelson, Krapohl & Handler, (2008). In that study, seven participant scorers, who were polygraph students in the 8th week of training, each scored a sample of N=100 confirmed field cases using a scoring rubric that is now known as the ESS. This sample was described previously in a study by Krapohl and Cushman (2006) and consisted of n=50 confirmed guilty cases and n=50 confirmed innocent cases from the Department of Defense confirmed case archive. The examinations were event-specific criminal investigations using an examination format that included three repetitions of a question sequence that included three relevant questions.

Table 1 shows the results from the first experiment, including the proportion of correct classifications and inconclusive results, in addition to the test sensitivity, specificity, false-negative and false-positive error rates. Also shown are the positive predictive value (PPV) and negative predictive value (NPV)[9]. In addition to the multinomial-ESS results with the symmetrical and asymmetrical alpha schemes, results are shown for Nelson, Krapohl and Handler (2008) and for Krapohl and Cushman (2006) using evidentiary decision rules. Evidentiary rules described by Krapohl and Cushman (2006) involved the use of two-stage decision rules (Senter, 2003; Senter & Dollins, 2003) and cutscores of that were modified from those traditionally used.

Table 1. Results from experiment 1. N=100 field cases from Krapohl & Cushman (2006), evaluated using the ESS by the participants in Nelson, Krapohl & Handler (2008). [95% confidence intervals calculated via parametric bootstrap]

	Krapohl & Cushman (2006) 7-position scores evidentiary rules	Nelson et al. (2008) ESS scores (alpha = .05 / .10)	ESS-Multinomial (alpha = .05 / .05)	ESS-Multinomial (alpha = .05 / .10)
Correct decisions	.865 [.791, .932]	.875 [.807, .943]	.888 [.820, .946]	.882 [.814, .945]
Inconclusive results	.096 [.040, .160]	.102 [.050, .160]	.109 [.050, .170]	.089 [.040, .150]
Sensitivity	.807 [.689, .909]	.776 [.653, .886]	.809 [.692, .911]	.809 [.692, .911]
Specificity	.757 [.630, .870]	.802 [.687, .906]	.774 [.652, .885]	.800 [.683, .905]
False-negative errors	.095 [.020, .183]	.129 [.042, .229]	.097 [.021, .185]	.111 [.032, .205]
False-positive errors	.150 [.058, .255]	.089 [.019, .173]	.103 [.021, .196]	.103 [.023, .192]
PPV	.843 [.733, .939]	.897 [.800, .976]	.887 [.787, .976]	.887 [.787, .975]
NPV	.888 [.786, .976]	.861 [.755, .956]	.889 [.787, .976]	.879 [.773, .966]

9 PPV is calculated as true-positives/all-positives. NPV is calculated as true-negatives/all-negatives.

Inspection of the confidence intervals shows that the classification of the sample cases with the naïve-Bayes multinomial-ESS did differ significantly from that of the original ESS. Point estimates for correct decisions was improved by approximately one percentage point, along with a reduction of inconclusive results by approximately one percentage point. A change of 1 percentage point for classifications may not be interesting. However, a change of a one percentage point for inconclusive results, for which the point estimate is near 10%, may be interesting. These results indicate that the Bayesian ESS model may perform similarly to the original ESS.

Experiment 2

The dataset for the second experiment was a sample of N=60 confirmed field cases from the Department of Defense confirmed case archive, evaluated by six experienced examiners for a study in which Nelson and Krapohl (2011) showed that 7-positive numerical scores can be transformed to ESS scores with good results. This sample consisted of n=30 confirmed guilty cases and n=30 confirmed innocent cases. This sample was described in previous studies on the Objective Scoring System (Krapohl & McManus, 1999), Objective Scoring System, version 2 (Krapohl, 2002), and the Objective Scoring System, version 3 (Nelson, Krapohl & Handler, 2008). The examinations were event-specific criminal investigations using an examination format that included three repetitions of a question sequence that included three relevant questions. Table 2 shows the results for the second archival dataset naïve-Bayes multinomial-ESS, along with the previously reported results from Nelson and Krapohl (2011).

Table 2. Results from experiment 2. N=60 field cases from Krapohl & McManus (1999), evaluated by three experienced scorers using 7-position scores that were transformed to ESS scores. [95% confidence intervals calculated via parametric bootstrap]

	Nelson & Krapohl (2011) 7 position evidentiary rules	Nelson & Krapohl (2011) ESS Scores (alpha = .05 / .10)	Nelson & Krapohl (2011) ESS Scores (alpha = .05 / .05)	ESS-Multinomial (alpha = .05 / .05)	ESS-Multinomial (alpha = .05 / .10)
Correct decisions	.872 [.775, .959]	.921 [.842, .982]	.913 [.827, .980]	.918 [.827, .980]	.922 [.830, .981]
Inconclusive results	.096 [.033, .183]	.104 [.033, .183]	.173 [.083, .267]	.183 [.100, .283]	.150 [.067, .250]
Sensitivity	.920 [.809, .999]	.923 [.815, .999]	.923 [.815, .999]	.900 [.767, .999]	.900 [.767, .999]
Specificity	.657 [.481, .828]	.728 [.560, .880]	.588 [.409, .762]	.600 [.421, .774]	.667 [.485, .833]
False-negative errors	.007 [.001, .043]	.010 [.001, .061]	.002 [.001, .034]	.000 [.001, .061]	.000 [.001, .061]
False-positive errors	.224 [.081, .382]	.133 [.030, .267]	.143 [.032, .276]	.133 [.029, .265]	.133 [.029, .265]
PPV	.803 [.657, .931]	.876 [.743, .971]	.866 [.735, .970]	.871 [.741, .971]	.871 [.741, .971]
NPV	.989 [.929, .999]	.986 [.920, .999]	.997 [.941, .999]	.999 [.904, .999]	.999 [.905, .999]

Because the confidence intervals have substantial overlap for the different scores in Table 2, it can be assumed that no significant differences exist between the different scores for the second dataset. These results provide additional support for the performance of the Bayesian/multinomial ESS as providing a level of effectiveness that is similar to the original ESS.

Experiment 3

The archival dataset for the third experiment was from Honts, Handler, Shaw and Gougler (2015), involving a sample of N=40 cases from a laboratory study that included the vasomotor sensor. The sample consisted of n=20 criterion guilty and n=20 criterion innocent cases. The examinations were event-specific criminal investigations using an examination format that included five repetitions of a question sequence that included three relevant questions. Scores were coded using the ESS. Honts et al., (2015) reported that addition of the vasomotor sensor resolved one of three inconclusive cases, though the difference in precision was not significant with the additional sensor. Results without the vasomotor sensor are shown in Table 3. Results are shown with the vasomotor sensor in Table 4.

Table 3. Results from experiment 3 without the vasomotor sensor. N=40 laboratory cases. Evaluated using the ESS by one experienced scorer. [95% confidence intervals calculated via parametric bootstrap]

	Honts et al., (2015) ESS scores (alpha = .05 / .10) with 5 charts	ESS-Multinomial (alpha = .05 / .05) with 5 charts	ESS-Multinomial (alpha = .05 / .10) with 5 charts
Correct decisions	.946 [.865, .999]	.947 [.865, .999]	.947 [.865, .999]
Inconclusive results	.075 [.001, .175]	.050 [.001, .125]	.050 [.001, .125]
Sensitivity	.900 [.750, .999]	.950 [.813, .999]	.950 [.813, .999]
Specificity	.850 [.667, .999]	.850 [.667, .999]	.850 [.667, .999]
False-negative errors	.050 [.001, .167]	.050 [.001, .167]	.050 [.001, .167]
False-positive errors	.050 [.001, .167]	.050 [.001, .167]	.050 [.001, .167]
PPV	.947 [.824, .999]	.950 [.833, .999]	.950 [.833, .999]
NPV	.944 [.818, .999]	.944 [.818, .999]	.944 [.818, .999]

Table 4. Results from experiment 3 with the vasomotor sensor. N=40 laboratory cases. Evaluated using the ESS by one experienced scorer. [95% confidence intervals calculated via parametric bootstrap]

	Honts et al., (2015) ESS scores (alpha = .05 / .10) with 5 charts	ESS-Multinomial (alpha = .05 / .05) with 5 charts	ESS-Multinomial (alpha = .05 / .10) with 5 charts
Correct decisions	.947 [.865, .999]	.947 [.865, .999]	.947 [.865, .999]
Inconclusive results	.050 [.001, .125]	.050 [.001, .125]	.050 [.001, .125]
Sensitivity	.900 [.750, .999]	.900 [.750, .999]	.900 [.750, .999]
Specificity	.900 [.750, .999]	.900 [.750, .999]	.900 [.750, .999]
False-negative errors	.050 [.001, .167]	.050 [.001, .167]	.050 [.001, .167]
False-positive errors	.050 [.001, .167]	.050 [.001, .167]	.050 [.001, .167]
PPV	.947 [.824, .999]	.947 [.824, .999]	.947 [.824, .999]
NPV	.947 [.824, .999]	.947 [.824, .999]	.947 [.824, .999]

Results with the third archival sample were identical for the symmetrical and asymmetrical alpha schemes without the vasomotor sensor, and were also identical for the two alpha schemes with the vasomotor sensor. Results with the multinomial ESS and naïve-Bayes classifier were similar, except that without the vasomotor sensor the naïve-Bayes ESS model classified one deceptive case correctly which was inconclusive for the original ESS. Also, one of two inconclusive cases was resolved correctly to a truthful classification with the addition of the vasomotor score, while at the same time the result of one correctly classified deceptive case was case now unresolved and inconclusive.

Inspection of the confidence intervals in Tables 3 and 4 for the original ESS results and the multinomial ESS results showed that the two methods perform similarly with and without the vasomotor sensor. Results from the third experiment further support the effectiveness of the Bayesian multinomial ESS as similar to the original ESS.

Experiment 4

The fourth and last dataset for this study is from Kircher and Raskin (1988), which used a sample of N=100 laboratory cases. The sample consisted of n=50 criterion guilty cases and n=50 criterion innocent cases. The examinations were event-specific criminal investigations using an examination format that included three repetitions of a question sequence that included three relevant questions. This sample was also included in a meta-analytic survey published by the American Polygraph Association, 2011).

The sample cases were evaluated by the original examiner and an independent expert using the Utah 7-position numerical system (Bell, Raskin, Honts, & Kircher, 1999), which provides a foundation of research for ESS feature extraction. Seven-position scores scores were transformed to ESS scores in order to compare the results of the new algorithm to previously reported results with and without the vasomotor sensor. Table 5 shows the results for the Utah 7-position scores for three, four and five repetitions of the question sequence without the vasomotor sensor scores. Table 6 shows the results with the vasomotor data.

Table 5. Results from experiment 4 without the vasomotor sensor. N=100 laboratory exams. Scored by two expert evaluators and researchers in psychophysiology using the Utah 7-position scoring method. [95% confidence intervals calculated via parametric bootstrap]

	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) with 3 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) with 4 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) with 5 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) and 3 to 5 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) and 3 or 5 charts
Correct decisions	.959 [.900, .999]	.983 [.944, .999]	.964 [.916, .999]	.959 [.911, .999]	.959 [.911, .999]
Inconclusive results	.391 [.300, .490]	.410 [.320, .510]	.175 [.010, .250]	.155 [.080, .220]	.150 [.090, .230]
Sensitivity	.500 [.361, .640]	.459 [.321, .596]	.816 [.700, .915]	.816 [.700, .915]	.816 [.700, .915]
Specificity	.667 [.533, .795]	.696 [.562, .820]	.775 [.652, .885]	.814 [.700, .915]	.804 [.690, .907]
False-negative errors	.031 [.001, .089]	.010 [.001, .044]	.041 [.001, .105]	.041 [.001, .105]	.041 [.001, .105]
False-positive errors	.020 [.001, .067]	.010 [.001, .044]	.020 [.001, .068]	.029 [.001, .083]	.029 [.001, .083]
PPV	.961 [.870, .999]	.978 [.900, .999]	.976 [.919, .999]	.964 [.902, .999]	.964 [.902, .999]
NPV	.958 [.872, .999]	.986 [.938, .999]	.952 [.872, .999]	.954 [.878, .999]	.953 [.875, .999]

Table 6. Results from experiment 4 with the vasomotor sensor. N=100 laboratory exams. Scored by two expert evaluators and researchers in psychophysiology using the Utah 7-position scoring method. [95% confidence intervals calculated via parametric bootstrap]

	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) with 3 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) with 4 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) with 5 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) and 3 to 5 charts	Kircher & Raskin (1988) 7-position with traditional cutscores (+6 / -6) and 3 to 5 charts
Correct decisions	.962 [.910, .999]	.978 [.937, .999]	.954 [.907, .989]	.950 [.901, .989]	.949 [.900, .989]
Inconclusive results	.335 [.250, .430]	.325 [.240, .420]	.130 [.070, .200]	.100 [.050, .160]	.115 [.060, .180]
Sensitivity	.551 [.413, .686]	.561 [.426, .696]	.847 [.740, .939]	.847 [.700, .915]	.847 [.700, .915]
Specificity	.725 [.600, .844]	.755 [.628, .870]	.814 [.700, .915]	.863 [.762, .953]	.833 [.723, .929]
False-negative errors	.02 [.001, .065]	.010 [.001, .043]	.041 [.001, .105]	.041 [.001, .105]	.041 [.001, .105]
False-positive errors	.029 [.001, .085]	.020 [.001, .067]	.039 [.001, .100]	.049 [.001, .115]	.049 [.001, .115]
PPV	.947 [.853, .999]	.965 [.885, .999]	.954 [.889, .999]	.943 [.870, .999]	.943 [.870, .999]
NPV	.974 [.914, .999]	.987 [.942, .999]	.954 [.889, .999]	.957 [.886, .999]	.955 [.881, .999]

Inclusion of the vasomotor scores reduced the point estimates for inconclusive results. However, point estimates for decision accuracy were optimized without the vasomotor scores. The confidence intervals show substantial overlapping coverage for all versions of the analysis with the 7-position scores, suggesting that observation or experience with other data may lead to similar performance with or without the vasomotor sensor for the 7-position scores with up to five repetitions of the question sequence.

Inspection of Tables 5 and 6 reveals that additional repetitions of the test questions sequence beyond the minimum three has the effect of reducing inconclusive results in a desirable way, but has less effect on classification accuracy. Table 7 shows the results after transforming the 7-position scores to ESS scores, using cutscores that were determined using the original empirical reference distributions. Table 8 shows the results for the Bayesian ESS model with and without the scores from the vasomotor sensor. For simplicity, only the results from five iterations of the question sequence are shown in Tables 7 and 8, though the effect of additional repetitions beyond the minimum three was the same as for the 7-position scores.

Table 7. Results after after transforming the 7-position scores to ESS scores (without the vasomotor sensor), using the original ESS reference distributions and two-stage decision rules with 5 charts. [95% confidence intervals calculated via parametric bootstrap]

	ESS (alpha = .05 / .10) Two-stage Rules 5 repetitions without vasomotor	ESS (alpha = .05 / .05) Two-stage Rules 5 repetitions without vasomotor
Correct decisions	.921 [.865, .969]	.929 [.874, .978]
Inconclusive results	.045 [.010, .090]	.085 [.030, .140]
Sensitivity	.888 [.795, .963]	.888 [.795, .963]
Specificity	.873 [.776, .959]	.814 [.700, .915]
False-negative errors	.071 [.001, .154]	.051 [.001, .135]
False-positive errors	.078 [.018, .160]	.078 [.018, .160]
PPV	.916 [.831, .981]	.916 [.831, .981]
NPV	.927 [.841, .999]	.943 [.860, .999]

Table 8. Results from experiment 4 for ESS scores with the Bayesian-multinomial decision method – with and without the vasomotor sensor. N=100 laboratory exams. Results are shown using the grand total rule and two-stage rules with 5 charts. [95% confidence intervals calculated via parametric bootstrap]

	ESS-Multinomial (alpha = .05 / .10) Grand Total Rule 5 repetitions without vasomotor	ESS-Multinomial (alpha = .05 / .10) Grand Total Rule 5 repetitions with vasomotor	ESS-Multinomial (alpha = .05 / .05) Two-stage Rules 5 repetitions without vasomotor	ESS-Multinomial (alpha = .05 / .05) Two-stage Rules 5 repetitions with vasomotor
Correct decisions	.921 [.863, .969]	.925 [.870, .978]	.921 [.863, .969]	.930 [.874, .978]
Inconclusive results	.050 [.010, .100]	.065 [.020, .120]	.050 [.010, .100]	.065 [.020, .120]
Sensitivity	.898 [.795, .923]	.888 [.795, .963]	.898 [.795, .923]	.889 [.795, .964]
Specificity	.853 [.750, .942]	.843 [.736, .938]	.853 [.750, .942]	.843 [.736, .938]
False-negative errors	.071 [.001, .154]	.051 [.001, .121]	.071 [.001, .154]	.041 [.001, .104]
False-positive errors	.078 [.018, .160]	.088 [.019, .173]	.078 [.018, .160]	.088 [.019, .173]
PPV	.917 [.833, .982]	.906 [.820, .980]	.917 [.833, .982]	.907 [.820, .980]
NPV	.926 [.837, .999]	.954 [.865, .999]	.926 [.837, .999]	.956 [.882, .999]

Although tests of statistical significance were not performed, inspection of the confidence intervals in Tables 5, 6, 7, and 8 reveals substantially similar performance for the 7-position scores and the ESS with and without the vasomotor sensor. Results from the fourth experiment further support the effectiveness of the Bayesian ESS method as similar to the original ESS and the earlier 7-position scoring method.

Summary

This project is a demonstration of the effectiveness, classification accuracy, of an update to the ESS using a multinomial reference distribution as the likelihood function for a naïve-Bayes classifier[10]. Four separate archival dataset were selected for their relevance to important pragmatic questions about the new model. Those questions include whether the updated ESS model can perform generally similarly to the original ESS, and also include attention to the details about test sensitivity, specificity, error rates, and inconclusive rates. Additional questions involve the value or contribution of the vasomotor sensor, and the structural model for the inclusion of vasomotor scores in the decision algorithm. Use of archival data in this project is not only expedient but permits a more direct comparison of the updated ESS model to the original model

10 Inclusion of weighted electrodermal score for the naïve-Bayes model can be argued as incompletely naïve. Weighting of electrodermal scores in the ESS is effectively like having two scores that covary perfectly. In reality, it is seldom the case that we actually know nothing about the relative importance of different sources of data. Use of naïve assumptions is done with the understanding that these are sometimes convenience assumptions that are not necessarily supported and may differ from an optimized statistical function. Regardless of their simplicity, naïve-Bayes models are known for their practical effectiveness.

when datasets can be obtained from previous publications that used the ESS.

The first experiment involved the use of the same dataset of student scores that was reported in the first study on the ESS, and showed the new model provides similar results. The second experiment involved a dataset of scores from expert evaluators and also showed the new model can provide similar results. Neither of the first two experiments includes scores for the vasomotor sensor.

The third experiment used a data set of ESS scores that included vasomotor scores. Data were evaluated both with and without the vasomotor sensor, and showed that the updated ESS performed similarly to the original ESS both with and without the vasomotor sensor scores. The fourth experiment also included scores for the vasomotor sensor, and also provided an opportunity to evaluate the effects of varying numbers of repetitions of the test stimuli, and the effects of different decision rules. These results provide clarity and support for field practices that involve the use of three to five repetitions of the test stimuli.

The new ESS model classified the cases similarly to the existing scoring model both with and without the vasomotor scores. Although some small differences can be observed in the point estimates, evaluation of the confidence intervals for these experiments suggests that observed differences are well within the range of normally expected sampling variation. Although no tests of statistical significance are reported herein, this publication includes sufficient information that significant differences can easily be explored through simulation by those who wish to do so.

Conclusion

This project is a unique development in the polygraph profession for three reasons. First, this project involves the use of an explicitly Bayesian decision algorithm. Secondly, this project makes use of the recent developments of a multinomial distribution for CQT scores. Multinomial distributions, like other mathematical/theoretical distributions are calculated from facts and assumptions that are subject to mathematical and logical proof, and are constructed around a mathematical representation of the basic theory of the polygraph test.

The third important aspect of this study is the addition of the vasomotor sensor scores to the statistical decision model. Previous solutions for the inclusion of the vasomotor sensor scores into the statistical precision and error estimates were limited to computer algorithms – though most if not all commercially available scoring algorithms do not appear to include vasomotor data at this time. Inclusion of vasomotor scores with the original ESS may represent a form of overloading the reference distributions in a manner such that statistical estimates may be known to be potentially incorrect. This is accepted in field practice only inasmuch as the biasing effect of the overloaded ESS scores is presumed to cause an underestimation of the level of significance. In other words, the actual error estimate – which cannot be calculated when including vasomotor scores into calculations for the original ESS – are thought to be more extreme than those observed. Inclusion of additional sensor data in a statistical classifier is non-trivial challenge even when the new data have been shown to be correlate with the criterion of interest. For this reason, the updated ESS, the Bayesian ESS, and the availability of a multinomial reference model, analysis may represent an important accomplishment for the polygraph profession.

Finally, every new or modified classification or scoring method needs a memorable name so that it can be easily recognized, referenced conveniently, and differentiated from other methods. A possible name could be derived from a description of the new model: updated numerical distributions for the ESS, but the acronym (UNDrESS) may be problematic. A simpler name might refer to the use of the multinomial likelihood function, but again the acronym (M-ESS) may be sub-optimal. Clearly some problems cannot be solved with statistical analysis. In the mean-time, further interest in the updated ESS is recommended among field practitioners, researchers and others who rely on polygraph scoring methods.

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Rethinking the Interview Room:
Promoting Disclosure and Rapport through Priming

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Abstract

Interviewing and interrogation practice has attracted significant attention in the last decades. While much of this research focuses on the effects of particular interrogation techniques, our work instead explores how the dynamics of an interrogation are affected by non-conscious elements of the situation, such as the subtle characteristics of the interrogation room itself. More specifically, we focus on how priming – the activation of mental concepts – affects interviewees' tendency to disclose information. In this paper, we first provide an overview on theories of priming, with a particular focus on their applicability to the interrogation context. Second, we describe our previous program of research on how priming can be used to increase information disclosure in interviews and interrogations. Third, we report a new empirical study on how language can prime and promote information disclosure. Finally, we discuss the implications of the research for practical contexts.

Rethinking the Interview Room: Promoting Disclosure and Rapport through Priming

Interviews and interrogations are crucial components in many contexts, including criminal investigations and intelligence gathering. In recent years, the study of interviewing and interrogation has exploded. There is now a substantial literature on the topic derived primarily from psychology, but also from the related fields of sociology, linguistics and criminology. Much of this research has focused on two topics. The first is the nature and effects of currently employed interview and interrogation techniques. Research on this topic seeks to understand what techniques are used in practice, as well as the effectiveness of these techniques (e.g., whether they yield reliable information). The second topic focuses on developing new techniques derived from scientific research, with the aim of improving current practice.

This paper describes a new program of research that in critical ways expands on our current knowledge about interviews. While we share the ambition to promote current interview and interrogation practice through the application of sound scientific principles, our research questions are not focused on the overt questioning techniques being used. Instead, our research focuses on *how the dynamics of an interview - and ultimately, the information gained from it - can be altered by changing subtle aspects of the environment in which the interview takes place*. More specifically, we have invested considerable effort into studying the interview room itself. As we will discuss in detail, through a series of experiments, we have investigated whether certain spatial outlines and features of the interview setting can promote disclosure and rapport via a mechanism entitled *priming*.

This paper has two goals. First, we aim to provide the reader with an overview of the research program on how the features of the interview room can activate certain mindsets, which in turn can enhance specific goals of interviewing (e.g., forthcomingness, rapport). We will describe the theoretical frameworks that this research is anchored in. We will discuss these theories in some detail, for several reasons. We believe that they are highly applica-

ble to investigative interviewing. Furthermore, we think that in order to apply these theories successfully to the interview room, it is crucial to properly understand their basic principles. Following the theoretical review, we will then discuss how these frameworks can be applied to promote effective interviewing practice. Our second goal is to report an original empirical study, anchored in the same frameworks, which aims at promoting disclosure of information via priming mechanisms embedded in the language of the interview itself.

Interviews and interrogations have several goals. While American criminal interrogations tend to focus on generating confessions, other countries (e.g., the UK, Norway, Australia) have adopted a model of interviewing focused on generating as much reliable information as possible (Shepherd & Griffiths, 2013). This approach is often referred to as information-gathering interrogation, or investigative interviewing. Our program of research shares the basic premise of the investigative interviewing model by examining methods of promoting disclosure of information. More specifically, we have adopted a theoretical framework from social cognitive psychology entitled *implicit cognition*, and a related theory entitled *embodied cognition*. In the section below, we will provide an overview of these theoretical frameworks, followed by a discussion of how we have applied these theories to investigative interviewing settings.

Implicit Cognition

Implicit cognition broadly refers to the operation of social and cognitive processes outside of one's conscious awareness. There is now a considerable body of evidence which supports behavior is driven by processes that people generally lack insight to (e.g., Bargh, 1997; Gawronski & Payne, 2010; Greenwald & Banaji, 1995). The notion that the unconscious part of the mind is powerful has a long history, and is most famously known through the work of Sigmund Freud (1901/1965). The contemporary study of non-conscious processes is sometimes referred to as 'the new unconscious' (Hassin, Uleman, & Bargh, 2005), and is currently an important topic in social and cognitive psychology (Carlston, 2013).

The basic premise that a large portion of cognitive processing is automatic and unconscious makes sense from an efficiency point of view: we are constantly bombarded with information to attend to, digest and remember. It would be impossible and inefficient to process all this information on a conscious level (Bargh & Morsella, 2008). A mundane scenario illustrates why the brain largely operates on autopilot. Imagine sitting at a desk reading the paper and drinking coffee. Here, one must attend to 1) basic physical experiences of all senses (e.g., temperatures, smells, lighting, tactile experiences); 2) basic physical actions (e.g., reaching and lifting the mug); 3) information processes including reading, comprehending, abstraction, remembering and; 4) integrated actions, for example, turning the page because you are not interested in an article and realize that you only have five minutes left until a meeting. To consciously process all of this would be paralyzing. For this reason, most of these processes occur automatically, without our awareness.

As for the origin of unconscious, automatic processing, it can arise as a function of repeated associations between concepts – for example, the concepts *gun* and *violence* frequently coincide, leading to an automatic link between the two. In simple terms, if the concept of gun is activated (e.g., a person is presented with an image of a weapon), the concept of violence is also activated, without deliberate effort. In more general terms, automaticity can operate according to the so-called *perception-behavior link* (Berkowitz, 1997; Chartrand & Bargh, 1999). This model suggests that perception can affect behavior through a process that involves no deliberate effort (nor conscious awareness). Consider the following example: in an experimental study, Carver, Ganellen, Froming, and Chambers (1983) exposed some participants to words related to hostility; ostensibly as part of a study of language. They then assigned participants to the role of a 'teacher' in a learning study. As teachers, participants were asked to administer electric shocks to confederates posing as 'learners.' Participants who had been exposed to hostility-related words administered longer shocks compared to participants who had been exposed to neutral words. The activation of hostility that subsequently led to increased aggression is a mechanism entitled *priming*. As we will describe in further detail below,

priming is a central feature in our research.

Priming. Research shows that priming can have effects across a vast number of domains. Before describing this research further, it may be helpful to make a distinction between two types of priming: First, there is *subliminal priming*, where the concept being primed is presented under the threshold of consciousness, leaving people completely unaware of the fact that they have been exposed to it. Second, there is *supraliminal priming*, where the concept being primed may reach awareness (as in the example above, where participants read words related to hostility). The most dramatic examples of priming effects tend to involve subliminal priming. In an experiment examining the influence of priming on visual perception, participants were tasked with identifying objects in degraded images on a computer; some objects were crime-relevant (e.g., a gun), and others were not (e.g., a book). During the task, participants were subliminally presented with images of either Black faces or White faces on a computer screen (Study 1, Eberhardt, Goff, Purdie & Davies, 2004). The presentation of these images was so brief (30 milliseconds) that participants did not consciously register them. Those who had been subliminally exposed to Black faces more quickly identified the gun and knife than the crime-irrelevant objects, while those who were exposed to White faces needed more time to identify the gun and knife compared to crime-irrelevant objects. This can be explained by the pervasive stereotype of Black Americans as criminal. In other words, what appeared to happen in this experiment was that the stereotype was activated automatically and without participants' awareness, which then lead them to behavior in accordance with the stereotype. More, this stereotypic association operates independently of racial attitudes, meaning people who do not explicitly espouse racist beliefs are about as likely as those who do to exhibit this stereotypic association. This is an example of the automatic perception-behavior link discussed above. Critically, regardless of the degree to which people "notice" the prime, the prime's influence on them remains unnoticed. So while participants who read hostility-related words noticed that they read such words, they did not notice that reading those words primed aggression and led them to administer more shocks, just as participants who did not notice the images of Black and White faces were unable to attribute this influence on their visual perception of the degraded images.

Priming can have remarkable effects. In one study, participants were primed with the stereotype of a professor by writing down the traits that came to mind when they thought about the profession. Participants in a control condition did not complete this task. Subsequently, in an ostensibly separate task, participants were asked to answer general knowledge questions taken from the game "Trivial Pursuit." Participants who had been primed with the concept of a professor (presumably a profession stereotypically associated with intelligence) answered more questions correctly compared to the non-primed control group (Dijksterhuis & van Knippenberg, 1998). Conversely, participants who were led to think about soccer hooligans (who are likely to be associated with stupidity) performed poorer on the general knowledge game than a non-primed control group. These findings show that the activation of a concept (e.g., a professor) which is associated with another concept (intelligence) induces cognitive processes consistent with these concepts.

Priming not only influences cognition; its effects extend to behavior. For example, Bargh, Chen, and Burrows (1996) primed some participants with the concept of elderly people by exposing them to words stereotypically associated with old age. Following the priming task, participants were told that the experiment was over and that they were free to leave. However, researchers measured the time it took for participants to walk from the laboratory to the nearest elevator, and found that those who had been primed with the 'elderly people' stereotype walked more slowly compared to unprimed participants (for a replication, see Dijksterhuis, Spears, and Lepinasse, 2001).

To summarize the discussion so far, there is a substantial body of research showing that activation of various concepts – so called priming – can generate cognitive and behavioral effects consistent with the primed concept. These processes are implicit, meaning that people are unaware of their operation. In the section below, we will discuss a specific theory within implicit cognition entitled

embodied cognition. We will outline the basic premises of this theory, and then turn to our line of empirical work where we have applied this theory to investigative interviewing.

Embodied Cognition

Embodied cognition is a theory about the interplay between the body and mind. In essence, it is a rejection of the famous Cartesian notion that the body and mind are two separate entities. Instead, embodied cognition postulates that a substantial portion of mental activity is rooted in bodily experiences. In essence, embodied cognition holds that our sensorimotor experience of the physical world provides the basis for much of our complex understanding of psychological constructs (Shapiro, 2014; Barsalou, 2008; Niedenthal, Barsalou, Winkielman, Krauth-Gruber & Ric, 2005). For example, from infancy, we experience physical sensations such as warmth when we are close to our caregivers, creating neural associations between physical and interpersonal experiences. As our cognitive capacities develop, we come to understand the more complex concept of psychological intimacy through the metaphor of warmth (Williams, Huang & Bargh, 2009). That is, our concept of psychological intimacy is "embodied," or grounded in the physical experience of temperature.

Metaphors play a critical role in the theory of embodied cognition (Lakoff & Johnson, 1980). The theory holds that metaphors operate as fundamental tools for understanding the world. Ordinary language is a reflection of this. For example, there are numerous examples of the metaphor of sight as a way to talk about understanding ("I see what you mean", "he clarified his statement"). We talk about power, strength and status by using metaphors of an up-down dimension ("my new job is a higher position", "they are at the bottom of the hierarchy"). We also think of emotional concepts like mood along this up-down dimension ("I feel down today", "she really lifted my spirits"). Of particular importance for our program of research, we think of our own selves as containers, with an inside and an outside, and with content ("I am full of regret", "I feel empty inside").

Metaphoric transfer effects. As we will describe in the following section, our work relies heavily on the use of so-called *metaphoric transfer effects* (e.g., Landau, Meier, & Keefer, 2010). Metaphoric transfer effects occur when a metaphor is activated through one modality (e.g., a physical manipulation), which gives rise to metaphor-consistent behavior in a different modality (e.g., changing psychological perception or behavior). Let us illustrate this using two experiments. In a classic study, Williams and Bargh (2008) had participants hold either a warm or a cold cup of coffee just prior to being asked to evaluate a person. Thus, they manipulated warmth using a physical intervention. In line with predictions from embodied cognition, people who had been primed with warmth rated the person in more positive terms – expressed differently, and using the relevant metaphoric language, they felt more warmly about the person. In this instance, the physical activation of warmth transferred to a psychological level. However, the process of transference can also go in the other direction, where psychological processes influence physical experience: Zhong and Leonardelli (2008) induced feelings of social exclusion (which is metaphorically related to coldness) in participants under the cover story of writing about an autobiographical memory. After the study was ostensibly finished, participants were asked to provide an estimate of the room temperature in the laboratory. Participants who had been primed with social exclusion rated the room as colder compared to those who recalled being socially included, and expressed a stronger desire for warm food.

Embodied Cognition in Interviews

The research we have reviewed shows that priming of various concepts can have a wide range of psychological and behavioral effects. Such priming can occur in subtle ways – as we discussed above, it is not even necessary that participants consciously register the stimulus that primes them. We suggest that this research has enormous potential for being exploited during investigative interviews. More specifically, we posit that interviewers can use priming in strategic ways in order to accomplish various goals. In our inquiry of this premise, we have conducted a series of experimental studies. Below, we will review these studies in some detail, after which we will discuss the broad implications of our re-

search for investigative interviewing.

Openness Priming

In recent years, researchers have generated a substantial body of research on interviewing and interrogation techniques (Bull, 2014; Milne & Powell, 2010; Shepherd & Griffiths, 2013). A comprehensive discussion of this research is beyond the scope of this paper. However, a central element of particular relevance to our work is the shift in ethos advocated by interview and interrogation researchers. In simple terms, the scientific consensus is that interrogations should shift their focus from generating confessions to gathering as much information as possible. Expressed differently, researchers have argued that interviews with suspects should be characterized by the same goal as interviews with victims and witnesses: they should all aim to produce as much reliable information as possible in order to advance the investigation. This approach, which is often labeled investigative interviewing, has been implemented in several countries in the Western world (e.g., Canada, the UK, Norway, and the Netherlands, to mention a few), and has also been applied to military and intelligence-gathering settings (Hartwig, Meissner, & Semel, 2014).

By adopting the investigative interviewing model, we can generate a number of empirical research questions. Some questions pertain to the challenges of obtaining reliable information, given the fallibility of human memory (Memon, Meissner & Fraser, 2010). Other questions pertain to the nature and structuring of questions in order to enhance the quantity and quality of information obtained. One of the challenges we focus on is *how to promote openness and disclosure of information* from interviewees who might not be highly motivated to cooperate. Given the problems of using coercion as a means to produce cooperation (Hartwig et al., 2014), there is a clear need for effective methods that are also ethically defensible.

One strand of our research program departs from the literature reviewed above, and focuses particularly on the concept of openness as a metaphor for sharing of information. Ordinary language reflects that we associate openness with information disclosure (e.g., "she was very open with me about her past", or "when I asked him to tell me more, he closed up"). This complex metaphor appears to be based on several basic metaphors: 1) the body is a container; 2) information is matter; 3) information is held and; 4) disclosure involves release of information into space. In line with theories of embodied cognition and metaphoric transfer, several lines of research show that this metaphor is salient and can be activated through physical and mental manipulations. Important information feels heavier to people than trivial information, suggesting that information has "weight" (Jostmann, Lakens, & Schubert, 2009). This appears to relate to the burden of secrecy. In a series of studies examining the perceptions and behavior of people who had (or did not have) sensitive secrets about partner infidelity and sexual orientation, those who held secrets were more likely to view a hill as steeper (and thus harder to climb) and less likely to help someone with a physical task, suggesting that the psychological burden of holding a secret literally made people feel act as though weighed down (Slepian, Masicampo, Toosi & Ambady, 2012). Moreover, when people are forgiven (Zheng, Fehr, Tai, Nayaranan & Gelfand, 2014), feel understood (Oishi, Schiller & Gross, 2013), feel supported (Schnall, Harber, Stefanucci & Proffitt, 2008), are affirmed (Shea & Masicampo, 2014), or reveal their secrets (Slepian, Masicampo & Ambady, 2013), they perceive situations and make judgments like those who are physically unburdened.

Taken together, these findings support that disclosure as openness is a salient metaphor, resting on premises that information has weight, and is held or released. Building on this, several lines of research support that priming openness increases disclosure of information. In one study, participants who were primed with openness concepts through word unscrambling tasks (a supraliminal prime) wrote more information about themselves and their feelings about a personal experience than those who were not primed with openness (Grecco, Robbins, Bartoli & Wolff, 2013).

Openness can also be activated through the environment. In two studies, researchers asked participants to imagine that they were in a patient consulting room waiting to see a doctor; to aid their visualization,

participants were shown a picture of either a large or small room. Results converged: participants were more comfortable and more likely to intend to disclose personal information to the doctor when the consultation took place in the larger, as opposed to smaller waiting room (Okken, van Rompay & Pruyn, 2012a). Building on the finding that perceived spaciousness influenced intentions to disclose, researchers tested whether putting people in a more or less spacious room would influence their decisions to disclose sensitive personal information (Okken, van Rompay & Pruyn, 2012b). In this study, participants were interviewed about behaviors such as substance use, sexuality, and negative emotional experiences in either a large or small room that featured either a large or small desk. Results indicated that increased spaciousness, via a larger room or a larger desk, led people to self-disclose more personal information than those placed in a small room or with a small desk.

Priming Openness in Investigative Interviews

Effects of the physical environment on a person's behavior has been studied in therapeutic, medical, organizational, retail, and other contexts. Presently, there is no research which examines how the interview room space may encourage or discourage cooperation and positive dynamics with an interviewer. Given the importance of eliciting reliable, actionable information from people in investigations, our research has sought to apply basic principles of priming and embodied cognition to the interview setting. In a series of studies, we have explored the effectiveness of cognitive and contextual manipulations of openness on peoples' information disclosure and experience in simulated investigative interviews. Our procedure is as follows: participants (adult community members) arrive to the lab and are tasked with delivering a flash drive to a member of a potentially radical environmental organization. The environmentalist (a research confederate) introduces the participant to the organization's mission and then plugs in the flash drive, which plays a recorded message from the ostensible group leader. The recording contains about 25 details of an eco-terrorist attack against a natural gas company. Participants are asked to remain quiet about anything they overheard and are given pictures to bring back to the lab. Back in the lab, participants await being interviewed in a simulated intelligence interview. Prior to the interview, they are put in a decision-making dilemma. Specifically, participants are told that while being cooperative may earn them the liking of the interviewer, and a potential reward for information, disclosing information can also draw the interviewer's suspicion, with a potential for further interviewing and investigation. Participants are then interviewed in a semi-scripted, structured information gathering style interview. After being interviewed, participants are given questionnaires to assess their impressions of the interview and interviewer. Our outcomes of interest are the details about the organization and plot that they disclose to the interviewer, as well as their perceptions of the interviewer (on items such as trustworthiness, closeness, friendliness). For a full description of the method, see Dawson, Hartwig, & Brimbal, 2015.

Priming openness using secure attachments. In our first study, we used a cognitive priming method. That is, we sought to activate the concept of openness by asking participants to mentally reflect on a secure, trusting relationship they have with someone. Attachment theory posits that people are innately motivated to seek secure, trusting attachments with others (Bowlby, 1982); drawing from this, empirical research supports that when secure attachments are activated, people behave more "securely" – that is, they exhibit less bias, more compassion, and more altruistic behavior than those who are not primed or primed with other attachment styles (Mikulincer & Shaver, 2005). We expected that participants primed with a secure attachment (compared to a non-primed control group) would be more likely to view the interviewer as someone they could trust and confide in, in turn leading to greater information disclosure and forthcomingness. In other words, we expected that qualities associated with the secure attachment activated in participants would transfer onto the interviewer, leading participants to feel securely. While we did not find support for the hypothesized transference mechanism, participants primed with a secure attachment were more forthcoming than those who were not primed. On average, participants primed with a secure attachment disclosed about eight details (compared to an average of

six details from the non-primed participants) and primed participants were more likely to provide a statement alluding to a threat or the plot specifically than those who were not primed, who typically provided a statement assuring the interviewer that the group was non-violent (see Dawson et al., 2015).

Priming openness through an open setting. After finding support for cognitive manipulations of openness, we examined the influence of a contextual prime on participants' willingness to disclose information about the eco-terrorism conspiracy (Dawson, Hartwig, Brimbal & Denisenkov, 2017). Drawing from theories of embodied cognition and metaphoric transfer, we tested a theory-driven hypothesis that a setting designed to prime openness would promote disclosure, while an enclosed setting would lead to withholding behavior. That is, we expected that people would "open up" to the interviewer about the plot when placed in a more spacious setting with openness primes, and that they would "close up" when interviewed in a small, bare interview room. In one study, after completing the courier task described above, participants were escorted to one of two interview rooms. The *control setting* was modeled after a prototypical custodial interview room: it was small, bare, and windowless, featured a two-way mirror, and had fluorescent overhead lighting. The experimental, *open setting* was designed to prime openness: it was twice the size, had windows, softer lighting, and included several objects to prime openness (e.g., pictures of open spaces, an open book). Our results indicated a clear enhancing effect for the spaciousness of the room on disclosure. On average, participants who were interviewed in the open setting provided about eight details about the plot (including four critical details, those deemed most actionable), compared to the five details (three critical) on average that participants who were interviewed in the control setting provided. In addition, the content of their statements differed. Participants interviewed in the open setting tended to provide a statement encouraging the interviewer to continue investigating the organization as a threat, whereas those interviewed in the control setting tended to provide a statement indicating that the group was not suspicious or worthy of further investigation.

Following up on this study, we conducted a second study to replicate the space effect and isolate the influence of the spatial and object manipulations. Using the same procedure, participants were escorted to one of four setting conditions resulting from a 2 (space: small or large) x 2 (objects: present or absent) between-subjects design. As in the first study, the small room was the same control setting, and the large room was a room approximately four times bigger; the object primes remained the same. Thus, after their delivery task, participants were interviewed in either the control setting without object primes, the control setting with object primes, the open setting without object primes, or the open setting with object primes. Results found a main effect for the spaciousness of the room, replicating the finding from the first study that a larger space promotes disclosure. There was no enhancing effect for the object primes in the open setting, indicating that disclosure is primarily influenced by the size of the room one is interviewed in. In fact, the object primes appeared to backfire in the control setting by increasing people's concern that the interviewer was suspicious of them.

Priming warmth to enhance rapport. Building on our findings that implicit, metaphoric influences operate in interview contexts and can be exploited to promote disclosure, we sought to examine the concept and influence of warmth in relation to interpersonal perceptions of interviewers. Researchers and practitioners agree that positive, maintained rapport between the interviewer and subject can be critical to eliciting information, and that a lack of, or damaged rapport can irreversibly hinder cooperation (Alison, Alison, Noone, Elntib & Christiansen, 2013). In a study, we tested cognitive and contextual manipulations of warmth in order to see if we could prime people to view the interviewer more "warmly," and to see if enhanced rapport lead to greater disclosure (Dawson, Hartwig, Hellgren, & Luke, in preparation). Here, we manipulated warmth through the interview setting and a cognitive priming task. The *control setting* was small, drab, windowless, and had overhead fluorescent lighting; participants and the interviewer were seated in rigid chairs across a small table from each other. The *warm setting* was a comparably small space in the corner of a larger room, with dimmer lighting, a red

area rug, comfortable red chairs, and various objects designed to prime warmth (e.g., small heaters, pictures of warm places, a blanket). The priming manipulation included sentence unscrambling tasks and a brief bogus personality measure designed to encourage participants to rate themselves as warm, genuine people. Thus, there were four groups of participants resulting from a 2 (setting: control versus warm) x 2 (prime: warmth versus none) between-subjects design. One quarter of participants were interviewed in the control setting without being primed, one quarter of participants were interviewed in the control setting and were primed with warmth, one quarter of participants were interviewed in the warm setting without being primed, and one quarter of participants were interviewed in the warm setting and were primed with warmth. Our outcomes of interest were ratings of the interviewer (as a proxy for rapport) and information disclosure. Results indicated that neither the room setting nor the priming alone influenced rapport ratings or disclosure. However, we observed an interaction between the room setting and priming by which participants who were primed with warmth in the control setting reported significantly more positive impressions of their rapport with the interviewer than all other participants. Specifically, participants who were primed with warmth in the control setting rated the interviewer as more respectful, more engaged, more caring, more trustworthy, and friendlier than all other participants.

The Present Research

In our previous studies, we have found that openness and warmth can be activated through cognitive and contextual primes to influence interviewees' perceptions and behavior. In each of these studies, the cognitive manipulations occurred prior to the interview, limiting their utility to practitioners. The current study builds on this by examining whether openness primes *can be delivered by the interviewer within the interview itself.* That is, we hypothesized that employing an interview script that involved a semantic priming of openness through the use of words related to the concept of openness would lead to greater forthcomingness and more information disclosure compared to an interview script without such words. Specifically, we predict that:

H1: Participants primed with openness will show greater cognitive activation of openness concepts than participants who are not primed.

H2: Participants primed with openness will be more forthcoming than participants who are not primed.

H3: Participants primed with openness will disclose more information than participants who are not primed.

Method

Participants

We recruited 100 adults from the community via online advertisement. 7 participants failed the manipulation check and two provided unusable data, so our final sample consisted of 91 adults between the ages of 18 and 63 years old (M = 33.0, SD = 12.2). 53% were female; by race/ethnicity, our sample was 38% White, 33% Black or African-American, 15% non-White Hispanic, Latino, or Spanish, 10% Asian, and 4% Mixed Race/Other.

Procedure

After arriving to the laboratory and providing informed consent, participants were provided with task instructions. They were asked to imagine themselves as affiliated with an environmental organization whose activities were peaceful, but which included members suspected of violent radicalism, and then they were asked to deliver a flash drive ostensibly containing details about an upcoming event to a (confederate) member of the organization (this paradigm was adapted from Dawson et al., 2015). The confederate informed participants about the mission of the organization and then plugged in the flash drive, which played a message containing details about a bomb plot aimed at interrupting the operations of a natural gas company. After listening to this information, the confederate asked them to not disclose anything about the plans that they had just been exposed to.

When returning to the laboratory, participants completed a brief recognition test to verify that they encoded the critical details, especially about the nature of the plot they overheard, which served as our manipulation

check. They were then informed that the interviewer was investigating a plot to attack a major corporation, that he knew they had met someone involved with the plot, and that the interview would concern the details of their interaction. Additionally, participants were told that being cooperative had benefits of minimizing their own involvement, gaining the interviewer's favor, and a possible reward for providing information, but that greater knowledge may also raise the interviewer's suspicions about their involvement, potentially resulting in further investigation. They were given a few minutes to prepare their statements.

Participants were randomly assigned to each condition. The interviewer came in and introduced himself, stating that he was there to gather information. In order to semantically prime openness, we manipulated his elaboration on the nature of the interview. This manipulation was pilot tested in a separate study: 68 participants were read either the experimental or control script and after three minutes of filler tasks, they completed a 36-item word stem and fragment completion measure, with 18 target words relating to openness and disclosure. Results indicated that participants who heard the experimental script completed more openness-related words (M = 3.8, SD = 1.8) than participants who heard the control script (M = 3.1, SD = 1.4) on the word completion measure, $t(66) = 1.858$, $p = .06$, $d = 0.45$.

In the experimental condition, the interviewer used words relating to openness:

"I want to be *clear* with you about the purpose of this interview and hope that you feel *free* to *come forward* with anything you may have been *exposed* to... that you *trust* me enough to be *forthcoming* and *honest* about your experience. This interview is a *space* for you to be *open* and *air out* any concerns you may have. Do you have any questions before we proceed?"

In the control condition, the interviewer used a comparable script, but with neutral words:

"I want you to understand the purpose of the interview. It'd be great if you could provide me with information about your experience. I hope that we can have a good working relationship as we meet today. This interview is a place where you can tell me about any concerns you have. Do you have any questions before we proceed?"

The interviewer then asked all participants if they could tell him about their day and whether they'd done anything unusual or met anyone new. When interviewees were withholding, the interviewer had two scripted prompts to employ to try to get them to be more forthcoming: one prompt assured the interviewee that s/he was not under suspicion, and one appealed to their morality about the dangers of extremism. The use of prompts varied depending on interviewees' disclosure, but both prompts were used with all withholding interviewees, giving them an equal number of opportunities to be forthcoming. The interviewer concluded all interviews asking the interviewee if there was anything else of importance they wanted to disclose. Thus, in total, everyone received two-to-four chances to provide information. All interviews were conducted by a research assistant with extensive experience of interviewing in laboratory studies.

Following their interview, participants were given dependent measures and a suspicion probe about the purpose of the study. They were then debriefed, compensated, and thanked for their time.

Measures. Participants completed a 36-item word stem and fragment completion measure, with 18 target words relating to openness and disclosure.

Participants' information disclosure was measured in units of information. Information was broken down into non-critical and critical details, creating two scores: overall details about the organization and plot, and critical details about the organization and plot. The *overall details* measure includes critical details and non-essential details about the organization and the plot (e.g., the highway route to the site, past activities of the organization). The *critical details* measure includes the organization's name, its members, the specific plot to bomb a fracking site, the corporate target, the attack date, the location of the attack, and details about the escape plan. There was also a 7-point continuous measure of *forthcomingness*, ranging from 1 (extremely withholding,

i.e., did not even admit to meeting anyone new that day) to 7 (extremely forthcoming, i.e., disclosed everything s/he could remember).

Coding Procedure. Two research assistants with experience coding statements coded a random 20% subsample of the videos. We conducted interrater reliability analyses to measure agreement between coders on overall details, critical details, and the rating of forthcomingness. The raters achieved near-perfect reliability on each measure (all ICCs = 0.956 - 0.986) and resolved discrepancies through review and discussion. The remaining videos were randomly assigned and split between the two coders.

Results

Word Completions

Results showed that participants who were primed with openness concepts completed more openness-related words (M = 4.3, SD = 1.6) on a word completion measure than participants who were not primed (M = 3.7, SD = 1.6), $t(79) = 1.569$, $p = .06$, one-tailed, d = 0.35. Thus, our first hypothesis was partially supported.

Information Disclosure

Participants who were primed with openness concepts during the interview were rated as more forthcoming (M = 4.3, SD = 2.1) than participants who were not primed (M = 3.6, SD = 1.95), $t(88) = 1.605$, $p = .056$, one-tailed, d = 0.34. Hence, our second hypothesis received support. Participants who were primed provided more overall details (M = 6.5, SD = 4.8) than participants who were not primed (M = 5.5, SD = 4.6), but this difference was not significant, $t(88) = 1.045$, $p > .1$, d = 0.22. Participants who were primed also provided more critical details (M = 3.4, SD = 2.7) than participants who were not primed (M = 3.1, SD = 2.9), though this difference was not significant, $t(88) = 0.469$, $p > .1$, d = 0.1. As such, our third hypothesis was not supported.

Discussion

This study builds on our previous research on implicit influence in investigative interview studies. Here, we were interested in whether semantic priming could be built into an interview script. We conducted a simple experiment comparing information disclosure as a function of two different interview scripts; one script included words related to openness, and one excluded these words.

The results generally support our previous research: participants who were primed with the concept of openness disclosed more information compared to participants who were not primed. This makes sense based on the pilot study we conducted, where we found that participants who were exposed to the experimental interview script tended to complete more words consistent with the concept of openness (using a word completion task) compared to those who received the control script. In other words, the pilot study suggested that the interview script indeed lead to a cognitive activation of openness. Importantly, the main study showed that this effect held through a sustained interaction with an interviewer, in that participants in the experimental condition conveyed more information about the mock terrorism conspiracy to which they had been exposed. From the perspective of implicit cognition, this is an important finding: it suggests that priming effects can go beyond affecting static interpersonal impressions, and manifest themselves through a social interaction.

The practical implications of these results are clear: based on our study, it seems that the language used by an interviewer can have a subtle but powerful effect on the behavior of interviewees. More specifically, interviewers can strategically tailor the semantic structure of the interview in order to accomplish desired goals. Eliciting information from sources is a critical challenge of interviews in investigative and intelligence gathering contexts. Our research suggests that a simple manipulation of the language used during an interview can push interviewees in the direction of disclosure. Of course, we are not suggesting that semantic priming should be the sole component of attempts at information

disclosure. We recognize the importance of rapport-building, the use of open-ended questions, etc. These results suggest that semantic consideration - put simply, the words employed by the interviewer - when framing their questions or the interview as a whole can be a complement to previously establish principles of effective interviewing. Indeed, new research suggests that priming manipulations can complement explicit interviewing techniques to influence people's emotions and behavior. In a series of studies, Meissner and Swanner (in preparation) looked at how priming concepts and overt interviewing approaches (i.e., direct requests, context reinstatement instructions) influenced people's feelings about and willingness to provide details regarding transgressions they have previously committed. In one study, they found that priming openness and closedness via cognitive tasks complemented the interviewing approach to influence how negatively (shameful, remorseful, guilty, etc.) people felt about their transgressions: those primed with openness and interviewed with a context reinstatement felt less negatively about their transgressions, whereas participants who were primed with closedness and directly asked to provide information felt more negatively (Study 1). In a separate study, priming concepts of coldness (e.g., aloof, distant) interacted with a rapport-based approach to enhance information disclosure, revealing a contrast effect that benefitted disclosure (Study 3).

As with any research, our methodology is not without limitations. Because we employed an experimental approach with a mock terrorism paradigm, the primary concern is the external validity of these findings. That is, would our results generalize across populations and settings? While we believe that the general mechanisms of priming are likely to be universal rather than culture-specific, it would be interesting to replicate these findings using a non-Western sample, especially given the fact that many interviews in the human intelligence collection domain are cross-cultural in nature. It is also important to examine the extent to which the initial level of cooperation of the source plays a role. Here, we attempted to put all participants in a state of mind where they were aware of the potential risks of disclosure, but also of the possible benefits of cooperation. Thus, we tried to create a situation in which participants were neither extremely motivated to withhold information nor extremely motivated to disclose. It is an empirical question whether semantic priming would be effective for a source who is extremely reluctant to comply with the interviewer's request for information. While it might be methodologically difficult to examine this question, it is practically important, and we suggest future research should be pursued.

In conclusion, our study supports and extends our previous research showing that priming of openness concepts can have beneficial effects on interviewees' tendency to provide information. These findings are easy to translate to practical context. However, we recommend that continued research examine the generalizability of these findings across cultures and contexts.

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Whether or Not ASL Interpreters are Needed to Administer Polygraph Examinations on Deaf Individuals

Kelly Roth, Jessica Bentley-Sassaman, and Kristin Lizor

Abstract

A comparative study on deaf populations tested the effectiveness of administering a polygraph examination first without an interpreter and then with an interpreter. The study results suggested that there is a higher chance of successfully completing a polygraph examination when a certified ASL legal interpreter is provided. The pretest interview questions should be modified for the population because in many cases English is not their first language. In addition, the researchers found that when a polygraph examination booklet/mock pre-employment screening booklet that was used it also needs to be modified.

Keywords: *polygraph, deaf, ASL legal interpreter*

Introduction

This quantitative study examined the effectiveness of administering a polygraph test to a deaf person by utilizing two approaches to communication: 1. Only the polygraph examiner and the deaf participant (no interpreter) and 2. An ASL interpretation using a hearing certified legal interpreter who can hear. This exploratory study was conducted in an attempt to determine the proper method that should be utilized when conducting a polygraph examination on Deaf and hard-of-hearing individuals. This study examined the reliability and effectiveness of the polygraph examination with and without a nationally certified interpreter present. This research is important because no previous quantitative studies examining polygraph examinations conducted on Deaf and hard-of-hearing individuals exists. A demonstration was conducted on giving polygraph examinations to Deaf participants but none compared the administration of the polygraph with and without an interpreter. Some studies utilized an interpreter, others used a person who knew sign language but was not an interpreter, and others did not provide access to the information in ASL. The majority of the existing studies required the participant to lip read. As all of the participants used sign language to communicate we are using Deaf (with a capital D) to denote cultural affiliation.

This research study was conducted two faculty members in the American Sign Language (ASL)/English Interpreting Program and one faculty member from the Criminal Justice Program at Bloomsburg University. The Bloomsburg University Institutional Review Board serial number for this study was 2016-46. The criterion for assessing a completed polygraph examination was the ability to obtain readable charts and to complete the polygraph examination process with and without an interpreter being provided. This

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study was necessary to attempt to determine the proper protocol for conducting polygraph examination on Deaf and Hard-of-Hearing individuals who are involved in the criminal justice system or in some way asked to take a polygraph.

Methods

This quantitative study used a within-subjects design to compare the number of completed polygraph charts (ranging from 0 to 3) which was our dependent variable during phase I versus phase II of the study. The study was designed to answer the following research question:

Research Question 1. Is there a statistically significant difference in the number of completed polygraph charts when a hearing interpreter is used versus no use of an interpreter?

Hypotheses:$H1_{0:}$ There is no statistically significant difference in the number of readable polygraph charts when a hearing interpreter is used versus no use of an interpreter.

H1a: There is a statistically significant difference in the number of readable polygraph charts when a hearing interpreter is used versus no use of an interpreter.

$H1_0$: There is not a statistically significant difference in the number of readable polygraph charts when a hearing interpreter is used versus no use of an interpreter.

SPSS software was utilized to examine the quantitative data for this research study. Descriptive statistical analysis was conducted for the participant demographics. The treatment conditions being without an interpreter and with an interpreter. A paired-sample *t*-test was conducted for the inferential statistical analysis. A *t*-test is used to examine whether the differences between two means are significantly different from zero (Field, 2013). An advantage of this type of study is that it uses exactly the same participants are used for all treatment conditions (Gravetter & Wallnau, 2008; Field, 2013). Using the same participants helped eliminate potential extraneous variables that may affect the results. The within-subject design was also less time consuming because the participants only had to complete one mock polygraph pre-employment screening booklet (DACA, 2008). The same polygraph booklet was used for each phase of the study.

The within-subjects designs is also known as the repeated-measures design (Jackson, 2012). Within-subjects designs require fewer participants than between-subject designs, yet there is more statistical power when the within-subjects design is utilized (Jackson, 2012). One problem that can occur in the within-subjects design is the order effect (Jackson, 2012). The order effect occurs when the order of the conditions has an effect on the dependent variable (Jackson, 2012). The order effect can be controlled for through counterbalancing. The researchers decided not to use counterbalancing because if an interpreter was provided during the first phase for some participants it would significantly impact their understanding during the phase when they were not provided an interpreter.

Counterbalancing requires randomly presenting the treatment for each subject (Jackson, 2012). The order effect was not a concern in this study because there are no known requirements to limit the number of times and the time period between taking polygraph examinations. In this study, counterbalancing could have resulted in the participant understanding more without an interpreter because of the previous polygraph experience when the participant was provided and interpreter. As a result, it was determined that all participants should take the polygraph without an interpreter during the first phase and with an interpreter during the second phase.

The participants in this study were all deaf and were from the eastern part of Pennsylvania, ranging from the northeast to the southeast. The participants volunteered to attend two different study dates, the first date was part of Phase I and the second date was part of Phase II. At the end of Phase II participants were paid $60 for their time attending both dates. Payment only required attendance on both dates. The participants were advised that the results of their polygraph examination would not influence their payment. There were 14 participants in this study. The study was

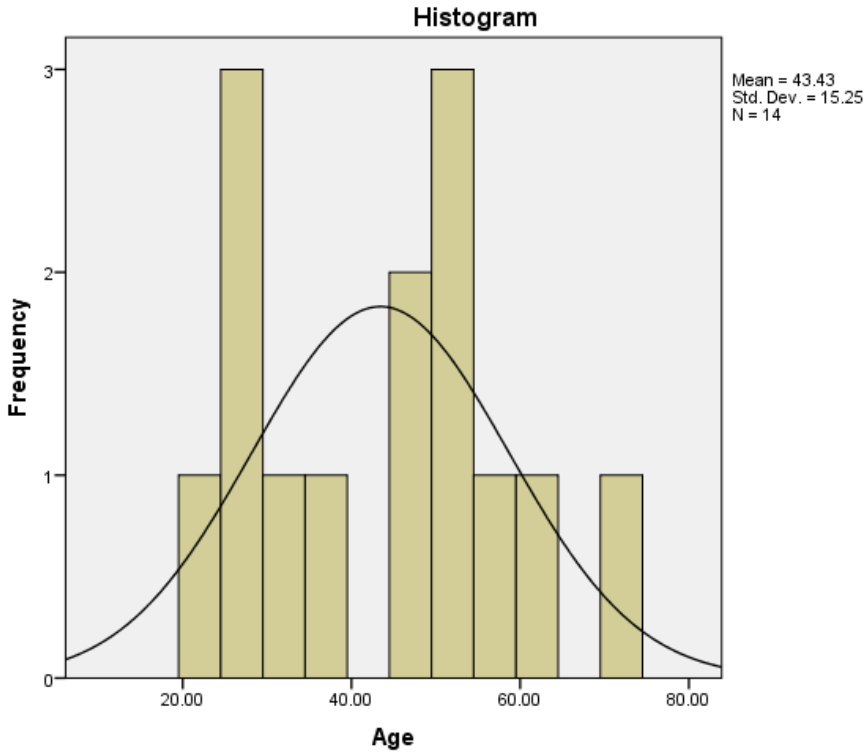
advertised through a flyer which was emailed out to an interpreting agency in the south-east portion of Pennsylvania and also through email recruitment by two of the researchers in addition to Facebook posting of the research study. In order for a person to participate he or she had to meet the following criteria stipulated by an experienced polygraph examiner who conducted all exams:

1. must be age 18 or older
2. must not be pregnant
3. must not have seizures
4. must not have any heart conditions
5. must not be using mind altering substances
6. must not be on probation or awaiting trial

Over twenty-three people contacted one of the researchers and out of those 23, 15 participants applied and were accepted to participate in the study after it was determined they met the criteria. One participant had a medical emergency and had to withdraw prior to the study, the other 14 participants were able to complete the study. Twelve of the participants were Caucasian, one was Hispanic and the other was Asian. The participants were between 22-70 years old. The mean age was 43. The histogram shows that the age of participants that participated in this study was a normal distribution.

The majority of the participants relied on ASL as their preferred communication style (71%). The other 29% commented that they used a mix of ASL and more English grammar signing. All of the participants were emailed a copy of the mock pre-employment screening booklet which was modified by the research team (see appendix for the modified booklet). The original version of this booklet was provid-

Figure 1. Histogram of Participant Ages



ed to the team by the polygraph examiner and was used because of the wide variety of questions. The team removed questions that were:

1. specific to law enforcement

2. specific to mandated reporting

Some of the questions were modified to ask about work history in general instead of specific to law enforcement. The wording of other questions were modified to make them more understandable to the deaf participants as studies have shown that deaf people often graduate high school at a third or fourth grade reading level (Andrews, Vernon, & LaVigne, 2007). A confounding variable when testing persons in a language that is not their primary means of communication is a serious concern.

Once the participants arrived to the study site, they were all given consent forms from the research team and from the polygraph examiner. The forms, which were written in English were also translated into ASL and shown to each participant so they had access to both ASL and English versions of the forms. Participants then signed off on the forms. They also either provided the already filled out modified mock pre-employment polygraph screening booklets to the researchers or filled them out on site when they arrived. Participants could have chosen between two sites to come for Phase I or Phase II of the study. One site was located in the northeastern part of the state and the second in the southeastern part of the state.

Participants were asked whether or not they were wearing any type of amplification devices to support their hearing loss. Three of the fourteen participants wore Cochlear Implants, one wore hearing aids, and the remaining participants used no amplification devices. Six out of 14 participants completed a bachelor's degree or higher. Three of the participants attended a trade school or took some college level courses. Five of the participants completed a high school diploma. Based on the Flesch-Kincaid scores from the writing sample and interaction with the researchers it was determined that 57% of the participants were bilingual, 29% were semilingual and 14% were bimodal bilingual. Bilingualism means that a person is competent in reading and written English and using ASL, semilingual means that a person is not proficient in either reading or writing English and the use of ASL grammar. Finally, bimodal bilingualism means that a person with a hearing loss can speak, or sign and is competent in reading and writing English and the use of ASL. This information was not used for findings in this study. This information was obtained and provided to show that the participants form various educations levels participated in this study. Fletch-Kincaid score after we made revisions to the mock pre-employment screening booklet was at a 10.2 level.

Figure 2. Flesch-Kincaid Scores

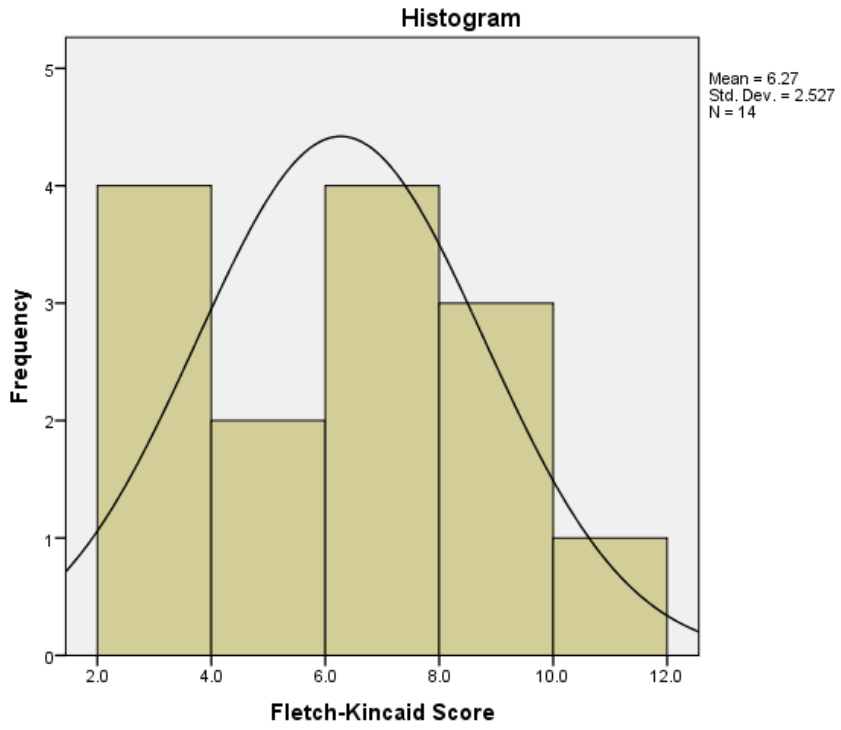
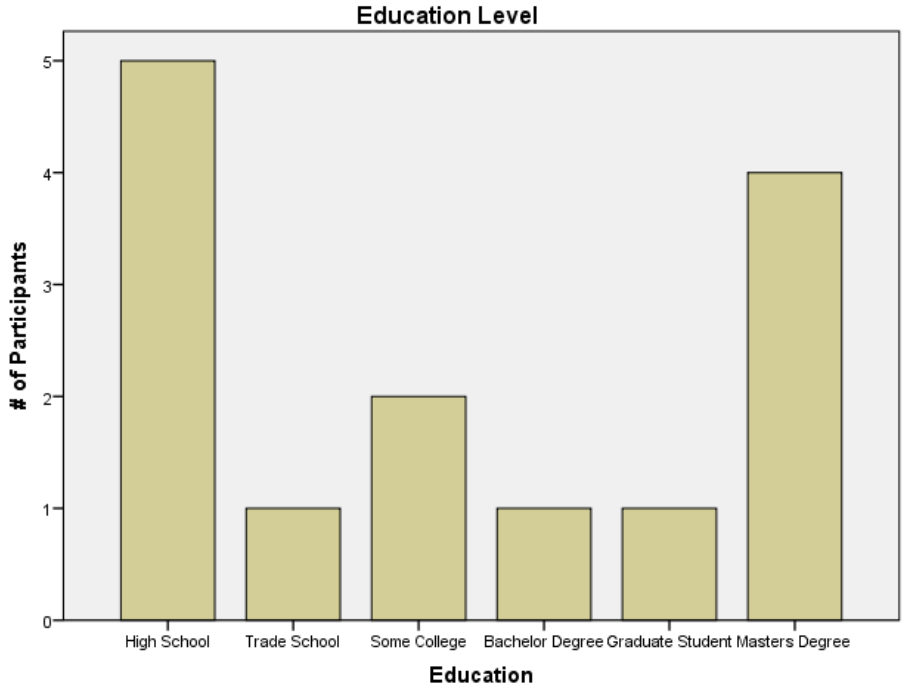


Figure 3. Education Level of Participants



Phase I

In Phase I participants went in for the pretest interview portion of the polygraph examination, then if possible the polygraph test, and then afterwards the results were reviewed with the polygraph examiner. The polygraph examiner used the DACA standards when analyzing any chart data. During Phase I there was no sign language interpreter provided to facilitate communication between the participants and the examiner. The examiner was given a tablet to write on by one of the researchers. The polygraph examiner had no experience working with individuals who were deaf and who used ASL to communicate. During the pretest, as the examiner reviewed the questions in the screening booklet he pointed to English words in the screening booklet, wrote on the tablet, and tried to have the participants read his lips. The examiner noted that the process was more time consuming but rapport was still able to be established. After the pretest concluded the participants had a short break, then returned for the polygraph examination, after which they had a break, then a review of the results was completed. Only 21% (three out of fourteen) of the participants were able to complete the polygraph examination. This was due to the breakdown in communication with the polygraph examiner and the participant when reading lips became the only means of communication when moving into the test phase or if the examiner felt that the examinee lacked comprehension of what was being asked of them during the pretest and ethically could not continue.

Phase II

During Phase II the same fourteen participants returned to one of the two sites. This time the participants and examiner were given an interpreter who was a nationally certified sign language interpreter and who held the Specialty Certificate: Legal from the Registry of Interpreters for the Deaf. This interpreter was from the southeastern part of the state and interpreted during the whole process, pretest interview, polygraph examination, and a posttest review of the results. After the posttest review of the results, the participants were interviewed by one of the research team members in ASL about their experiences comparing Phase I to Phase II. They also supplied a writing sample to be used to determine their reading level utilizing the Flesch-Kincaid. Thirteen out of 14 participants were able to complete the examination with this accommodation. This is an increase of 71% completion rate going from only 21% in Phase I to a 92% in Phase II. This was a result of communication not breaking down as much due to having an interpreter present.

Independent Variable

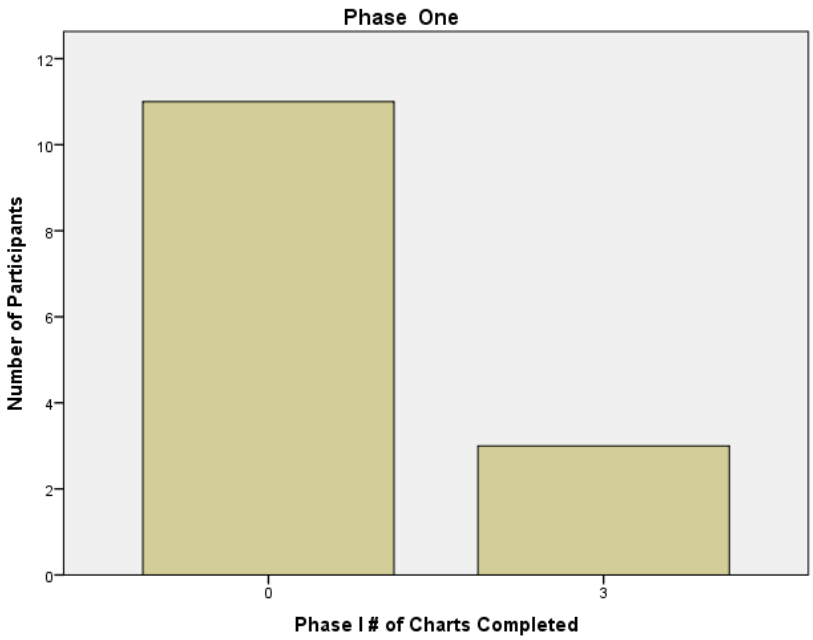
The independent variable for this study was Phase I and Phase II and the dependent variable is the polygraph examination results. The following test results with the possible outcomes for a completed exam are as follows Significant Response (SR), No Significant Response (NSR), and No Opinion (NO). Like all polygraph exams, this polygraph exam had a pretest, test, and posttest review format.

Results

Phase I

For the first phase of the study only, three participants were able to successfully complete the polygraph examination. Three charts that were able to be scored were obtained based on the DACA test data analysis numerical evaluation scoring system (DACA, 2006). The treatment effect, being provided an interpreter, did have statistically significant effect on the number of completed charts and the ability to successfully complete the polygraph examination, $t(13) = -5.70$, $p < .01$, $r^2 = .71$. The effect size was calculated using the following formula, $r^2 = t^2 / t^2 + df$. The null hypothesis was rejected. There was a significant difference in the number of completed charts. Significantly more charts were completed during Phase II of the study (see Figures 3 and 4). The value obtained, -5.70 is greater than the critical value; therefore, we concluded that the experimental manipulation has had an effect.

Figure 4. Completed Charts Phase I



Out of the three participants who were able to complete the polygraph examination, one had a No Opinion (NO) test result and the other two had a No Significant Response (NSR) test results. For the three completed exams with the test results, the examiner and Polyscore were in agreement. The NO response indicates that there is not enough data for a definitive SR or NSR test result. For our research, the NSR indicates that the person passed the polygraph. A pass means that the scoring was a +3 or better in each column. A Significant Response (SR) means that the scoring was -3 or greater in one of the sub-columns. Our examiner scored the charts himself using DACA standards for evaluating chart data and using the 3 point scale (-1, 0, +1) as per a DACA standard for Law Enforcement Pre-Employment Testing (DACA, 2008, p. 7). All our research tests conducted used a quick field expedient quality control, using Polyscore to see where saliences existed in the relevant and comparison test questions.

Again, only three participants were able to complete the polygraph process in Phase I; the remaining eleven were incomplete. Participant #4 had a NO test result. The main reason why she received this score was due to a large spider that startled her when she had seen on the floor while taking her exam. Participant #4 is afraid of spiders and being startled by one caused her to move and created artifacts during her exam that were not able to be scored by DACA standards.

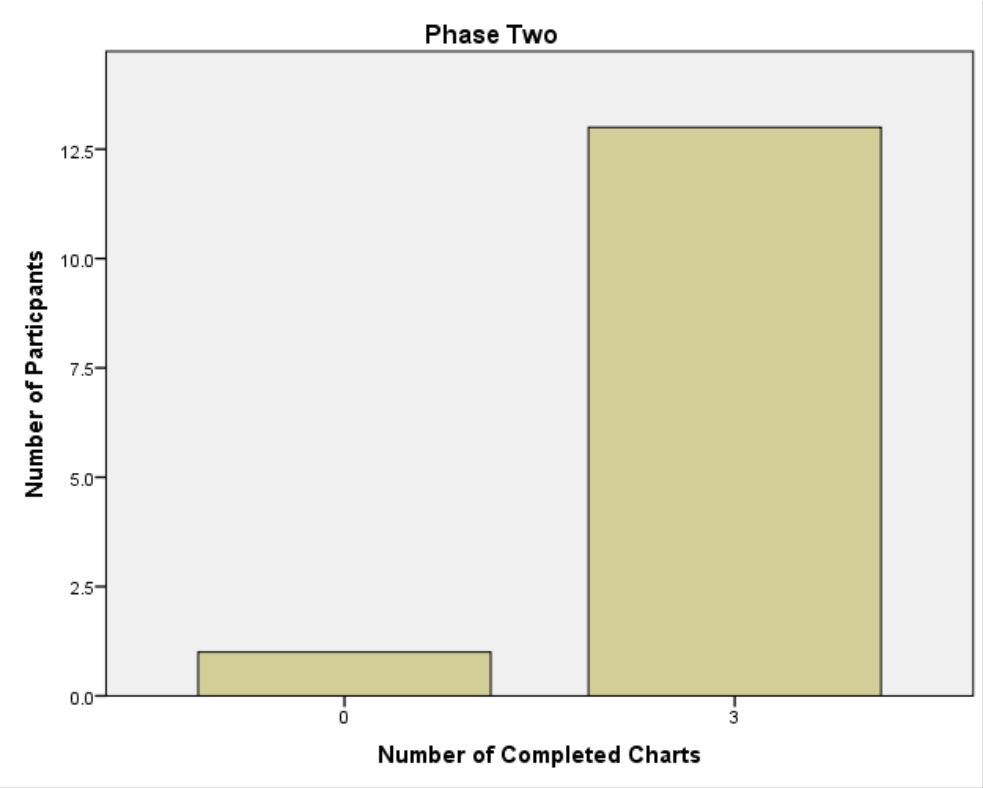
Phase II

In Phase II with the use of an interpreter, 13 out of 14 (93%) of the polygraph examinations were able to be completed. Twelve out of the 13 completed exams using Polyscore, concurred with the examiner's findings. The one time it did not, Polyscore had an NO, while the examiner had an NSR. The one polygraph exam that was unable to be completed in both Phase I and Phase II was Participant #10. The researchers and polygraph examiner posit that the communication breakdown was due to education level, reading ability, and lack of understanding of the words and phrases as noted by the examiner. Participant #10 scored a 2.9 on the Flesch-Kincaid and uses homemade signs along with ASL to communicate. People who are semi lingual have not mastered English or ASL (Andrews, 2013) and

this lack of mastery affected his ability to complete the examination. Even with the use of an interpreter, the lack of comprehension did not allow the examiner to ethically continue with the examination process.

The polygraph examiner's opinion with his NSR score versus Polyscore's NO score for Participant #4 was due to artifacts during that participant's chart data collection specifically during the last chart which is why a discrepancy existed between the two. Participant #4 received a NO for both the polygraph examinations due to too much movement during the tests. The remaining 12 exams; Polyscore concurred with the examiner's interpretation of the charts.

Figure 5. Completed Charts Phase II



For participants #1 and #8 the polygraph charts were determined to be SR. Polyscore had SR as well as the examiner. In the posttest interview with the examiner, Participant #1 and Participant #8 both admitted that they were not forthcoming with all the information, which also confirmed the SR results.

In Phase II Participants #4 and #15 the polygraph charts were determined NO. Participant #4 during their exam moved which created the artifacts resulting in NO. Participant #15 was nodding and moving her head, which created artifacts resulting in an NO test as well. Participant #13 was falling asleep during both Phases I and II polygraph. For Phase I she scored an NSR, but in Phase II she had scored an NO. In Phase II the polygraph examiner felt that Participant #13 was not a willing participant which resulted in their NO test results.

Discussion

This study examined the effectiveness of either not providing an interpreter or utilizing an interpreter during a polygraph examination when administering it to a deaf person. Based on the results of this study, the number of participants who were able to complete the polygraph examination increased from 21% to 93% and increase of 71 percentage points with the use of a nationally legal certified interpreter. This leads the researcher to believe that the use of interpreters should be provided to people who are deaf and who have identified ASL as their preferred mode of communication.

There were limitations to this study, such as the study taking place in only the eastern part of the state. The sample size was also small, only 14 participants were in the study. The study also only compared the use of no interpreter to the use of an interpreter and did not include the possibility of using a Certified Deaf Interpreter. One of the participants could not complete the pretest interview in Phase I and II due to his language and comprehension level. He may have benefitted from the use of a Certified Deaf Interpreter who can modify the language use to make it understandable to people who may have limited language abilities. Another limitation was the lack of a counterbalance design.

During the pretest phase, the polygraph examiner noted that many words in the booklet were not understood by the deaf participants. It is suggested that the booklet be modified when working with deaf people as for many of them ASL is their first language and English is their second language (if you would like a copy of the modified booklet, please contact the researchers). ASL and English have different grammatical structures which can make it difficult for second language learners to comprehend the terminology and grammar in the booklet. Even though the researchers modified the booklet, it was still at a tenth grade reading level. The polygraph examination booklet that was used in Andrews et al. (2007).

It is recommended by the researchers that a certified legal sign language interpreter is utilized as there are many legal terms in the booklet. Also, based on the findings, the use of a sign language interpreter provides effective communication for participants in order to be linguistically present during the examination. We also recommend that the interpreter is not from the same area as the deaf person who is taking the examination so there is less chance of a conflict of interest. During the study the interpreter knew some of the participants from the southeastern area and she recommended that an interpreter from out of that area be used in a real polygraph examination as she knew a few of the participants on a personal level. Interpreters are bound by the Registry of Interpreters for the Deaf's Code of Professional Conduct which indicates that all content that is interpreted must be kept confidential. Interpreters behave in a neutral, unbiased manner and keep all communication confidential. Signers, people who know sign language, but are not professional interpreters are not bound to the Code of Professional Conduct and are not recommended to be utilized for interpreting services.

Another recommendation based on personal experience of one researcher who has interpreted for polygraph examinations is that if the examiner has a deep voice, the deaf person may be able to hear the tone and that may then cause them to react prior to the interpreter signing the message. It was recommended by that examiner (who was not the examiner in this study) that the questions are

given to the interpreter who then translates the questions on cue of the examiner and the examiner does not speak during this time. A further recommendation would be to always provide an interpreter who communicates in a primary language that is different than the polygraph examiner.

Due to the nature of ASL, deaf people are very expressive and use their hands, arms, and body to communicate. Due to the nature of the SAT method, some of the Deaf people commented it was very hard to sit still for the entirety of the examination. Currently there is no normative data and validity information related the administration of polygraph examinations to Deaf individuals. Further research is needed with Deaf individuals related to test accuracy, effectiveness, and interpretation of countermeasures. This is important for an examiner to take note of as the movements of the person will be detected by the polygraph equipment and could potential impact the results. Also, examiners can assess the movements during the pretest interview to find the norm for that participant. Ethically, examiners should not test someone who is not competent in English and who may not be mentally competent to take the polygraph examination this is based on the APA Standards of Practice 1.2.4 these are not suitable candidates for a polygraph examination (APA, 2015). Based on the candidate not being suitable for polygraph examination due to language competence, it would be interesting to see if a Certified Deaf Interpreter could be utilized to further facilitate communication due to their ability to communicate in native ASL. Further research on the use of Certified Deaf interpreters should be conducted to see if their participation furthers the effectiveness for administering polygraph examinations.

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Bloomsburg University ASL/English Interpreting and Criminal Justice Research Study

Polygraph Screening Booklet

Participant #			
IRB # 2016-46			
Polygraph Examiner's Name			

POLYGRAPH SCREENING BOOKLET CONFIDENTIALITY AGREEMENT AND INSTRUCTIONS TO APPLICANTS

1. **As an applicant taking this research study IRB #2016-46 Polygraph Examination, I certify that I will not divulge to anyone, anything about the polygraph questions or any facet of this examination.**
2. You are advised that the contents of this booklet are held strictly **CONFIDENTIAL** and No information will be disseminated to any person. Every answer entered will be reviewed during the polygraph examination.
3. If you wish to submit a long explanation in your reply to any question, answer the question briefly and then place a check mark next to the question number. The examiner will give you an opportunity to make any explanation regarding any question marked.
4. By placing your signature in the space allotted below, you are giving us your written permission for the examiner to administer the polygraph examination.
5. Answer every question in this booklet. If the question is Not applicable, enter "N/A."
6. All corrections shall have a single line through the incorrect answer and be initialed.
7. Print legibly all information in this booklet.

_____
Printed Name of Applicant (First-Middle-Last)

_____
Signature of Applicant

_____
Date

THE POLYGRAPH EXAMINER IS AUTHORIZED BY THIS RESEARCH STUDY IRB #2016-46 TO DETERMINE IF YOU HAVE BEEN TRUTHFUL IN YOUR RESPONSES TO THE QUESTIONS REGARDING PERSONAL DATA, EDUCATION, MARITAL STATUS/DEPENDENTS, AND OTHER INFORMATION.

PERSONAL DATA

1. Number_____

2. Date of Birth _____

3. Any other names used applicant_____

_____

4. Explanation for use of other names _____

_____

5. Current Residence _____
(Number) (Apt No) (Street)

_____
(City) (State) (Zip Code)

6. Telephone Number _____

EDUCATION

7. Did you graduate from High School? ☐ Yes ☐ No _____ Year Graduated

(a) G.E.D. _____ Year Obtained

8. Name of high school attended _____

9. City/State of high school _____

10. Did you graduate from college? ☐ Yes ☐ No _____ Year Graduated

(a) Approximate number of credits _____

11. Name of college attended _____

12. City/State of college _____

MARITAL STATUS/DEPENDENTS

13. Single ☐ Married ☐ Divorced ☐ Widowed ☐

14. Spouse's maiden name _____

15. Do you have any children? ☐ Yes ☐ No

Name	Sex	Age
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

16. How long have you been married? _____

17. Is this your first marriage? ☐ Yes ☐ No

18. Have you ever hit, slapped or struck your spouse or significant other? ☐ Yes ☐ No

Explain: _____

19. Have you ever been the subject of a Protection from Abuse Order? ☐ Yes ☐ No

If Yes; Explain (Where, When, Police Agency, County and Date) _____

_____

20. Are you currently paying alimony or child support? ☐ Yes ☐ No

If yes; are payments being made voluntarily or court ordered? ☐ Yes ☐ No

OTHER

21. Have you ever been given a polygraph examination? ☐ Yes ☐ No

22. Were you denied or turned down for a job as a result of the polygraph examination? ☐ Yes ☐ No

23. Are you presently, or have you ever participated in organizations advocating violent interruption of government operations? (Militia, etc) ☐ Yes ☐ No

If Yes; Explain _____

_____

24. Have you ever been a member of a group who advocates discriminatory acts against persons due to their race, religion or sexual orientation? ☐ Yes ☐ No

If Yes; Explain: _____

25. Have you ever been questioned by law enforcement authorities? ☐ Yes ☐ No

If Yes; Explain: _____

26. Have you ever been placed on probation/parole or accepted on the ARD Program as a juvenile or adult? ☐ Yes ☐ No

If Yes; Explain: _____

27. Have you ever lied under oath in Court? ☐ Yes ☐ No
If Yes; Explain: _____

28. Have you ever been fingerprinted by any law enforcement agency? ☐ Yes ☐ No
If Yes; Explain (Why, Where, When and Agency): _____

_____

29. Did you get money from criminals? ☐ Yes ☐ No
If Yes, Explain: _____

30. Have you ever stolen anything while working? ☐ Yes ☐ No
If Yes, Explain: _____

31. Did you accept a bribe from anyone? ☐ Yes ☐ No
If Yes, Explain: _____

32. Did you touch or destroy evidence? ☐ Yes ☐ No
If Yes, Explain: _____

33. Did you keep the evidence or throw it away? ☐ Yes ☐ No
If Yes, Explain: _____

34. Did you erase sensitive information from a computer?
☐ Yes ☐ No
If Yes; Explain: _____

35. Have you ever hide evidence? ☐ Yes ☐ No
If Yes; Explain: _____

36. Were you ever asked not to work for a while (suspended)? ☐ Yes ☐ No

If Yes; Explain: _____

37. Did you ever life for a friend or family member who broke the law? ☐ Yes ☐ No
If Yes; Explain: _____

38. Did you share any information about the case with family or friends? ☐ Yes ☐ No
If Yes; Explain: _____

39. Did you lie on any file, computer, or police report? ☐ Yes ☐ No
If Yes; Explain:

40. Have you ever participated in a sex act while at work at any job? ☐ Yes ☐ No

If Yes; Explain: _____

41. Have you ever showed up to work at any job while impaired or intoxicated?
☐ Yes ☐ No

If Yes: Explain: _____

42. Are you currently under any pending police investigations? ☐ Yes ☐ No

If Yes; Explain: _____

THE POLYGRAPH EXAMINER IS AUTHORIZED BY THIS RESEARCH IRB #2016-46 TO DETERMINE IF YOU HAVE BEEN TRUTHFUL IN YOUR RESPONSES TO THE QUESTIONS REGARDING CRIMINAL JUSTICE WORK/EMPLOYMENT.

EMPLOYMENT

43. Have you ever been terminated, disciplined or reprimanded by an employer for poor performance, missing work, abuse of leave or sick time, sexual harassment or any other reason not listed? ☐ Yes ☐ No

If Yes; Explain: _____

_____

44. Have you ever been suspended, removed, FIRED or resigned from any position or job?
☐ Yes ☐ No

If Yes; Explain: _____

_____

45. Did you ever lie on a job application or cheat on a test in school? ☐ Yes ☐ No

If Yes, Explain:_____

THE POLYGRAPH EXAMINER IS AUTHORIZED BY THE RESEARCH STUDY IRB# 2016-46TO DETERMINE IF YOU HAVE BEEN TRUTHFUL IN YOUR RESPONSES TO THE QUESTIONS REGARDING YOUR CREDIT HISTORY.

CREDIT

46. Have any debts that you owe(d) ever been turned over to a collection agency?
☐ Yes ☐ No

If Yes; Explain why: _____

47. Do you attempt to pay your debts in a timely manner? ☐ Yes ☐ No

If No; Explain: _____

48. Have you filed for bankruptcy? ☐ Yes ☐ No

If Yes; Explain when and Where: _____

49. Have you ever had anything repossessed? ☐ Yes ☐ No

If Yes; Explain _____

50. Do you have any undocumented loans / debts to Non-family members (i.e. bookies, loan sharks, etc.)? ☐ Yes ☐ No

If Yes, explain: _____

_____

51. Have you ever deliberately written bad checks knowing that there was no money in your Checking account or on a closed account? ☐ Yes ☐ No

If Yes; Explain: _____

52. Have you ever used credit cards or ATM cards that were not yours or fake? ☐ Yes ☐ No

If Yes; Explain: _____

_____

THE POLYGRAPH EXAMINER IS AUTHORIZED BY RESEARCH STUDY IRB #2016-46 TO DETERMINE IF YOU HAVE BEEN TRUTHFUL IN YOUR RESPONSES TO THE QUESTIONS REGARDING YOUR DRIVING HISTORY, VEHICLE ACCIDENTS AND TRAFFIC VIOLATIONS.

ACCIDENTS/TRAFFIC VIOLATIONS

53. Do you have a valid license? ☐ Yes ☐ No

54. How long have you had your driver's license? _____

55. List **ALL** accidents that you have had as the operator of a vehicle, include approximate dates, citations issued, investigated by police: _____

_____

_____

56. Had you been drinking prior to any of the above listed accidents? ☐ Yes ☐ No

57. Has you driver's license ever been suspended? Include any out-of-state suspensions ☐ Yes ☐ No

If Yes; Explain: _____

_____

_____

58. Has your automobile insurance ever been cancelled? ☐ Yes ☐ No

If Yes; Explain _____

59. List ALL traffic violations with approximate year.

_____

_____

_____

_____

60. Do you have any traffic or parking tickets in this State or any State that have not been paid? ☐ Yes ☐ No

If Yes; Explain _____

61. While driving, have you ever hit another vehicle, pedestrian or object, and left the scene without stopping? ☐ Yes ☐ No

If Yes; Explain _____

_____

_____

_____

62. On how many occasions, do you believe that you have operated a motor vehicle while Driving Under the Influence in the last year? _____

When was the most recent occurrence? _____

THE POLYGRAPH EXAMINER IS AUTHORIZED BY THE RESEARCH STUDY IRB #2016-46 TO DETERMINE IF YOU HAVE BEEN TRUTHFUL IN YOUR RESPONSES TO THE QUESTIONS REGARDING ARRESTS AND/OR UNDETECTED CRIMES.

WHEN ANSWERING THE FOLLOWING QUESTIONS, INCLUDE PARTICIPATION, ARREST, CONVICTION, QUESTIONING, ACCUSATION OR PLANNING.
ALL QUESTIONS ANSWERED "YES" MUST HAVE AN EXPLANATION NOTING DATE, AGE, LOCATION, PARTICIPANTS, PROPERTY VALUES. USE ADDITIONAL SHEET OF PAPER FOR EXPLANATION IF NEEDED

ARRESTS/UNDETECTED CRIMES:

Have you ever committed, assisted, or planned any of the following acts;

63. Have you unlawfully killed another human being? ☐ Yes ☐ No

Explain: _____

64. Have you unlawfully held someone against their will? ☐ Yes ☐ No

Explain: _____

65. Have you ever illegally exposed your genitals to anyone? ☐ Yes ☐ No

Explain: _____

66. Forcible sex act (against an individual's consent or knowledge)? ☐ Yes ☐ No

Explain: _____

67. Sexual contact with an animal? ☐ Yes ☐ No

Explain: _____

68. Have you ever been required to register as a sex offender? ☐ Yes ☐ No

Explain: _____

69. Videotaping an individual without his/her consent or knowledge? ☐ Yes ☐ No

Explain: _____

70. Prostitution or solicitation of a prostitute? ☐ Yes ☐ No

Explain: _____

71. Had sex with a family member? ☐ Yes ☐ No

Explain: _____

72. Have you ever knowingly violated a court order? ☐ Yes ☐ No

Explain: _____

73. Harassment? ☐ Yes ☐ No

Explain: _____

74. Stalking? ☐ Yes ☐ No

Explain: _____

75. Did you ever go to places where you should not have been after hours? ☐ Yes ☐ No

Explain: _____

76. Giving alcohol to minors no matter your age? ☐ Yes ☐ No

Explain: _____

77. Giving your ID to a minor to purchase alcohol? ☐ Yes ☐ No

Explain: _____

78. Making a false ID for yourself or any other person? ☐ Yes ☐ No

Explain: _____

79. Assault by striking another person with the intent to hurt? ☐ Yes ☐ No

Explain: _____

80. Attempted to hurt another person using any type of weapon? ☐ Yes ☐ No

Explain: _____

81. Involved in a domestic assault (hit, slap, choke, knockdown, etc.)? ☐ Yes ☐ No

Explain: _____

82. Arson (starting a fire) in an attempt to destroy property, endanger or injure a person? ☐ Yes ☐ No

Explain: _____

83. Started a fire or causing an explosion to damage or destroy property? ☐ Yes ☐ No

Explain: _____

84. Have you damaged or destroyed property on purpose? ☐ Yes ☐ No

Explain: _____

85. Terroristic threats? ☐ Yes ☐ No

Explain: _____

86. Manufacturing explosives or devices? ☐ Yes ☐ No

Explain: _____

87. Breaking into a house, vehicle, building or anything not owned by you? ☐ Yes ☐ No

Explain: _____

88. Did you ever shoplift anything? ☐ Yes ☐ No

Explain: _____

89. Hass anyone every given you stolen property? ☐ Yes ☐ No

Explain: _____

90. Stealing anything from an employer? ☐ Yes ☐ No

Explain: _____

91. Vehicle theft, use of vehicle without consent or joyriding? ☐ Yes ☐ No

Explain: _____

92. Stolen anything valued at $50.00 or more during the last two (2) years? ☐ Yes ☐ No

Explain: _____

93. Altered price tags in a store? ☐ Yes ☐ No

Explain: _____

94. Any other kind of theft? ☐ Yes ☐ No

Explain: _____

95. Have you ever been with anyone when they stole money, goods, merchandise, etc. (Describe what you did during and after incident) ☐ Yes ☐ No

Explain: _____

96. Have you ever used another person's information with or without their consent? ☐ Yes ☐ No

Explain: _____

97. Have you ever engaged in the business of selling copyrighted property for profit, including but not limited to: tobacco, prescription drugs, alcohol, purses, audio/video recordings, DVD's etc? ☐ Yes ☐ No

Explain: _____

98. Insurance fraud? ☐ Yes ☐ No

Explain: _____

99. Filed a false report to any police officer? ☐ Yes ☐ No

Explain: _____

100. Impersonating a police officer or law enforcement official? ☐ Yes ☐ No

Explain: _____

101. Resisted arrest, evading or fleeing from a police officer? ☐ Yes ☐ No

Explain: _____

102. Involving illegal gambling? ☐ Yes ☐ No

Explain: _____

103. Have you ever been arrested? ☐ Yes ☐ No

Explain: _____

104. Have you ever gotten a ticket for?

a. Disorderly Conduct ☐ Yes ☐ No
b. Public Intoxication ☐ Yes ☐ No
c. Underage Drinking ☐ Yes ☐ No
d. Criminal Mischief ☐ Yes ☐ No
e. Criminal Trespass ☐ Yes ☐ No
f. Fish or Game Law Violations ☐ Yes ☐ No

Explain: _____

_____

105. Have you ever had any charges or arrests removed from your record? ☐ Yes ☐ No

Explain: _____

_____

_____

106. Have you violated any of the firearms laws (i.e. carrying a concealed weapon without a permit or license, possessing sawed-off shotguns, carrying a loaded shotgun, rifle or handgun in your vehicles, etc) ☐ Yes ☐ No

Explain: _____

_____

_____

THE POLYGRAPH EXAMINER IS AUTHORIZED BY THIS RESEARCH STUDY IRB # 2016-46 TO DETERMINE IF YOU HAVE BEEN TRUTHFUL IN YOUR RESPONSES TO THE QUESTIONS REGARDING DRUG AND ALCOHOL USE.

107. DRUG CHART - Have you used any of the following items List Month and Year?

DRUG	NO. OF TIMES USED	LAST TIME USED
MARIJUANA		
HASHISH		
COCAINE		
HEROIN		
AMPHETAMINES		
BARBITURATES		
ANABOLIC STEROIDS		
MUSHROOMS		
LSD		
PCP		
ECSTASY		
GHB – date rape drug		
OXYCONTIN (OPIATES)		
OTHER ILLEGAL DRUG/SUBSTANCE		
BATH SALTS or SYNTHETIC DRUGS		

108. Making, selling, delivering marijuana, cocaine, heroin, LSD or any other drugs to include prescription narcotics? ☐ Yes ☐ No

If Yes; Explain: _____

109. Have you purchased any illegal drug in the last two (2) years? ☐ Yes ☐ No

If Yes; Explain: _____

110. Have you sold any illegal drug in the last two (2) years? ☐ Yes ☐ No

If Yes; Explain: _____

111. Have you ever used another chemical to feel good? i.e. household cleaner, Glade, glue, whip cream, etc.? ☐ Yes ☐ No

If Yes; Explain: _____

112. When were you last with someone when they were using illegal drug(s) in your presence? (Month/Year, illegal drug(s) being used, etc.) _____

If Yes; Explain: _____

113. Have you ever given anyone any illegal drugs? ☐ Yes ☐ No

If Yes; Explain: _____

114. Have you ever given anyone any prescription drugs that were not theirs? ☐ Yes ☐ No

If Yes; Explain: _____

115. Have you ever sold any prescription drugs? ☐ Yes ☐ No

If Yes; Explain: _____

116. Approximately how many friends or associates of yours use marijuana? _____

Other illegal drugs? _____

117. Have you ever or do you now possess or use drug-related objects?

☐ Yes ☐ No

If Yes; Explain: _____

118. Have you ever forged or altered a drug prescription? ☐ Yes ☐ No

If Yes; Explain:

_____

_____

119. Approximately how much alcohol or liquor have you consumed in the last thirty (30) days?

_____

120. What do you generally drink? _____

121. When was the last time you were drunk? _____

122. Approximately how many times have you been drunk in the last 2 years? _____

123. Were you ever terminated from a job or been in trouble due to alcohol/drugs, including but not limited to, being absent from work, hung-over at work or going to work drunk?

☐ Yes ☐ No

If Yes; Explain: _____

_____

124. Have you ever been treated by a doctor, psychologist, social worker, counselor or other professional for any alcohol or drug related addictions? ☐ Yes ☐ No

If Yes; Explain: _____

_____

125. Have you ever had any family problems caused by alcohol/drugs? ☐ Yes ☐ No

If Yes; Explain: _____

126. Are you now or have you ever belonged to Alcoholics Anonymous or any similar organization?

☐ Yes ☐ No

If Yes; Explain: _____

127. Have you ever contemplated or attempted suicide? ☐ Yes ☐ No

If Yes; Explain: _____

_____

13

128. Have you ever been placed, willingly or un-willingly to any hospital or treatment facility for mental health reasons or psychological problems? ☐ Yes ☐ No

If Yes; Explain: _____

129. Have you ever or do you now take any medications, drugs or any substance to improve attention, behavior, or physical performance? ☐ Yes ☐ No

If Yes; Explain: _____

_____

130. Have intentionally omitted or withheld any fact or facts from this questionnaire, or withheld any information?

☐ Yes ☐ No

If Yes; Explain: _____

_____

DO NOT ANSWER THE FOLLOWING QUESTIONS

YOU WILL COMPLETE THESE QUESTIONS AT THE TIME OF YOUR POLYGRAPH EXAMINATION.

YOU MUST INDICATE, BY WRITING YES OR NO TO EACH OF THE FOLLOWING QUESTIONS.

131. Have you been honest regarding your personal history and employment? _____

132. Have you been honest regarding traffic violations and traffic accidents? _____

133. Have you been honest regarding criminal arrests/convictions? _____

134. Have you been honest regarding your debts? _____

135. Have you been honest regarding the usage, purchase, possession, manufacturing or distribution of any illegal drug? _____

136. Have you been truthful regarding the sexual crimes questions in this booklet? _____

137. Have you deliberately lied to any of the questions contained in this booklet? _____

138. Are you currently taking any medication that may alter the results of the Polygraph examination? _____

139. Do you intend to cheat the outcome of this Polygraph Examination? _____

THIS COMPLETES THE POLYGRAPH SCREENING. YOU SHOULD NOW REVIEW YOUR ANSWERS TO THE QUESTIONS IN THIS BOOKLET. YOU MAY GO BACK THROUGH THIS BOOKLET AND CHANGE YOUR ANSWER. YOU ARE TO ENSURE THAT YOUR INITIALS ARE PLACED BESIDE THE CHANGE THAT YOU MADE. ENSURE THAT YOU HAVE ANSWERED EACH QUESTION TRUTHFULLY. THIS BOOKLET WILL BE SUBMITTED TO THE POLYGRAPH EXAMINER.

READ AND SIGN THE FOLLOWING STATEMENT:

The information in this booklet contains true and accurate statements. I understand that withholding any information, falsification or misrepresentation of any information in this booklet will result in disqualification.

_____ _____

(Number) (Date)

Attitudes of Polygraph Examiners and Examinees

Manuel Novoa[1], Felipe Malagon[2] and Donald Krapohl[3]

Abstract

It is axiomatic that automated systems are more reliable (consistent) than are humans performing the same task, and reliability is foundational to validity. Polygraph screening tests entail a combination of routine steps and dynamic interactivity between examiner and examinee. The development of decision algorithms, text-to-speech software, and preprogrammed visual presentations have prepared the way to automate portions of the polygraph examination that are fixed and unchanging between examinations, and so exploit the advantages of computers in the polygraph process. What is unclear at this early stage is the impact of automation on the examination participants, whether it is viewed as a benefit or detriment by the examiner and examinee.

The Directed-Lie Screening Test (DLST) is a very structured methodology in which large portions of the examination can be automated. In this field study, we surveyed examiners and examinees following DLST examinations to assess whether there were shifts in attitudes for these two groups between the automated and traditional approaches to the DLST. The trend across several categories of survey items showed a generally positive view of the expanded use of automation during polygraph screening examinations. Implications are discussed.

Key words: *Automation, Directed-Lie Screening Test, DLST, polygraph, forensic psychophysiology, polygraph test, polygraph technique, concentration, interest, fatigue, concentration, admissions, perception.*

Introduction

If polygraphy is to be more widely considered a scientific discipline, practitioners would be ethically compelled to implement standardized procedures to ensure reliability of the outcomes. In 2011 the American Polygraph Association (APA) published a committee report which set about to summarize the available evidence of validity and reliability of various polygraph techniques (APA, 2011). Though never an official policy of the Association, the document nevertheless became a commonly cited reference for the validity and reliability standards of the APA. Since its publication there has been a collective movement among field practitioners to employ the methods listed in the report.

To deliver the estimated accuracy of a given test technique listed in the committee report an examiner would need to strictly follow the testing and analysis protocols that are attendant to the chosen technique. It should be clear that the variability in the execution of the protocols could directly affect the reliability of the results. Examiner variability has been implicated as the leading cause of compromises to reliability (Blalock, 2009). One promising approach to minimizing this variability is to automate the routine and unvarying portions of the polygraph examination that do not require human interaction. This automation could include audiovisual materials to further the examinee's understanding of the procedure, instructions and the need for cooperation. Theories of observational or vi-

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carious learning (Cabrera, 2010) suggest that visual representations of concepts and examples during the polygraph examination should have a favorable influence on outcomes and examinee engagement.

Previous writers have recognized the potential advantages when automation augments the polygraph examination process. Charles Honts and Susan Amato conducted a laboratory study using the Relevant - Irrelevant technique, with which they concluded that the tests that included automation produced higher decision accuracy than those that did not (Honts & Amato, 2007). In their research, pre-recorded audio instructions were used in the pretest phase, as well as the presentation of the questions during testing phase. More recently, Krapohl and Shaw (2015) suggested the possibility of automation in the polygraph technique Directed Lie Screening Test, that routine and repetitive parts of the examination can be turned over to the computer, such as the explanation of the procedure, physiology, instructions for behavior, etc. Raskin and Kircher (in Kleiner, 2002) emphasized the use of automation in the presentation of stimuli (questions) to the examinee during the test phase and suggested that, overall, automation should reduce the adverse impact on test results arising from individual examiner skills, professional competence, biases, and other factors. The DLST, with its rigid structure and use of directed lie comparison questions make it the most favorable choice among polygraph techniques for adding automation to improve standardization (Handler et al., 2008).

Methodology

Sample: 500 subjects, men and women, aspiring to various positions in client's companies of the Latinamerican Polygraph Institute.

Examiners: Twelve certified polygraphists, employees of Latinamerican Polygraph Institute.

Polygraph instruments: Limestone Technologies, reference DataPac_USB and Paragon instruments were used.

Automation: The following prerecorded audio or video materials were used, involving the following stages of the test:

- Introduction and familiarization with the procedure and the examination room; explanation of the procedure (audio-video)
- Explanation of the instrument, the underlying physiology and voluntariness of the test (audio video)
- Application of the acquaintance test (Audio)
- Explanation of behavior during the acquaintance test (Audio)
- Feedback of the acquaintance test (Audio)
- Behavior instructions for Subtest A (Audio)
- Behavior instructions for Subtest B (Audio)
- Instructions for a repetition of any of the Sub Tests (Audio)
- Closing of the test (Audio)

Procedure

Corresponding scripts for each of the automated phases were designed, and video support materials were developed for explaining the instrument and human physiology. The materials were recorded in a professional recording studio, and professional announcers were hired to read the texts: A male and a female speaker were used so that each polygraphist could use the recordings according to his or her own gender. The use of gender-specific voices was only a convenience for the examiners, as there was no expectation that the gender of the voice would affect the test. The exams and the surveys were conducted in Spanish (native language of the examinees).

Each of the examination rooms was equipped with a 14" monitor intended for presentation of the phase 2 of automation; that is, the explanation of the instrument and the underlying physiology, as well as voluntariness of the test. Likewise, the performance of each one of the instruments was assured through respective functionality checks.

Surveys aimed at assessing the perception of examinees and examiners about the use of automation were designed. As examiners, the variables analyzed were:

- Duration of the polygraph test
- Concentration level of the examinee
- Distraction level of the examinee
- Attention level of the examinee
- Comprehension of the examinee
- Behavior of the examinee in the charts
- Examiner's fatigue
- Friendlier methodology
- Highest admissions
- General advantages

As for the examinees, the analyzed variables were:

- Concentration level
- Distraction level
- Attention level
- Clarity in the instructions
- Examinee fatigue
- Friendliness of the procedure

Each survey item had five response options. For examinees who have had previous polygraph tests, survey questions were written in terms of "Compared to your previous test(s) ...".

Prior to conducting the polygraph tests, a training process of the polygraphist involved in the project was performed in order to standardize each of the phases of the polygraph process. In the same way, survey formats with the perception of the benefits or drawbacks of the use of automation were presented.

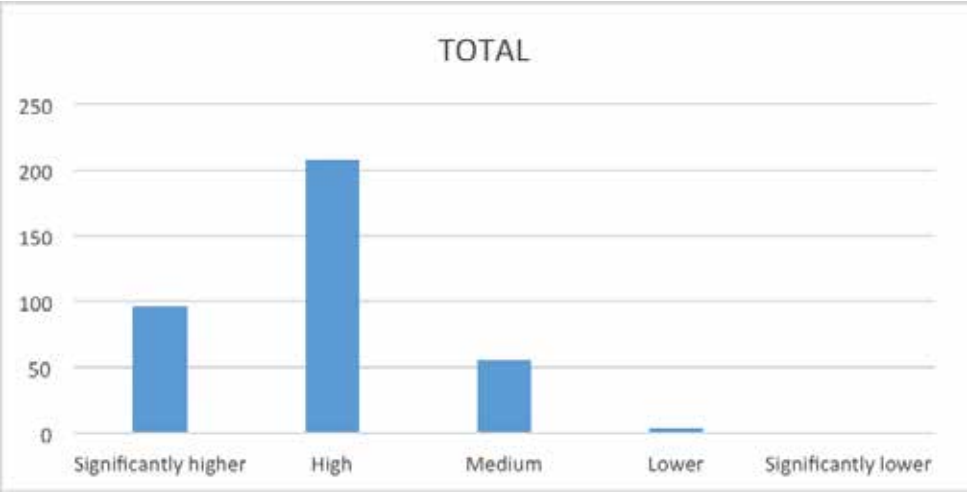
Company's reception staff was trained in order to deliver to the examinees an attitudinal survey related to the automated polygraph procedures. At this point it was crucial to determine whether the examinee had previous tests, as different surveys were handed out according to such circumstances.

Once these preliminary activities were fulfilled, the polygraph tests were conducted. Subsequently, the surveys were processed and the respective results were analyzed. All the returned surveys were anonymous.

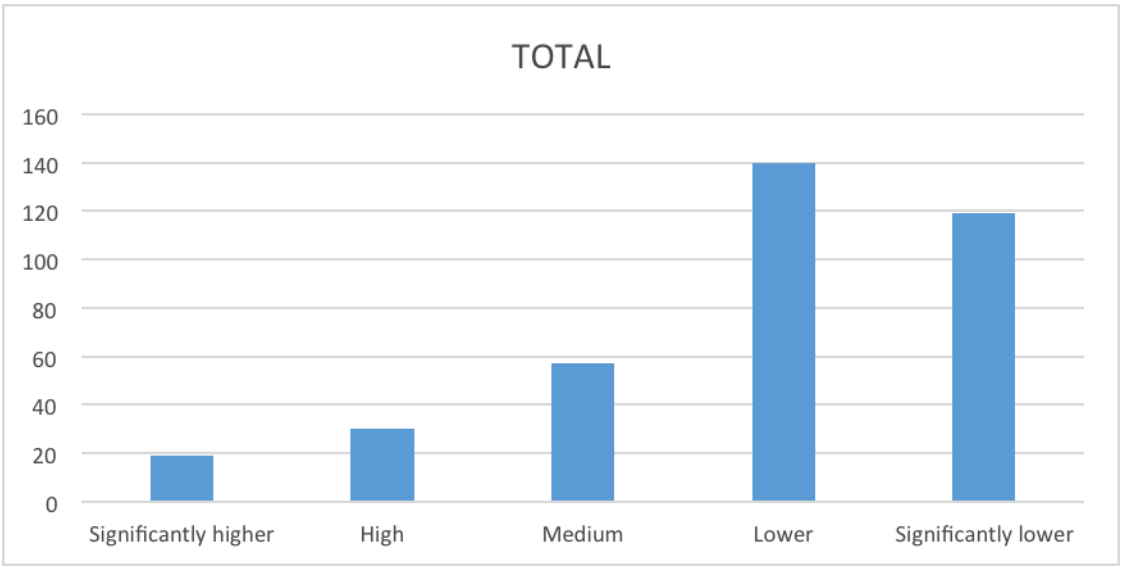
Results

With regard to the examinees without previous polygraph tests, the following results were obtained:

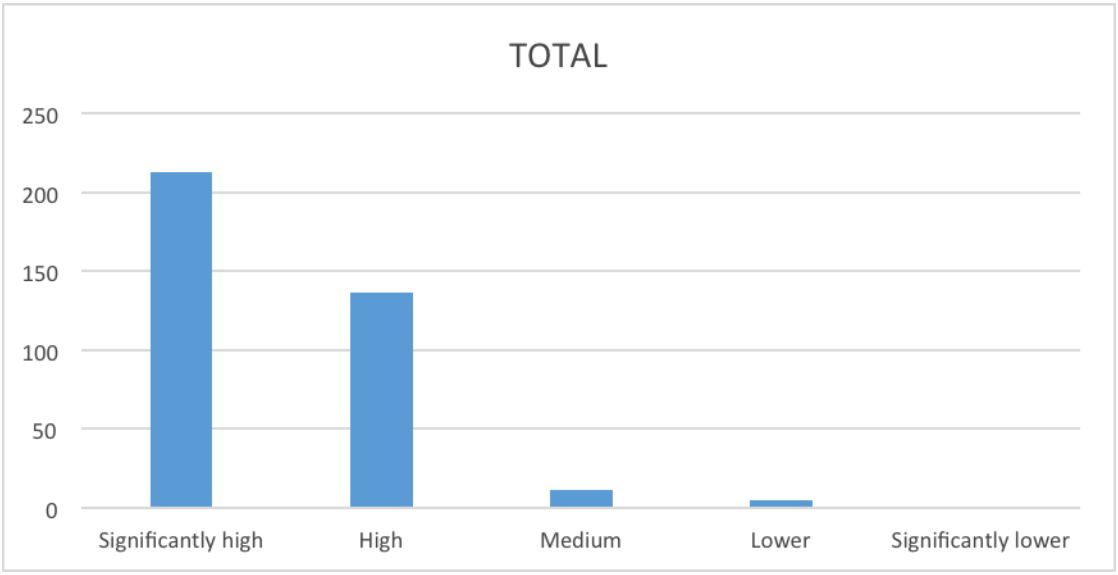
How would you rate your level of concentration during the test?



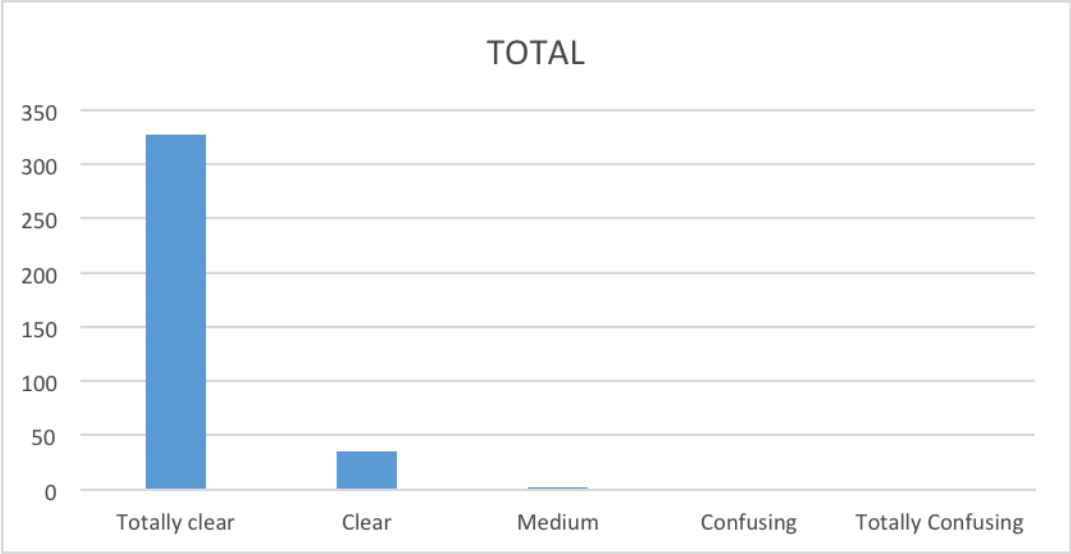
How would you rate the level of distraction that you experienced during the test?



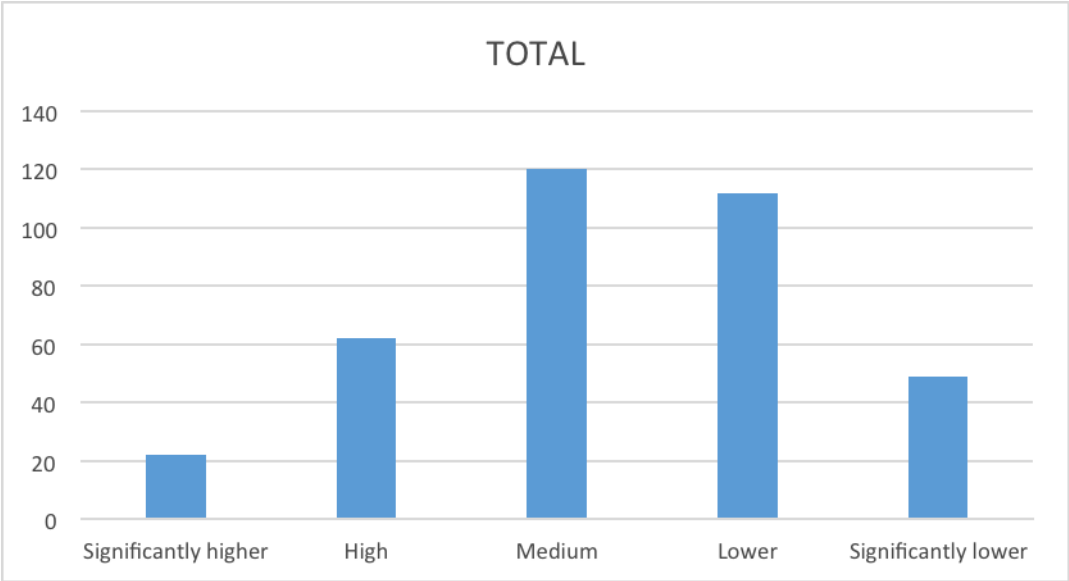
How would you rate the level of attention that you had during the test?



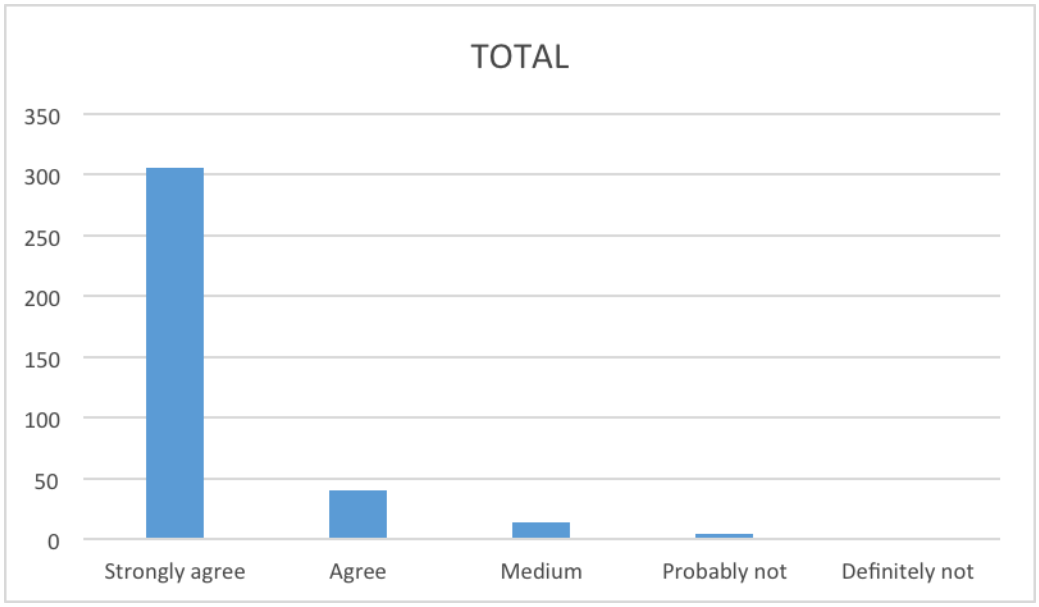
With regard to the instructions you received by the examiner, you would grade them as:



How would you rate the level of fatigue that you experienced at the end of the exam?

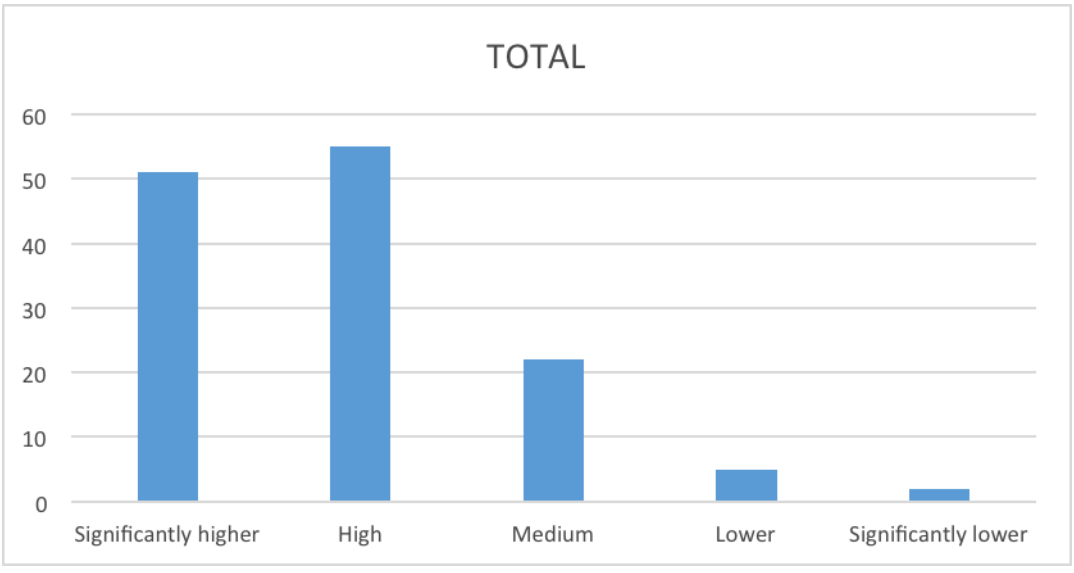


Do you consider that the procedure was friendly towards you as examinee?

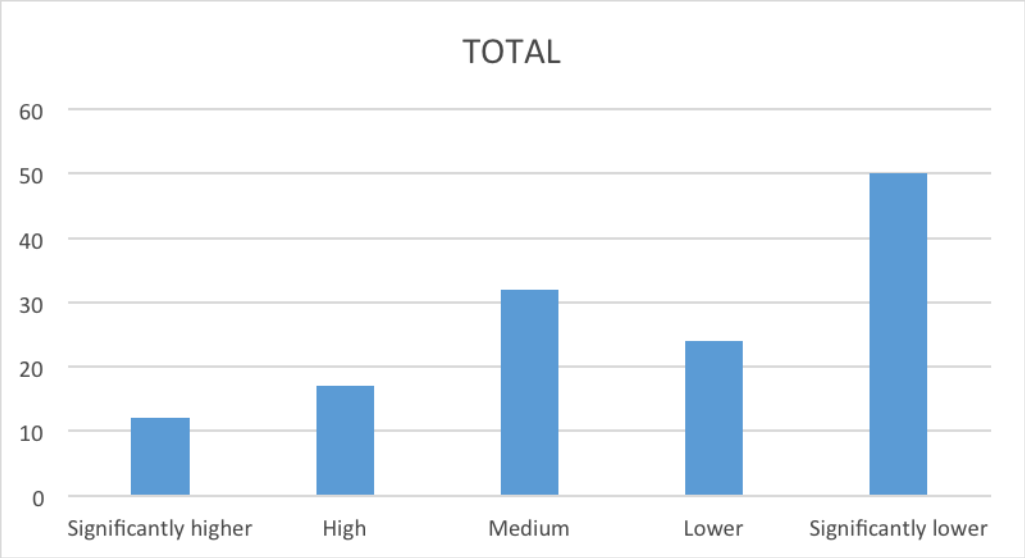


Regarding the examinee with previous polygraph test, the following results were obtained:

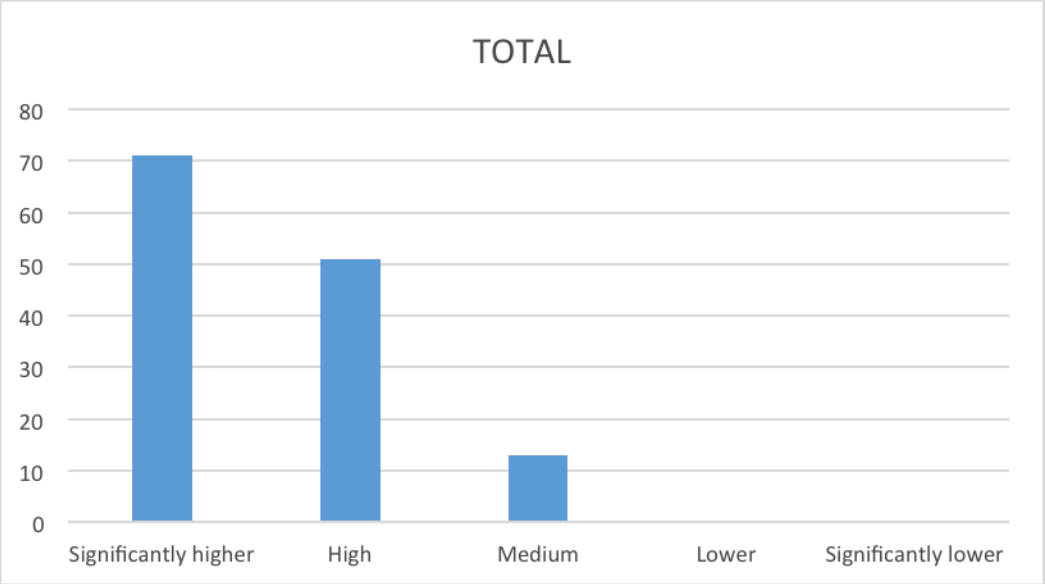
Compared with previous tests, how would you rate the level of concentration that you managed to maintain during the development of the test?



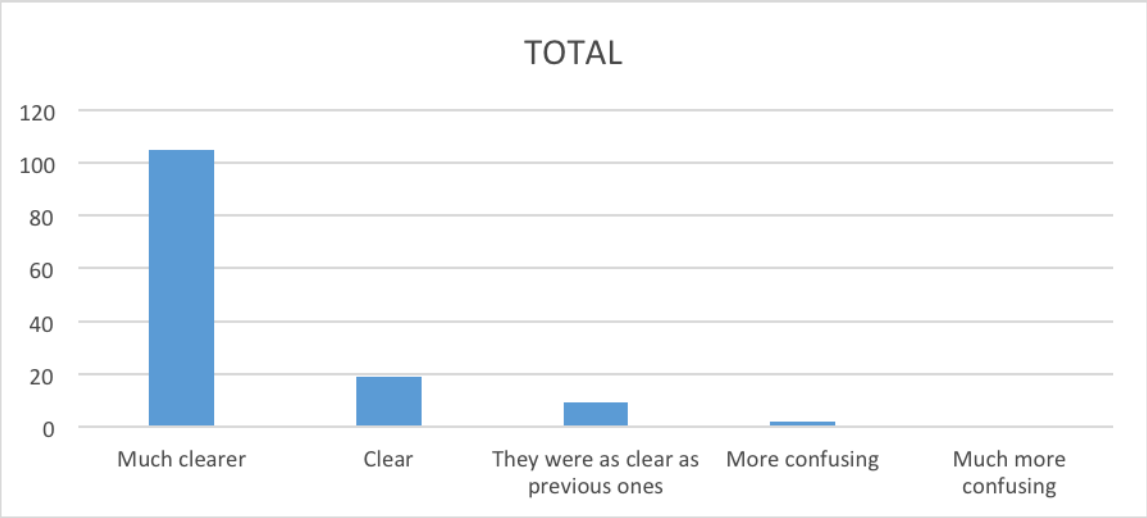
Compared with previous tests how would you rate the level of distraction that you experienced during the test?



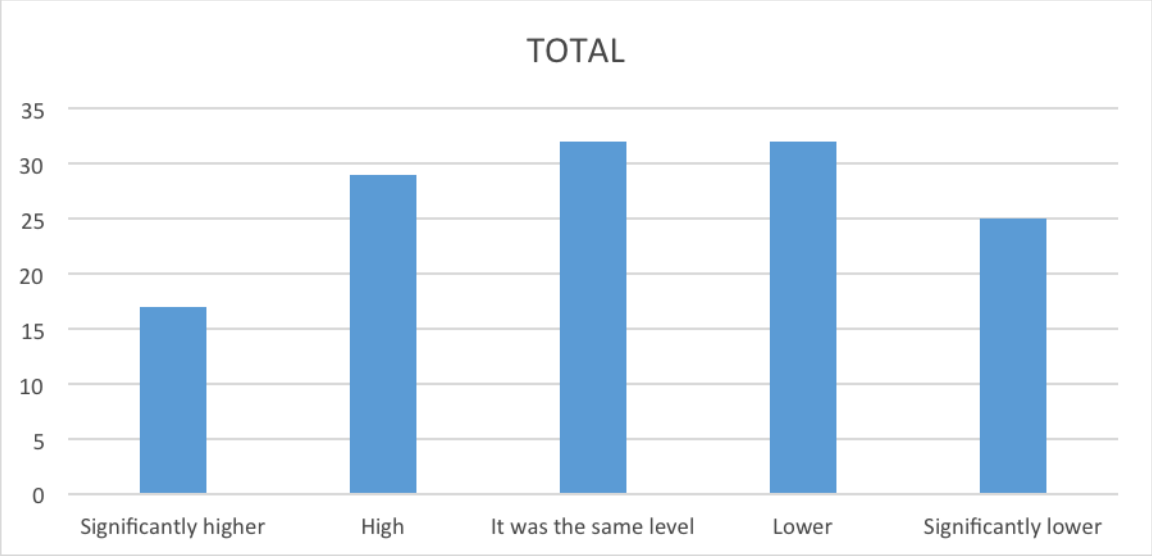
Compared with previous tests how would you rate the level of attention that you had during the test?



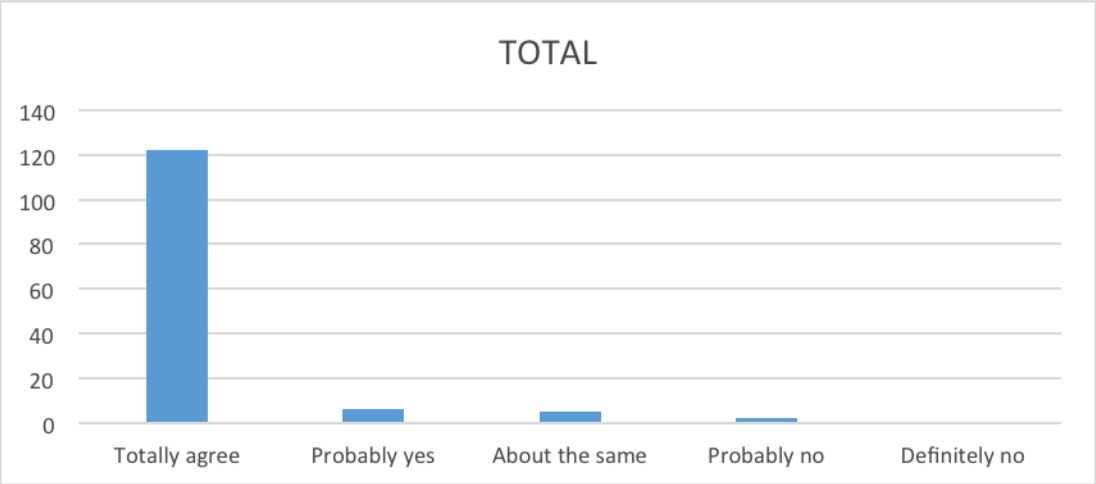
Compared to your previous tests regarding the instructions you received by the examiner, they were:



Compared with previous tests how would you rate the level of fatigue that you experienced at the end of the test?

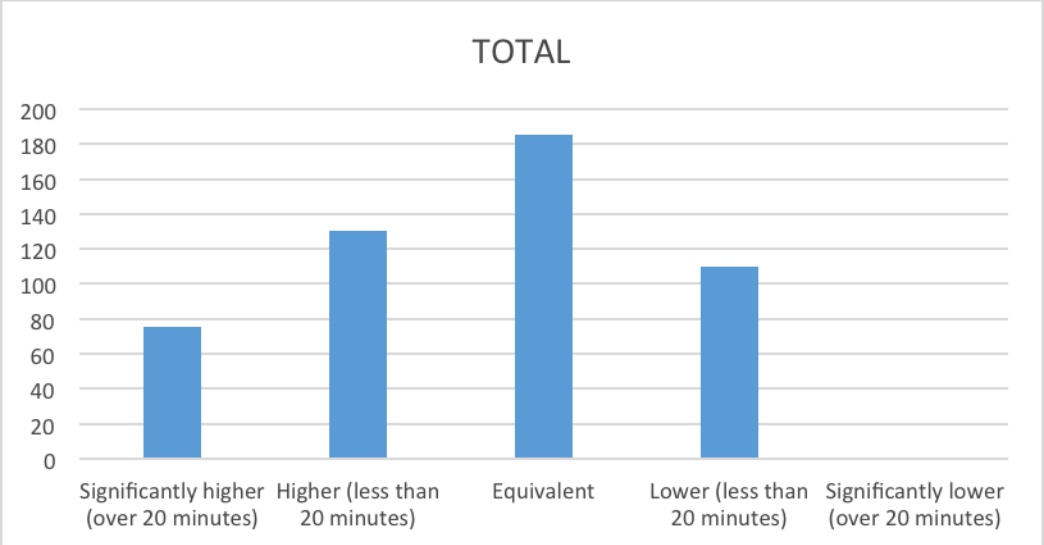


Compared with your previous tests, do you consider that the procedure was friendly to you as to the examinee?

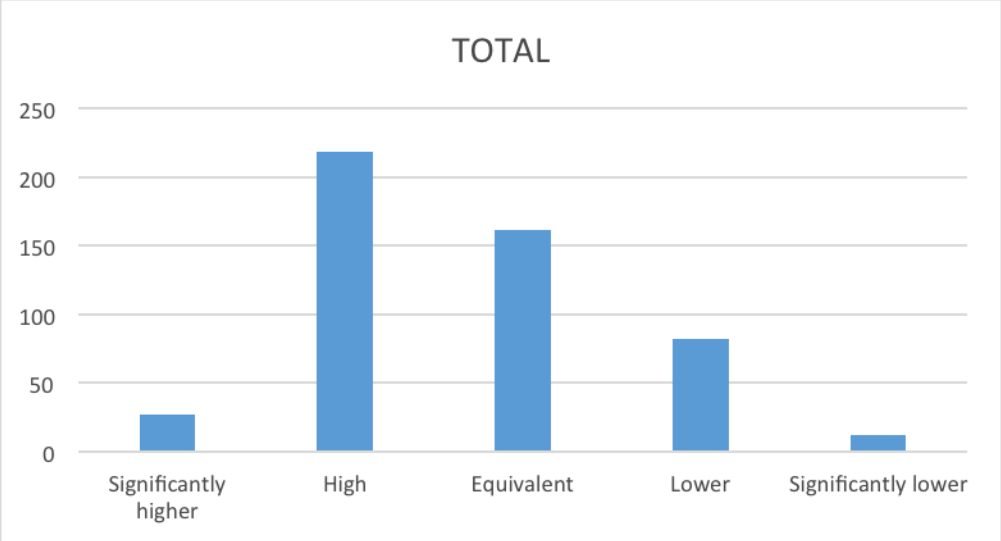


As for the surveys for the polygraphists, the following results were obtained:

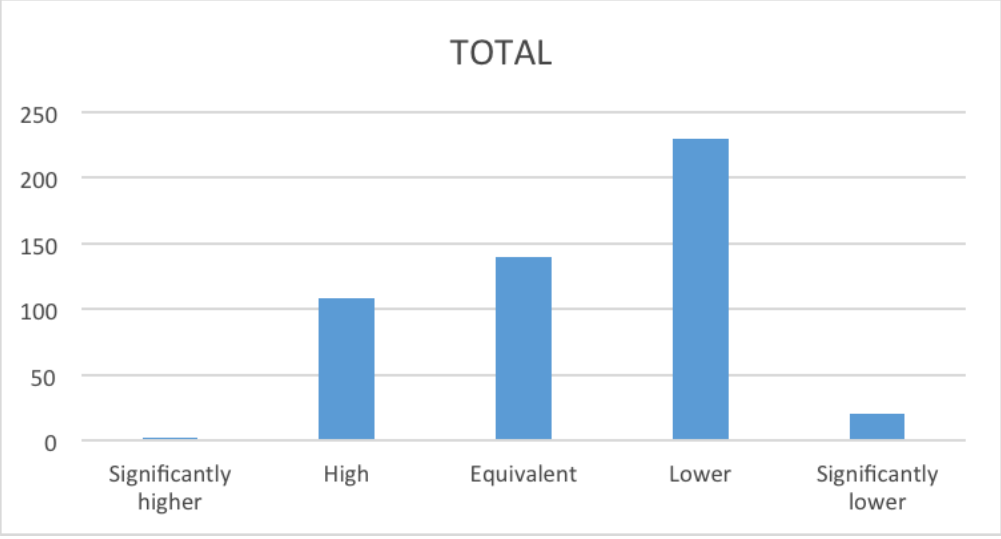
With respect to your standard, the test had a duration:



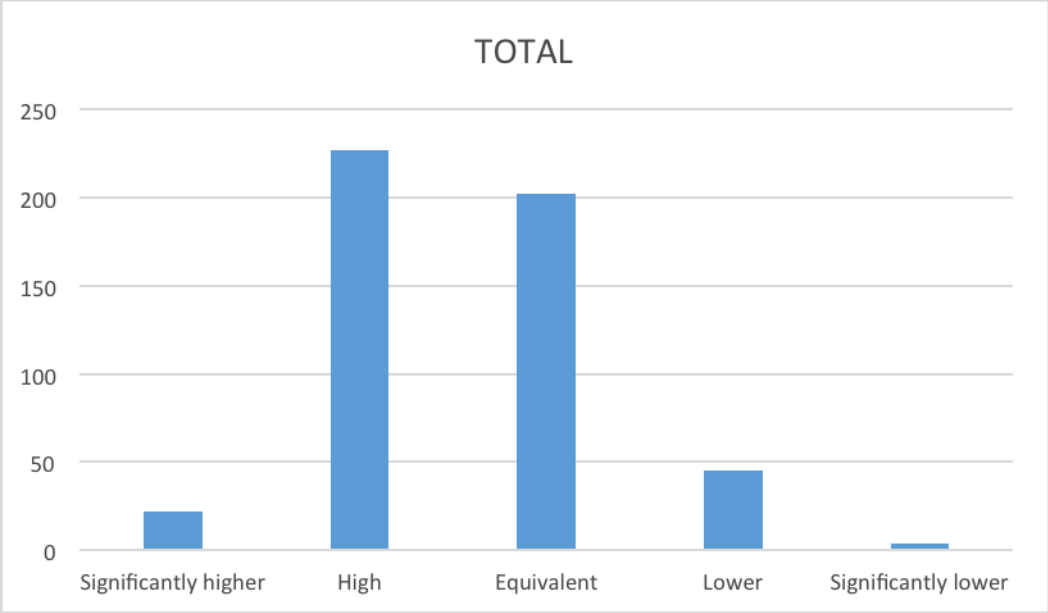
How would you rate the level of concentration of the examinee during the test, relative to the usual average level of concentration of an examinee in a test with the traditional methodology?



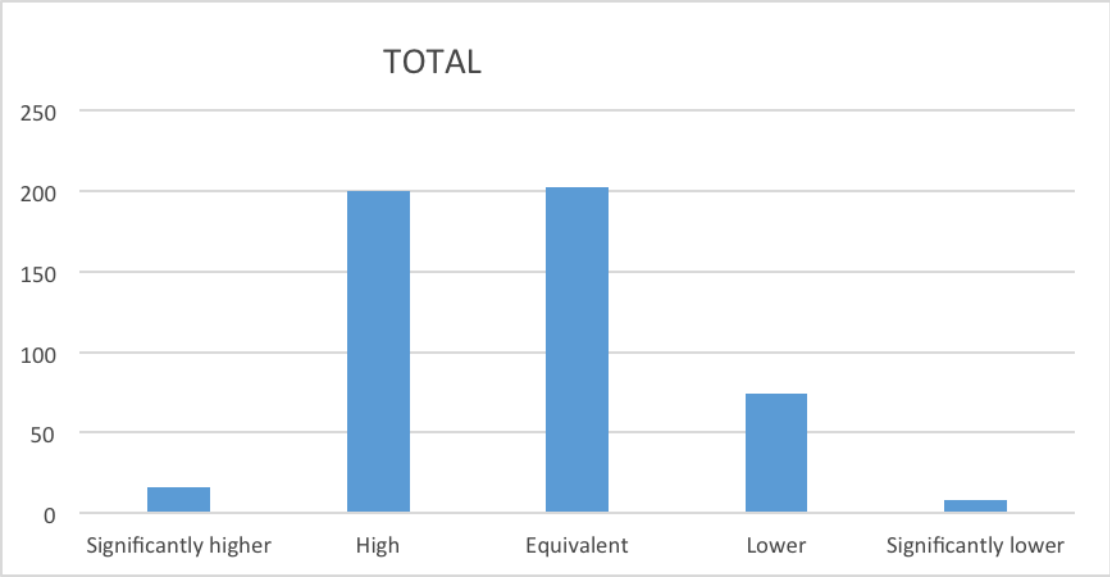
How would you rate the level of distraction of the examinee during the test, relative to the usual average level of distraction of an examinee in a test with the traditional methodology?



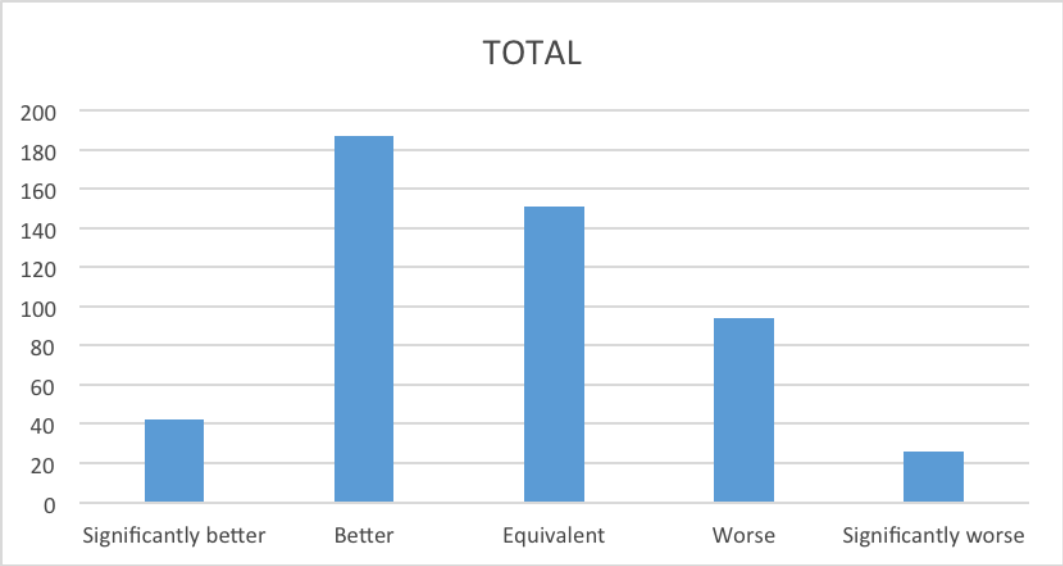
How would you rate the level of attention of the examinee during the test, relative to the usual average level of attention of an examinee in a test with the traditional methodology?



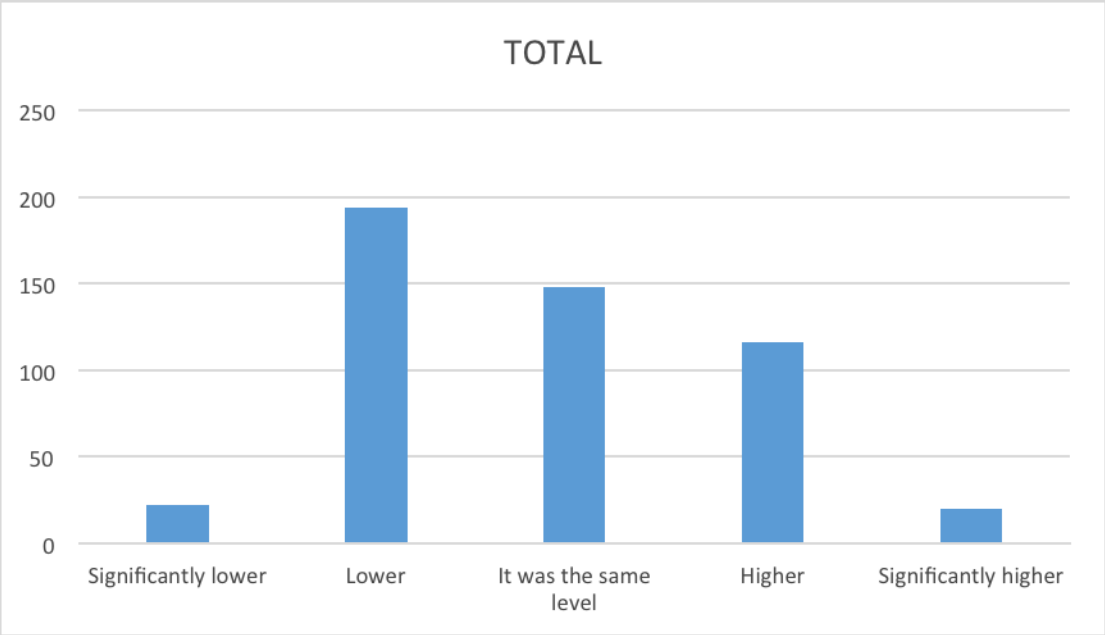
Regarding the level of comprehension of the instructions by the examinee, do you consider that the performance of the examinee (compared with the traditional methodology) was:



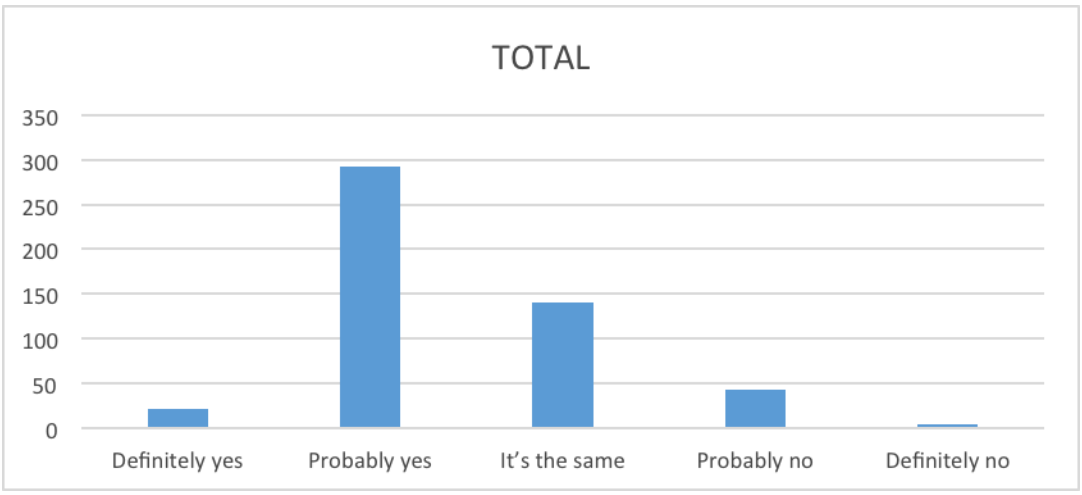
Regarding the cooperation of the examinee, would you rate the performance of the examinee (compared with the traditional methodology) as:



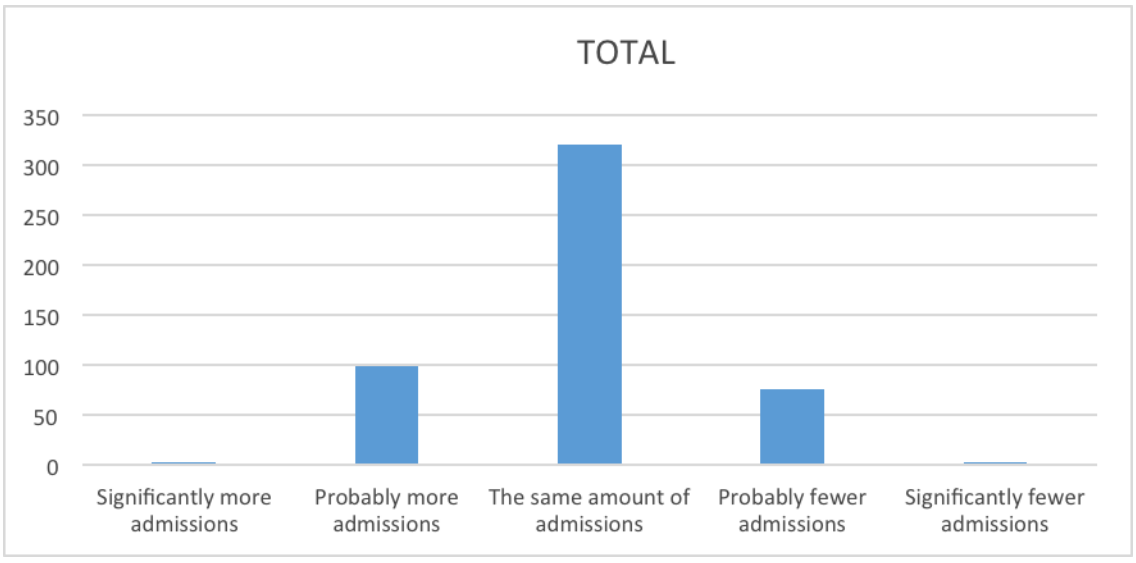
The level of fatigue that you experienced at the end of the test compared to the usual level when performing a test with the traditional methodology was:



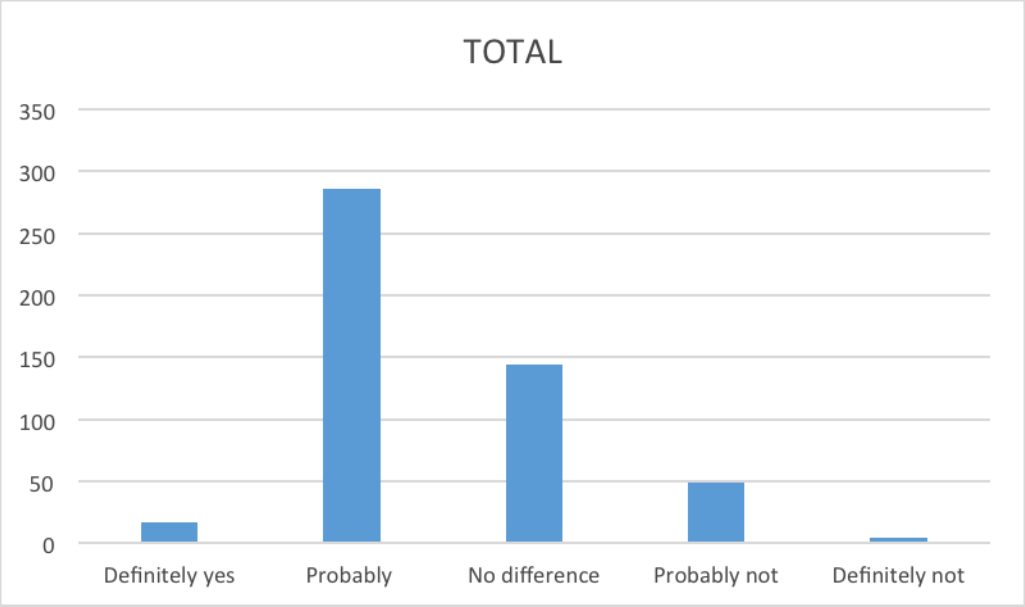
Would you grade the automated procedure as more friendly to the examinee than the traditional procedure?



Do you consider that the procedure resulted in more / fewer admissions compared to the traditional system?



In your opinion, automation has advantages over traditional methodology.



Conclusions

The findings were positive in this first-ever attitudinal survey regarding polygraph automation. Both examiners and examinees reported favorable attitudes about the inclusion of automation in the polygraph screening examination to replace the routine presentation of standard information by the examiner. This is especially telling among examinees who contrasted their experience with automation against a previous polygraph examination that was conducted in the traditional manner. If these findings are replicated elsewhere, it could pave the way for greater integration of automation and examiner in the conduct of routine screening examinations[4]. Obvious benefits include greater standardization in testing processes, reduction of demands on polygraph examiners, freeing examiners to be more observant, and undercutting claims by examinees that they had been treated differently from other examinees.

Further studies are necessary on this subject. Empirical work remains in finding additional areas where automation may provide benefit, whether it improves or limits self-report from the examinee, and the all-important question regarding the effects on polygraph decision accuracy. Because computers and humans have different strengths, it is our belief that the thoughtful melding of their best capabilities will provide more productive and accurate screening examinations than either can deliver alone. We encourage more research efforts in this promising area.

4 Those interested in obtaining the scripts for use in a replication experiment should contact to the first author.

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A Physiology Manual for PDD Lifelong Learners of the Science (Part 1)

Joel Reicherter[1] and Mark Handler[2]

I. INTRODUCTION

Many practitioners of the science of psychophysiological detection of deception (PDD) have entered the profession in mid-career from disciplines other than the life sciences or biology. Typically, many entering PDD come from the criminal justice or related professions with limited exposure to the life sciences. In polygraph science, the investigator must record and evaluate visceral physiological data from selected body organ systems regulated by the brain. This means the polygraph professional must gain and maintain a sufficient understanding of the basis of physiologic changes they are attempting to measure. These physiological parameters required for PDD assessment are typically studied in the life science disciplines.

Despite the general public's view, there is no metric of lie detection. PDD science can, however, provide a statistical measure of the probability of truthful or deceptive responses to relevant questions concerning a matter in question. The **Cardiovascular System (heart), Integumentary System (skin), and Respiratory System (breathing)** regulated by the **Central Nervous System** need to be reasonably understood by the polygraph examiner to be an effective decision maker in PDD science. Terms written in boldface type in this manual are of increased importance. They are reviewed in general terms in the *Overview*, Part 1 section and more thoroughly described in the *Detailed Section,* Part 2. Students and lifelong learners may want to ensure they have an especially good grasp on these terms.

This project began in 2005 when one author Joel Reicherter (JR) shared the outline for his 62-hour physiology course, arguably the most comprehensive and challenging physiology courses taught in any PDD training regimen, with the other author Mark Handler (MH). MH took the outline and developed what later became the "detailed" section of the current document. The authors felt readers would benefit from a less detailed overview and JR first-authored that section of this document. There were two intentions: First, to create a document that could be used as a foundation for review of this sometimes difficult subject—a physiology-*light* – and, second, to provide the more motivated or curious examiner a tool with which one might get deeper "into the weeds."

The general outline of the overview should follow fairly closely with the *Detailed Section*[3]. There may be some overlap of the information in those sections, as editing out all redundant material may have left one or the other difficult to understand. We ask the reader's pardon and tolerance for redundancy. We also ask for errors to be brought to our attention, and accept the responsibility *a priori* for errors or omissions.

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2 Mark Handler is…… and be reached at polygraphmark@gmail.com.

Author's note: One examiner who epitomizes our belief in lifelong learning tirelessly reviewed and edited this document. Without Dale Austin's attention to detail, deep understanding of the PDD examiner learning process and overall expertise in PDD this document would be considerably less than it is. The authors and our profession owe Dale Austin a great debt of gratitude. This document has been previously published on the APA website.

3 Begins on page 23.

We believe a professional's, and a collective profession's, learning should never stop. We have developed this document for those students, examiners and schools who share our ideals. We hope the reader finds it useful and hope to be able to update it as we continue to learn, and as time permits.

II. PHYSIOLOGICAL AND CHEMICAL BACKGROUND

In a healthy body, the body-systems work together in harmony in a balanced internal physiological environment of wellness. This is described as being in a *homeostatic state of equilibrium*, otherwise known as *homeostasis,* or as a medical term, in a "state of wellness." If an external circumstance disrupts this balance within the organ systems, a state of sickness might develop. However, routine changing environments such as exercise, compared to the relaxing state of reading a book, will naturally cause an alteration in the homeostatic balance in the body systems. The physiological adjustments made in homeostatic balance within the organ systems were recently described in the PDD setting by Mark Handler as *allostasis*, which is described in the *Detailed Section* under *Homeostasis and Allostasis*.

All physiological activities addressing living activities follow basic laws of chemistry. Much of the chemistry occurring in the human body is beyond the scope of this manual, but there are a few important concepts which must be addressed to provide a fundamental understanding for those learning PDD science.

To begin our study, all matter on earth is composed of only 92 naturally occurring different atoms, also described as elements. The living body is composed of 26 of that total. Examples of these atoms, you no doubt have heard, include hydrogen, carbon, nitrogen and oxygen. These four elements constitute about 96% of the body. Calcium, phosphorus, potassium, sulfur, sodium, chlorine, magnesium and iron constitute 3.8%. The remaining 14 elements are classified as trace elements because collectively they constitute only 0.2%. All elements are typically represented with one or two letters from the English language alphabet. For instance, **C** represents carbon, or **Ca** represents calcium.

Briefly, these atoms are composed of particles called protons, neutrons and electrons. The total number of protons and neutrons in each atom are found in the center of the atom (nucleus) and is referred to as the atomic mass. The lightest in atomic mass is hydrogen, which has only 1 proton, and 0 neutrons. The heaviest atom is uranium, which has 92 protons and 146 neutrons. The protons have a positive charge compared to neutrons, which have no charge. Orbiting in prescribed areas or shells around the nucleus are negatively charged electrons. Atoms usually have equal numbers of positive protons and negative electrons organized in the various areas (shells) around the center of the atomic nucleus. This arrangement of positive and negative charges makes the atom neutral. More information about the architectural design can be found in the detail section of this work, or in basic chemistry or anatomy and physiology texts. For basic understanding of PDD, however, it won't be necessary to research additional chemistry concepts unless you are inspired to do so.

Since there are multiple forces acting on these atoms, based on the number and location of electrons in an atom, sometimes electrons are pulled away or attracted to another atom. When that happens, an atom that loses an electron is left in a positive state, which is referred to as a positive ion or cation. If the atom gains an electron it is referred to as a negative ion or anion. Some of the most important ions you will see in physiology are sodium, potassium, chlorine (also called chloride), calcium and hydrogen. The symbol notation will be Na+, K+, Cl-, Ca++ and H+ etc. The + sign indicates a loss of an electron, the – sign indicates a gain of an electron. The Ca++ symbol indicates two electrons have been lost. These ions, and others, play significant roles in Nervous, Cardiovascular, Respiratory, and Sweat Gland function, and ultimately in the physiological events that occur during PDD examinations.

Other forces of physics and chemistry will cause atoms to share electrons in the outer shell resulting in a **sharing (covalent) bond** between two or more atoms forming **molecules.** Water, carbohydrates, and proteins are good examples of molecules. In other cases, one or more electrons will be liberated from

one atom and received by another, resulting in a positive ion and negative ion. In this case, the attraction between the two ions would be called an **ionic bond** forming a compound but not a molecule. Salt (NaCl) would be a good example. Salt could be represented Na+ Cl- but for convenience, the + and – are often not displayed.

III. HUMAN BODY ORGANIZATION

All living things, including the human body, are organized into **cells** which perform living activities. In more advanced life forms, various kinds of cells are organized into **tissues,** which perform more complex functions than a single cell does. Tissues are organized with each other to form **organs,** which perform more complex functions than does a tissue. Organs are organized with each other to form **systems,** which perform even more complex functions. Finally, the integrated mix of eleven different systems forms the **human being** organism.

As a model, consider the human being organism as our nation. The states would represent the systems, counties would represent the organs, cities and towns would represent the tissues, local neighborhoods would represent cells, and the people would represent the atoms, ions, and molecules.

Cells: View the cells as factories. Depending on the nature of the cell (factory), the factories, with its workers (**molecules and ions**), can produce a variety of products, useful to the local economy or the larger domains (counties, states, nation). Like any industry, raw materials must be delivered to the factory by trucks (**blood**), pass through the factory gates (**cell membrane**), converted to a product (**proteins or other complex molecules**), then shipped out through the factory gates (cell membrane) to other destinations by trucks (blood). As in any factory, the workers need to be organized and directed by the foremen and company directors (**enzymes and hormones**).

In all functional factories, the specific ways in which products are produced depend on the factory's organization, the ways raw materials and building supplies enter the factory, and how the products manufactured are packaged and shipped.

Just as a factory has a central decision making office, so does a cell. The nucleus of the cell is where the **DNA, in the chromosomes,** stores all the blue prints to make the product. Of course the blue print plans can't make the product in the office. The plans must be sent to the assembly line in the factory (**various organelles located in the cytoplasm**).

Tissues: Tissues are aggregates of different kinds of cells working together for a common and more complex purpose. Using the cell model above, visualize one factory manufacturing wheels, another fenders, another leather seats, another windshields, and another carpeting. All these products are shipped to the factory that assembles all the manufactured parts, producing an automobile (**Tissue**).

Organ: Now imagine factories which are producing sedans, SUV's, and sport cars, other factories building trucks and vans, and additional factories manufacturing planes, trains, etc. (**Organs**).

System: All the various vehicles transport people or products from one place to another within the nation's transportation system. The human body not only has a transportation system (Circulatory System), it also has ten other specialized systems.

Organism: Now consider the combination of a national transportation system, medical system, farming system, educational system, housing system, clothing system, police and military system (for protection), etc., managed and directed by a central government (**Brain and Endocrine System**). All together it's a nation (**Human Being).**

Now that we've laid out the working concept of human body organization, we are ready to explore those body systems that most directly respond in a way that produce the most significant signal values in PDD assessment.

IV. NERVOUS SYSTEM

Now that you have been introduced to human body organization, it is important to study, in a little bit more detail, the physiological events of those systems specifically used in

the diagnosis of PDD examinations. You can always explore more details of systemic physiology in the expanded section of this manual or the texts listed in the reference section.

The most significant cell in the nervous system—the "star" of the show— is the **neuron.** Although there are other support cells associated with nervous system function, much like support characters who play vital roles in supporting the show's star in a Broadway Show, we must focus most of our attention on neurons, with only an occasional reference to the support cells.

There are three main neuron stars in this show, **Association (interneurons), Sensory Neurons, and Motor Neurons.** The motor neuron has been the most studied in neurophysiology because of its size, rather elegant design, and relative easy access to researchers. Please refer often to the incorporated diagrams in the *Detailed Section* for better understanding.

Ions of various types can be separated in a discriminating way between the extracellular (interstitial) fluid and the internal cellular environment due to the highly significant **selectively permeable membrane** design of neurons and other cells. Many physiologists consider the extracellular fluid as the ocean, and human cells as all the living organisms in that ocean.

Ions such as Sodium (Na+), Potassium (K+) and Chloride (Cl-), (Chlorine before gaining an electron), can move in an electrical field. Ions capable of this movement are known as **electrolytes.** When Neurons use electrolytes to conduct a current-like impulse, it is known as an **action potential**. Neurons use action potentials to communicate and direct all body organs to perform their duties for the ultimate useful function of the body. Neurons, therefore, are referred to as *excitatory cells*. When your physician requests the laboratory draw your blood for analysis, the test will likely include an evaluation of your electrolytes. A blood test for electrolytes is simple and important. An imbalance of electrolytes can be caused by many factors including diet, medications, life style, etc. If the electrolyte levels are significantly imbalanced, all body physiology, including nervous system, cardiovascular system, respiratory system and sweat gland activity, can be significantly affected.

A resting potential must exist before neurons can conduct an action potential. Before a current can be created to turn on a light, a resting potential must exist to draw on the battery's stored power. The resting potential of the battery is quantified into units called **volts**. Since a neuron is so tiny, the unit of power is measured in **millivolts** (mV). Although batteries and neurons share similar concepts of stored energy, there are differences between them as to how that energy is converted into a current (amps, in electricity) or an action potential in neurons.

Cell voltage is calculated by measuring the **difference** between the charged molecules and ions on the outside of the cell membrane compared to the inside of the cell membrane. The resting potential difference in most neurons is about -70 mV. (Convention dictates that the resting potential, measured in mV, compares the inside of the cell to the outside. If the voltage was measured from the other side of the membrane it would be +70 mV.) In the heart and some specialized cells, the resting potential may be -90 mV or some other voltage. K+ is the most important ion for establishing resting potential. The selective permeability of the neuron membrane permits some of the K+ ions to diffuse out of the cell. As that happens, the cell is left less positive, or in effect, negative. As more potassium diffuses outward at a declining rate, the positive nature of the ion is electrochemically attracted back into the cell. There will come a point when the diffusional force driving K+ out of the cell falls into equilibrium with the electrochemical force to bring it back (like a tug-of-war game at a standstill). At about -70 mV, those forces are equal, which establishes the **Resting Potential**.

A visual description of sensory and motor neurons can be viewed on subsequent pages in the detailed section. The most significant parts of a neuron, in order of conduction of a nerve impulse, are the dendrites, cell body, axon and telodendria (synaptic terminals branches). For simplicity sake, many details of how a neuron generates and conducts impulses (action potentials) will not be described in this manual, but can be read in

any of the associated texts listed in the reference section.

Neuron

A neuron will receive a stimulus signal of many different types on the dendrites or cell body, which may alter membrane receptors (**chemical gates**) to permit Na+ to enter the cell and move toward the axon. When enough Na+ ions reach the axon, the voltage difference across the axon cell membrane will fall from **-70 mV** to about **-55 mV**. When that voltage occurs, **voltage gates--**special molecules in the axon cell membrane sensitive to that voltage--will open. This forms a channel, which allows many more Na+ in the extra cellular fluid to rush into the axon because the inside of the axon is negative and the concentration of sodium is lower than the outside. In a millisecond, the inside of the axon next to the cell body will become **+30 mV**. This change in transmembrane voltage from -70mV to +30 mV is referred to as **depolarization**. Sodium ions that just rushed into the axon will move to the adjacent area because the rest of the axon is still resting at -70 mV. This reduces the membrane potential to -55 mV, causing additional adjacent voltage sensitive channels to open. More Na+ then rushes into the cell, causing that spot on the axon to depolarize. These events keep reproducing in a manner very similar to knocking down a row of dominos. Once it starts, it can't be stopped. In neurophysiology, these repeating events are the **action potential**. Once it starts, just as with the domino model, it's self-generating in an **all or none** fashion. The firing of a gun is another model reflecting this concept. The bullet is not discharged until the pressure requirement of the firing pin onto the primer is reached. If the pressure is inadequate, the bullet is not discharged. The minimum stimulus needed to engage the action potential within a cell is often referred to as the **threshold stimulus**.

After the Na+ enters the cell, the neuron will pump out the Na+ and pull K+ back to their original positions so a new action potential can occur. This can occur 80 to 100 times per second. The chemical mechanism of the sodium/potassium pump is beyond the scope of this manual, and therefore, won't be described.

Some action potential needs to occur as quickly as possible, such as in a pain pathway. Therefore, neuron axons are wrapped in a special fatty membrane known as **myelin**, which is produced by **Schwann cells** or other special **glial cells**. Visualize wrapping a piece of paper around a pipe, then another layer next to the first wrap, but leaving a small space, and so on. This is what the Schwann cells do. As a result, the Na+ can only move into the cell at these spaces (**nodes of Ranvier**) between the Schwann cells. A string of hot dogs in the butcher shop may help you visualized the design. Observe the drawing in the *detailed section* of the manual. Since the depolarization can only occur at the nodes between the Schwann cell wrappings, the action potential effectively skips along the axon, known as **saltatory** conduction. The autoimmune disease multiple sclerosis (MS) results when the myelin is destroyed. Action potentials can't occur normally, leaving the patient's nervous system less effective.

When the action potential reaches the end of the axon, which may be less than a single mm in length, or up to one meter long, it spreads out like branches of tree. This branching pattern is referred to as **telodendria.** This allows the neuron to communicate with many other neurons. Any word with "telo" in the prefix means "end of". Tiny bulbous terminals (end bulbs) are at the end of the telodendria. These terminals contain vesicles that store highly specialized molecules called **neurotransmitters.** The branching like design of the cell body are also called dendrites, but not telodendrites, as you note from the drawing in the *Detailed Section*.

You will also see that the terminal ends of the axon come intimately close--but don't touch--the dendrites or cell body of the next neuron. This space or gap is known as the **synapse.** When the action potential reaches the end bulb, a complex reaction takes place causing a neurotransmitter to be released into the synaptic cleft (see diagram). The neurotransmitter will connect (like a key in a lock) to a special receptor on the post synaptic dendrite or cell body membrane causing a channel to open. Depending on the neurotransmitter and receptor combination, different ions could be allowed to enter the cytoplasm of the post synaptic neuron. Usually it will be either Na+

or Cl- . If Na+ enters, the post synaptic neuron will generate a new action potential. If Cl- enters the post synaptic neuron, it will not generate a new action potential because the inside becomes more negative (inhibitory). When the inside voltage of the cell is more negative, it is further away from the threshold voltage and an action potential is less likely (it is inhibited). Both excitatory and inhibitory management is necessary for proper management of the nervous system. Think of managing the operation of an automobile. There will always be a mixture of gas pedal and brake to properly operate the car. Unfortunately, sometimes accidents occurs when the gas pedal or brake are not properly coordinated. Guess what? Sometimes the proper neurotransmitters and receptors are not engaged properly resulting in bad behavior or inadequate regulation of body organs, which cannot be maintained adequately.

In PDD and other psychological sciences, several of the most important neurotransmitters to be understood are: **Norepinephrine (NE), Acetylcholine (Ach), Dopamine, Serotonin, Gamma aminobutyric Acid (GABA) and Glutamate.** Psychopharmacology addresses the issues of depression, anxiety, hyperactivity and other behaviors. This science has become intensified in recent years as the physiology and control of these neurotransmitters have become better understood.

The widespread use and abuse of prescription drugs as well as the illicit drug consumption has become an increasing concern in PDD. No drug is known to be site-specific, that is alters the neurological effect only at the relevant question or only at the comparison question. But we are concerned that the use of drugs could make assessment of physiological response more difficult to evaluate. Also keep in mind that some subjects elect to not take their prescribed medications the day of the test, or they may use an excessive dose, thinking it will interfere with the examination. These self-medicating individuals are creating additional problems when they withhold their prescribed medications, such as a rebound effect when a drug is suddenly withdrawn without medical supervision.

Central Nervous System

The Central Nervous System **(CNS)** is composed of the brain and spinal cord. The brain is an exceedingly complex organ from any level of study. We must, therefore, approach this subject somewhat topically. More details of brain function are described in the *Detailed Section*.

The largest part of the brain is composed of the **cerebrum** which is divided into two hemispheres, often described as the **right brain** and **left brain**. The two hemispheres are connected by many axons collectively known as the **corpus callosum,** which allows one hemisphere to communicate with the other. Each hemisphere is characterized by bumps, **gyri,** and indentations, **sulci**. The brain is functionally segregated into lobes, described as **frontal, parietal, occipital, and temporal**. Considerable research has studied these areas of the brain and the role each plays in our behavior. These lobes are found in both the right and left hemisphere, but contribute different aspects of our personality and behavior. These behavior patterns are often described as brain lateralization. For instance, certain areas in the left hemisphere are more dedicated to language skills while the right hemisphere may be more involved with music or judging speed and distance. Needless to say, these are very interesting areas of study and will be addressed to some degree later.

The surface of the brain is the **cortex** and is typically described as **gray matter** because of the appearance. The gray matter is composed of billions of neurons with trillions of synaptic connections. The brain areas can assess many incoming signals through this network, and direct the body to respond appropriately.

The brain can receive direct signals (action potentials) from the 12 pairs of cranial nerves. Some of these cranial nerves are classified as **sensory,** such as the optic nerve, which conveys visual signals to the brain. Others may be **motor,** which carry outflow signals from the brain to various areas of the body. Other cranial nerves are mixed because they contain both sensory and motor axons. The cranial nerves have specific names and are often identified by Roman numerals. Of the

twelve pairs of cranial nerves, the Vagus Nerve (number X) is the most important to PDD examiners. You will learn more about this nerve in the *Detailed Section.*

In the science of psychophysiology, the birthing mother of PDD, the prefrontal lobe of the cerebral cortex is considered the center of our **cognitive skills.** The **limbic system,** while not technically a system, is a functional group of selective areas, which channels all of the incoming signals into **emotional assessments** such as fear, anger, pleasure, sense of well-being, etc. Much of our personality is the product of the cognitive and emotional expression of these incoming signals. **White matter** is located under the brain's cortex of gray matter. **White matter** is composed of **myelinated axons,** again named because of the appearance. Recall, a "myelinated axon" is a term conveying the concept that action potentials are being conducted from one place in the body to another by way of salutatory conduction.

At the base of the brain is the **brain stem**, which is composed of several subdivisions. The most important is the **medulla oblongata**, or just "medulla" for short. The medulla is responsible for coordinating the outflow of action potentials to most of the body's organs. The PDD examiner is recording this coordinating activity from the medulla and vagus nerve during a polygraph examination. The vegetative outflow from the brain stem, which includes the medulla, is regulated by the inputs from the cognitive and emotional areas of the brain.

Spinal Cord and Peripheral Nervous System

In addition to cranial nerve input and output signals to and from the brain, the spinal cord also provides major input and output signals. The spinal cord contains gray and white matter which is described further in the *Detailed Section.* The gray matter in the central part of the spinal cord contains an elaborate network of synaptic connections. The white matter surrounds the gray matter. The white matter is further partitioned into ascending and descending tracts of axons. The ascending tracts convey action potentials from various body organs to the brain for assessment. The descending tracts convey motor action potential back to the body organs.

The spinal cord communicates with the body organs through 31 pairs of spinal nerves, all of which contain sensory and motor axons. These 31 pairs of nerves comprise the peripheral nervous system and will be described further in the *Detailed Section.* Briefly, most of the axons in the spinal nerves, about 95%, will synapse to skeletal muscles and control voluntary movement referenced as the **somatic nervous system (SNS).** The remaining axons form complex pathways that eventually synapse in soft organs, blood vessels, glands, and other areas to make physiological adjustments during times when the environment, or mental thoughts (cognition), provoke a perception of stress or rest. This system is the **autonomic nervous system** and is of particular interest to PDD science.

Autonomic Nervous System

The autonomic nervous system (ANS) is composed of the **sympathetic division and the parasympathetic division**. The human being is in a continuous state of evaluating environmental signals entering the brain through the eyes, ears, nose and skin. Based on experience and learning, the brain assesses the signal data and makes appropriate decisions. The decisions include marshalling together the body organs for the most appropriate response. Sometimes, it might be a perception of danger. Other times, it could be the aroma of food cooking, which stimulates hunger. Or perhaps the brain anticipates a potentially pleasurable or unpleasurable experience is about to occur and therefore needs to coordinate the organ systems to address the stimulus. Like a central government working with a local government, the brain, by way of the ANS, can make appropriate adjustments in the organs and cell factories to meet current situations.

During the formative years, the limbic system of emotion is the driving force to satisfy a pleasurable stimulus, such as the sight of a chocolate cookie. However, what if it's 10 minutes before dinner, and the mother says, "not now, wait until after dinner." The three year old begins to cry, lacking the understanding of his mother. In the immature state, the stimulus of pleasure rules behavior. When the

child matures, the cognitive part of the brain rules the limbic system and hopefully better directs the behavior. The ANS will drive the organ systems to respond appropriately based on the cognitive emotional mix. The details of this ANS management of body organs, particularly the cardiovascular system and eccrine sweat gland activity, will be described in the *Detailed Section.*

Mature humans recognize a variety of environmental stimuli, to which we react appropriately. We continuously assess situations from pleasant to dangerous, causing organ activity to increase or decrease accordingly.

The sympathetic nerve pathways originating in the brain stem are activated when the higher brain centers recognize a need for heightened awareness. The spinal cord provides the main pathway out of the brain through a specialized synaptic connecting system known as the **sympathetic chain ganglia**. Following synaptic communication, post synaptic action potentials communicate to the respective organs that will best respond to the environmental circumstance the brain has recognized. This complex series of physiological responses is often referred to as **"fight or flight."** Further discussion regarding sympathetic reactions can be seen in the *Detailed Section*.

The parasympathetic nerve pathways may also be activated by higher brain areas when the brain perceives the environment as tranquil. This pathway out of the brain is through selective cranial nerves, particularly, the Vagus Nerve, (cranial nerve X), and a pathway exiting the lower spinal area. Additional information concerning parasympathetic reactions is available in the *Detailed Section*.

It has been widely studied in the medical science of psychophysiology that many individuals have a degree of difficulty regulating the sympathetic and parasympathetic balance the continuously changing environmental circumstances present. Extreme cases are described as "manic depression," or more commonly, "bi-polar disorder." Numerous pharmaceutical agents have been developed to help the brain more properly assess the environmental landscape. This branch of medical science has greatly assisted individuals with various psychic anomalies; however, the profound misuse and abuse of these drugs is an increasing concern to the PDD examiner.

Let us now explore those systems regulated by the ANS, which provide the most diagnostic information related to PDD.

Integumentary System

The integument, more commonly referred to as the skin, provides multiple benefits to overall body function. Its histology (tissue design) is organized into two primary areas. The cutaneous membrane is composed of the **dermal (or dermis) and epidermal (or epidermis)** layers plus a hypodermis, which contains fat cells. Connective tissue anchors the cutaneous membrane to underlying structures. Overall, the skin provides protection from infection (referred to as the first line of defense), secretion of waste products, thermoregulation, increased grasping ability, tactile detection of external environmental changes (sense of touch), storage of lipids (fat), and the synthesis of vitamin D3.

For PDD purposes, the focus of attention will be on the cutaneous membrane and its electrical properties. The epidermis is composed of four or five layers of skin cells called keratinocytes. The body is mostly covered by four layers of thin skin. Thick skin covers the palms of the hands and soles of the feet and is completely hairless. The epidermis has no blood supply--it is "avascular"--while the dermis is highly vascular with robust physiological activity. At this point, you may be asking how the epidermis stays alive without a blood supply.

The deepest layer of the epidermis is the stratum germinativum (basale layer), which lies adjacent to the vascular dermis, from which it receives life support supplies. As the skin cells reproduce, they are pushed upward away from the blood supply and begin dying, a process takes several weeks to complete. As the progression continues, the cells develop distinguishing characteristics, which the science of dermatology has classified into identifiable layers. The outermost layer, the corneum, contains multiple layers of dead

cells, which protect the body from infection. While these cells continuously flake off, they are replaced by reproducing new cells from the germinativum layer pushing up their offspring. Advanced forensic science has focused attention upon the corneum's exfoliation of cells, conducting DNA sampling of these cells, testing who may have visited a crime scene.

The dermis--sometimes described as "true skin" because of actual blood supply--contains hair follicles, as well as numerous types of nerve endings providing tactile information to the brain. The functional understanding of the sweat glands of the dermis, classified as **eccrine sweat glands**, is most important to the PDD examiner. These glands are widely spread over the entire body, but are most densely populated on the palmer surface of the hands and fingers. See the diagram in the *Detailed Section*.

Most eccrine sweat glands secret a fluid containing sodium chloride ions, urea, uric acid, ammonia, and other chemicals. Although sweat from these glands has no apparent scent, bacteria that live on the skin can feast on the chemical wastes of the body and create a detectable odor. Because of easy access to data recording and the scientific evidence of the cognitive/emotional mix of brain function related eccrine sweat glands, they have become a good metric in psychophysiological studies and hence PDD evaluation.

Another class of sweat glands known as **apocrine sweat glands** secret their contents into hair shafts located mostly under the arms and in pubic areas. These sweat glands contain a more complex mix of secretions but don't become active until puberty. Bacteria on the skin surface will feast on these secretions at an even higher rate than the eccrine secretions. Coupling one's unique body chemistry with this sweat and bacteria metabolism creates a personalized scent that can be recognized by the family dog who knows exactly who's who in the family or house guests. Many behavioral scientists believe the apocrine gland function may elicit even more signal value of the brain's perception of cognitive and emotional stimuli than eccrine gland function. Due to their location, however, this hypothesis has not been widely studied.

Eccrine gland function of thermoregulation is accomplished by providing a water medium on the surface of the skin for the cooling effects of evaporation. Sweat glands on the palmer surface of the hand and fingers, however, improves grasping ability. There is some debate in PDD as to the better site to record sweat gland activity. Using gel pads on the thenar and hypothenar area of the hand or electrodes on the finger tips are both good locations to record the sweat gland activity. Were an examiner to encounter a person without hands, the plantar surface of the feet also have a high density of eccrine sweat glands.

Since sweat contains electrolytes (Na+ and Cl-) in the watery mix, the surface of the skin can become a good conductor of electricity when sweat glands become more active. In PDD science, an increase in electrodermal activity (EDA) provides good signal value of the brain's perception of the question. The skin conductance (and resistance) changes observed during PDD examinations is governed by **Ohm's Law (I=V/R).** I represents current (amperage), V represents voltage and R is resistance. Ohm's law may be rewritten as R=V/I to isolate the resistance component. Different aspects of the equation will be evaluated based on the specific polygraph manufacturer. In most psychophysiological laboratories, the voltage or current is held constant by the instrument. When the sweat glands are activated, water and NaCl are secreted. This increases conductance (or reduces resistance) to the flow of electricity between the contact points of the electrodes (fingertips or palmer surfaces). When either the current is held constant, a change in resistance will be reflected by a change in the result will be an increase in voltage. When the voltage is held constant, a change in conductance is reflected by a change in the measured current flow. The PDD examination can be a stress/cognition evaluator. Is the examinee experiencing more stress/more cognition to the Relevant or Comparison Questions as they relate to their goal of passing the PDD test? As more sweat is produced, quantifiable resistance declines resulting in associated changes in voltage and/or current. These changes are what produce the upswing and duration seen in the EDA tracing.

Most body organs are dually inner-

vated, that is, regulated by the sympathetic nerve pathways when stress increases, or by the parasympathetic nerve pathways when the stress is either dissipated or a sense of rest is perceived. One of the most widely secreted neurotransmitters at the synapse of sympathetic pathways of the target organ is norepinephrine (**NE).** Acetylcholine **(Ach)** is commonly released from parasympathetic pathways. **Sweat glands are unusual in that regard.** Sweat glands only need to be activated by sympathetic stimulation and will simply return to a less active state when the stimulation is reduced. Another notable difference is that Ach is the neurotransmitter in the sympathetic management of the eccrine sweat glands. This exception is somewhat perplexing.

Of concern to PDD examiners, is the proliferation of prescribed drug therapies which may either increase or decrease Ach release in certain organs. The digestive system, for instance, is dominated by parasympathetic release of Ach. A side effect of these drug therapies, classified as either a cholinergic agonist or cholinergic antagonist, is the unintentional effect it may have on sweat gland physiology. Just as a reminder, never suggest to a polygraph subject not to take his/her prescribed medication because of an upcoming polygraph test. When in doubt, always get the advice of the health care professional. Never interfere with the examinee's healthcare protocol.

Cardiovascular System

The cardiovascular system can be likened to a transport system within a nation. The blood is the vehicle which is capable to bringing the raw materials (nutrients from the digestive system) to the factories (cells) located in many locations (systems, organs, and tissues). As in any nation, (human body) there are millions of different kinds of factories which produce products of all kinds. Some factories produce products for local use, while others produce products for use in other places. As in a nation, the body's eleven systems are not all simultaneously functioning at maximum capacity. The nation's varied infrastructure can adapt to meet the changing environmental conditions depending on situations presented. The human body can also make the necessary adjustments. For instance, you wouldn't be having dinner (activating the digestive system) while working out at the gym (activating muscles, tendons and ligaments).

Blood

Although blood chemistry and physiology has not been the subject of PDD study, a brief introduction to its composition and function will be helpful to your understanding of human physiology and to the physiological activities which do play direct roles in PDD evaluation. Further study of blood is not required for practitioners of PDD science.

Blood is comprised of to two major components: formed elements (various cells), and plasma (a molecularly complex watery composition). The mix of blood components can vary somewhat depending on one's size, gender, and physical condition. An average person has about 5 liters of blood, consisting of roughly 45% cells and 55% plasma. Approximately 99% of the cells are described as red blood cells (RBC), and less than 1% is a mixture of five different kinds of white blood cells (WBC) and platelets. The RBCs contain complex molecules known as hemoglobin, which has a red color under light. Hemoglobin is responsible for transporting oxygen from the lungs to the tissues. It also carries most of the carbon dioxide produced by the cell's metabolism to the lungs to be discharged to the air. It is the combination of hemoglobin with oxygen which gives blood a bright red color in arteries, the vessels delivering blood to the tissues. Deoxygenated hemoglobin is dark red in veins, the vessels that return blood from the tissues. There has been a long standing myth portrayed that blood is blue and turns red when it hits the air. Don't believe it. It's a bad joke played out on the naïve.

The key concept of understanding blood is that the RBCs pick up of oxygen from the lungs, deliver it to the cells, and upon return, carry carbon dioxide from the cells to the lungs. WBCs are responsible for defending the body from infections. The plasma delivers nutrients and a host of regulatory molecules to the cells and returns a host of waste products from cell metabolism to the kidneys and liver to be excreted from the body.

As mentioned above, not all systems are performing to their maximum capacity at all times. As the brain perceives either a threatening circumstance or a need to address a stressful situation, selective adjustment in organ system physiology must be made. Since oxygen delivery and nutrient support is vital to the systems addressing the stress, it is now important for the understanding of PDD how this is accomplished. Already described, albeit briefly, the blood is the vehicle of delivery, but must be pumped in a manner that selectively increases delivery as circumstances require. Here comes the heart.

Heart

The heart, simply put, is a pump. Its design, however, is elegant. In fact, the heart has two pumping systems within the single organ. The right side of the heart is composed of the **Right Atrium,** a receiving chamber for blood returning from the tissues and **the Right Ventricle,** a pumping chamber sending the blood to the lungs so it can unload carbon dioxide and pick up oxygen. The left side of the heart receives blood coming back from the lungs in the **Left Atrium**, while the **Left Ventricle** pumps blood to the organ systems of the body. Why two separate receiving and pumping chambers?

The short answer is that pumping blood through just the lungs requires about one third the pressure than the same action through the other systems of the body. The lung design is composed of very delicate thin walled membranes, which cannot tolerate high pressure, but more about lung design when we get to the Respiratory System.

The other (non-respiratory) systems in the body, in their collective design, require a much higher pressure than what is provided to the lungs. This is to overcome the resistance of thousands of miles of blood vessels comprising the human body vascular network of **arteries, capillaries, and veins.** For this circulatory system to work, two separate receiving and pumping chambers, each with different pressure generating pumps is required. Inspection of the muscular wall of the right ventricle compared to the left ventricle wall reveals the left ventricle has considerable more muscle mass than the right ventricle. Again, this is because it must generate a pressure force significantly greater than the right ventricle.

It is helpful to inspect the vascular design of the arteries and veins to get an appreciation of the blood vessel map. Starting with the right heart pump, notice the **superior vena cava,** a large blood vessel vein returning blood from the head, shoulders, and arms, into the right atrium. The largest blood vessel (by diameter) in the body is the **inferior vena cava**. It returns blood from the legs, abdomen, and chest. Blood from the right atrium is delivered to the right ventricle and pumped through the pulmonary trunk, which branches into left and right pulmonary arteries to the lungs. The left heart pump receives blood from each lung into the Left Atrium by the **left and right pulmonary veins.** Blood from the left atrium is delivered to the left ventricle and pumped into the **ascending aorta** for distribution to the body organs. More about systemic blood flow distribution later.

An easily understood law of physics can be applied to the heart pumping cycle. If the volume of a chamber decreases, the pressure (which is force per area) in the chamber will increase and vice versa. This concept was originally applied to gases and is widely known as Boyle's Law. Since the pressure in the ventricles oscillates between the contractile phase and the relaxation phase, a valve system must be employed to ensure blood will flow in only one (forward) direction. A **tricuspid valve, located** between the right atrium and right ventricle, is forced closed when the ventricle contracts forcing the blood to enter the pulmonary artery toward the lungs. It is sometimes called the right atrioventricular (AV) valve. When the ventricle contracts, which would permit the blood to go backward into the atrium, the valve leaflets are secured by chordae tendineae anchored to the inside wall of the ventricle (see diagram). This prevents these valves from flapping completely into the atrium. When the right ventricle is contracting, so is the left ventricle. A similar valve design exists between the left ventricle and left atrium (the left AV valve). Due to the pressure on this side of the heart being about three times greater, the two flap design of the **bicuspid valve** is more effective. This valve is often referred to as the **mitral valve** in clin-

ical settings because it is said to look like a bishop's miter or hat. When the pressure increases in the left ventricle, blood is pumped into the ascending aorta for distribution to the organ systems.

After the ventricles contract, they must relax. By relaxing, the volume in the ventricles increases, causing the pressure to fall. This has the potential to suck (return) the blood that each ventricle pumped out during the previous cycle. Suction forces of the relaxing ventricles, however, actually prevent that from occurring because of valve with a three flap-like cusps in its design. These valves are described as the pulmonary and aortic **semi lunar valves** because of their appearance. During the cardiac cycle, as the ventricles oscillate between contraction and relaxation, the cuspid valves close, then open, followed by the semi lunar valves closing, then opening. The closing of the valves causes characteristic sounds which can be detected with a stethoscope. The closing of the cuspid valves is commonly described as the first sound or **lubb.** The closing of the semilunar valves is described as the second sound or **dupp.** These sounds result from blood bouncing off of the valves.

When the lubb sound occurs, the left ventricle is pumping blood through the systemic arteries, generating an increase in pressure referred to as the **systolic pressure** or **systole**. Simultaneously, the right ventricle is pumping blood to the lungs. When the ventricles relax, the systemic arterial pressure falls, referred to as the **diastolic pressure** or **diastole.** Note there are no valves between the venous blood return to either the right or left atrium (see the heart diagram). Since the ventricles are the pumping workhorses, when they are in the diastolic phase of the cardiac cycle, about 80% of the blood returning to the heart is sucked through the atria into the ventricles. When the thin walled right and left atria contract, the remaining 20% of the blood is pumped into the ventricles, joining the blood the ventricles pulled in during the relaxing phase of the cardiac cycle.

When individuals experience diminished ventricular contraction, the rebounding phase is diminished, much like a rubber ball thrown gently against the wall bounces back softly compared to a ball thrown vigorously against the wall. When the right ventricle weakens, swollen ankles (edema) are often detected because blood and tissue fluids are not being efficiently pulled back by the weakened right ventricle. When the left ventricle weakens, fluids accumulate in the lungs, often leading to pneumonia and other respiratory difficulties.

The cardiac cycle is governed by both an **intrinsic conductive system** and an **extrinsic conductive system**. Both of these management systems will be described in the *Detailed Section*. Briefly, though, when the cognitive and emotional brain assessment of an environmental stimulus is provocative, a sympathetic pathway releasing the neurotransmitter, norepinephrine **(NE)** to the heart's intrinsic conductive system occurs and a parasympathetic pathway decreasing the release of Ach to the heart occurs. This is similar to stepping on the gas and coming off of the brake at the same time. The synergistic effect on the heart is more effective than either one in isolation. This response will increase cardiovascular dynamics. Conversely, when the brain perceives the environment as tranquil, the vagus nerve, with the release of acetylcholine **(Ach),** dominates relaxing cardiovascular dynamics.

Like all well managed industrial plants, feedback information from the workers or foreman on the job would be welcomed information back at headquarters. Feedback information in cardiovascular system comes from two major areas reflecting blood pressure and blood chemistry. After you have inspected the blood vessel map, take notice of the ascending aorta leaving the left ventricle. It bends sharply (aortic arch), then descends into the chest and abdomen branching many times. At the top of the aortic arch arise three main arteries, **brachiocephalic, left common carotid** and **left subclavian**. The first artery, the brachiocephalic, divides into the right common carotid artery and right subclavian artery. The second branch is the left common carotid artery and the third branch is the left subclavian artery. The carotid arteries are the main vessels delivering blood to the brain. Each carotid artery bifurcates into an internal and external carotid artery. The **carotid sinus** is where the internal carotid arteries begin a small dilation

of the artery. There are many specialized nerve cell receptors in the walls of the carotid sinus and arch of the aorta. The receptors detect blood pressure and blood chemistry changes. Action potentials are relayed by cranial nerve IX and X to the brain stem and other brain areas based on what these cells detect. The heart rate and force of each cardiac cycle are then adjusted through the ANS to meet the body's blood flow needs.

Sphygmomanometer

Blood pressure is routinely evaluated as part of a medical assessment. Blood pressure is measured by placing a rubber bladder around the arm. The bladder, which is connected to a pressure gauge, is inflated with air until the pressure is great enough to overcome the left ventricle's contractile strength. The technician or doctor listens for the sound of passing blood below the cuff with a stethoscope. When no sound is detected the pressure in the cuff is greater than the left ventricle can overcome. Next, the air is slowing let out of the cuff. The first sound in the stethoscope indicates some blood is passing through the artery, but still partially restricted by the pressure in the cuff. The ventricular pressure created by the contracting ventricle, which is causing the blood to flow, is greater than the pressure in the cuff and is referred to as the **systolic pressure.** This pressure may be about 120 mmHg in many individuals. Air continues to be let out of the cuff until no sound can be heard which indicates the cuff is no longer offering resistance to the blood flow. This is referred to as the **diastolic pressure,** which may be about 80 mmHg. Blood pressure can have a wide range of values based on age and many other factors. If too extreme, the doctor may declare the blood pressure is abnormal and prescribe a medication.

In PDD science, variations in heart rate, relative blood pressure, and **pulse pressure** (the difference between the systolic and diastolic pressures), can provide diagnostic value in calculating the probability of deception. The sphygmomanometer, (hereafter referred to as the blood pressure cuff) used in the PDD, is secured on the arm for nearly five minutes during the recording of a single chart. This could become very uncomfortable and even cause distorted physiological recordings if the pressure was maintained between systolic and diastolic pressures. By adjusting the cuff pressure below diastolic pressure to about 60 mmHg, cardiac cycles and other pressure dynamics can still be recorded with instrument amplification because the artery under the cuff is pulsating against the tissues in the arm with each cardiac cycle. It would be helpful to observe the blood vessels of the arm from diagrams. Make particular note of the brachial artery because that is the blood vessel the cardio cuff is monitoring.

Respiratory System

The respiratory system is dedicated to extrapolating oxygen from, and returning carbon dioxide to, the atmosphere. The respiratory system is exposed to the environment and is subject to being invaded by pathogenic airborne diseases in the process of performing these roles. The system must be adaptive and be able to develop defensive mechanisms to prevent infectious diseases, or at least minimize the effect of these potential pathogens.

The respiratory system, by expiring air through the larynx (voice box), can create sounds for speaking, singing, and even louder sounds to signal danger or summon help from others. The nasal portion of the respiratory system detects stimuli of olfactory (sense of smell) which is alerts us to food and its taste as well as signaling danger such as smoke or the pleasure of attractive aromas. The sense of smell is also a stimulus to memory.

The respiratory system even participates in the regulation of blood pressure. A specific hormone is activated in the lungs which can help raise blood pressure. Blood pressure is also modified by the simple mechanics of breathing. The regular dynamics of inhalation reduce pressure in the thorax which helps to dilate the vena cava which reduces resistance and thus helps to suck blood back to the heart, raising blood pressure. Also, during inhalation the heart beats faster resulting in respiratory sinus arrhythmia. A faster beating heart is like a faster pumping pump and can result in increase in blood pressure.

During exercise, breathing rate increases. As a consequence, blood pressure

increases because more blood is pulled back to the heart, at a faster rate. In addition to this respiratory pump, many veins are located between muscles. These veins are squeezed during exercise, which helps pump the blood back to the heart (muscular pump). Perhaps it's more easily visualized that exercise creates the combined effect of two additional "pumps" which becomes the heart's "best friend."

After long periods of inactivity, such as sitting at a computer desk or driving a car for a long period of time, blood pressure begins to fall and a person may begin to yawn. The action of yawning intensifies the respiratory pump, drawing more blood back to the heart, raising blood pressure, at least for a short time. Think about waking up in the morning. After a night of sleeping, you need to raise blood pressure to stand vertically and start moving about. How do you accomplish that? You got it. You start yawning and stretching to activate the respiratory and muscular pumps while still in bed to raise blood pressure. If you get out of bed too quickly, you might stumble or fall because your blood pressure is too low from sleeping all night. This concept of forcing blood back to the heart to raise blood pressure by yawning and stretching is known as **Starlings Law of the Heart**. Within limits, the concept states the more blood returned to the heart, the more will be pumped out. Increased inhalation and increased muscular movements will increase blood **stroke volume (ejection volume).**

It becomes a concern in PDD that breathing dynamics are under somatic control, and can be controlled and modified. Skillful regulation of breathing cycles, that is, practicing **countermeasures,** can have detrimental effects on the cardiovascular system as well as EDA during a PDD examination. If you are an experienced examiner, you have observed that when a subject takes a deep breath, whether purposely or otherwise, the other recorded channels in a polygraph become contaminated, thus reducing or eliminating their diagnostic value.

Ventilation Anatomy

Pulmonary ventilation (breathing) begins as air flows into the body through the nares (nostrils), then the nasal passageway, and into the pharynx. The pharynx is shared with the oral cavity (mouth), which directs food into the esophagus while air is directed into the **larynx** (voice box), then into the **trachea.** This dichotomy is designed so that inhalation of air and swallowing of food or liquid cannot occur at the same time, that is, we can't swallow and breathe at the same time. The airway is protected from food or liquid entering it by a cartilaginous flap-like structure called the epiglottis. The epiglottis presses over the opening (glottis) of the larynx when swallowing.

The trachea divides into left and right **bronchi,** which continue to branch like a tree until the branches become microscopic (bronchioles) and terminate into millions of thin walled air sacs named **alveoli.** The microscopic alveoli are organized into two organs, the right and left lungs. The alveoli are surrounded with blood capillaries designed to receive oxygen from the air and return carbon dioxide to the air. The physiology of this gas exchange can be reviewed in detail in the text books or the *Detailed Section* of this manual if you are interested in a deeper understanding of the ventilation process.

When discussing respiration, what is most important to the PDD examiner is to be aware that gases exchanged in the lungs are needed to maintain metabolic requirements of the entire body. The exchange of oxygen and carbon dioxide, like all other molecular movements, are governed by laws of physics. Namely, gases move from areas of high concentration to areas of low concentration.

When the body is under stress, such as during exercise or perceiving a threatening circumstance, the autonomic nervous system (ANS) will stimulate the airway, particularly the trachea, bronchi, and bronchioles. This action dilates the airway, reducing airflow resistance, permitting air to flow more easily through the conduction zone between the atmosphere and the alveoli of the lungs.

In a typical challenging or intense athletic event, both a dilation of the airway by the autonomic nervous system, and an increase of ventilation dynamics (breathing rate) controlled by the somatic nervous system occurs, typical of the fight or flight reaction.

In the PDD setting, however, **a most unusual circumstance is present,** particularly for the subject attempting deception. All polygraph examinees are directed not to move during the presentation of the question series, in an effort to avoid artifact contamination of the polygraph recordings. In effect, the physiological oxygen demands are met by the autonomic stimulated-dilated airway for a body **not in motion**. Consequently, ventilation dynamics of breathing cycles is reduced. Typically the amplitude of each breathing cycle is reduced and the respiratory breathing cycles are reduced when the subject perceives the question more challenging their goal of passing the test, than another question. These respiratory dynamic patterns are recorded through the ventilation transducers. If the wave length pattern were placed in a straight line compared to a less threatening question, one could observe the **Respiratory Line Length (RLL) (or respiratory line excursion)** would often be shorter when the more challenging question is presented.

Ventilation Dynamics (Breathing)

On average, during restful or relaxing times, a person inhales and exhales about 12 – 14 times a minute, referred to as quiet breathing or eupnea. The diaphragmatic muscle, which separates the thoracic (chest) cavity from the abdominal cavity, contracts, enlarging the chest cavity. While the diaphragm is contracting, external intercostal muscles between the ribs are pulling the rib cage upward and outward, contributing to chest expansion.

Between the lungs and the chest wall is a double layered membrane, the parietal and visceral pleurae. Between the enclosed layers is a slit-like space with a pressure average of approximately -4mmHg below atmospheric pressure. This negative pressure acts as a suction to hold the lungs to the thoracic side wall. During inhalation, the lungs are pulled outward with the expanding thoracic cavity. In consequence, as the lungs expand, the intrapulmonary pressure within the airway and alveoli also decreases about 1mm Hg, causing air to be pulled into the alveoli (recall Boyle's law of pressure/volume earlier in this manual). During exhalation, the chest wall passively returns to its resting state while the diaphragm relaxes. This phase of quiet breathing forces air out of the lungs.

For an average person, the amount of air exchanged during a single breath is about 500ml, known as the **tidal volume**. During stressful breathing (hyperpnea), other muscle groups and muscles under the external intercostal muscles, the internal intercostal muscles, actively pull the rib cage down so the breathing cycle rate can increase to meet the oxygen demands of contracting muscles. This increased breathing cycle is not likely to be seen during a PDD examination.

Regulation of Breathing Cycles

The respiratory rhythmicity centers are located mainly in the medulla oblongata of the brain stem. These centers can be modulated by areas above the medulla, such as centers in the pons. They can also be modulated by cognitive and emotional areas of the brain. You may recall, the respiratory system also participates in making voice sounds of speech, loud sounds of emotion, singing, etc. Therefore, respiratory centers can be voluntarily adjusted to meet these desires, but needs to have master control of breathing cycles for gas exchange to meet metabolic demands. Some examinees, as you may have observed, will manipulate their breathing cycles. When altered from rhythmic patterns, changes in the cardiovascular physiology can be affected. These factors are of great concern to the PDD examiner.

Chemical changes in the blood such as oxygen, carbon dioxide, and acid levels, affect the characteristic of breathing cycles. The most significant breathing center in the medulla is the Dorsal Respiratory Group (DRG). When certain blood chemicals are changing, the DRG sends out action potentials to the spinal cord. This connects to pathways leaving the spinal cord in the cervical areas of C3, C4, and C5 to form the **phrenic nerves,** which innervate the diaphragm. Other pathways leave the spinal cord in the thoracic region to innervate the intercostal muscles. These pathways lead to the inspiration phase of breathing. Special nerve cells and elastic fibers signal the brain that the lungs have stretched enough, stopping the inspiration and allowing expiration to occur **(Hering-Breuer Reflex).**

There are many other factors which affect how the respiratory system performs its duties, but the physiological details go beyond the scope of this manual. They can be researched further if desired, along with many other physiological activities of the organ systems.

As mentioned earlier, the authors realize the life science background of most PDD examiners is limited by the career choices made before deciding to enter this field. That being said, we hope everyone can appreciate the need to understand the physiological basis we have outlined, albeit in a limited way, so that you will have a good understanding how the human body responds in the PDD setting.

End of Part 1

Detailed Section of Physiology Overview For PDD Lifelong Students of the Science

(Part 2)

Mark Handler and Joel Reicherter

I. INTRODUCTION

See Overview for Introduction.

II. PHYSIOLOGICAL AND CHEMICAL BACKGROUND

A. Chemical level of organization

1. The basic structure of an atom- The structure of an atom consists of the nucleus, which contains the protons and the neutrons tightly bound together. Protons have a positive electrical charge and neutrons are neutral. Protons and neutrons have about the same mass, which is designated as one atomic mass unit. Each proton and each neutron is one atomic mass unit. Electrons have a negative electrical charge and are small in comparison to protons or neutrons. Electrons have about 1/2000 of the mass that a proton or neutron has and are usually designated as zero atomic mass units.

2. Ions are important in cell signaling- An ion is an atom with a positive or negative electrical charge. Calcium (Ca++), Potassium (K+), Chlorine (Cl-) and Sodium (Na+) are all involved in nerve impulse conduction. Ion flow across the membrane conducts the nerve impulse.

3. Molecule- When two or more atoms combine chemically, they form a molecule. Molecules can consist of two or more of the *same* atoms (hydrogen or H_2) or they can form compounds, which are molecules of *different* atoms (H_2O or water).

III. HUMAN BODY ORGANIZATION -cells-tissues-organs-systems-organism

A. CELLS

1. The cell is the basic structural and functional unit of a living organism.

2. There are three generalized regions of human cells and their functions-

a. The *nucleus* lies near the center of the cell and manages the cell's activities through its DNA construction.

b. The cell or plasma *membrane* separates the cell from its internal environment of a watery mix of ions and nutrients, often referred to as extracellular or interstitial fluid. The membrane serves as a regulator of what substances will enter the cell and what will be excreted. Many specialized cells have unique molecules known as receptors, which regulate the movements of certain ions into or out of the cell. As a result of this regulation, cells can have more positive ions on the outside of the cell membrane, which will establish a charge difference between the outside and inside of the cell. This is known as a resting potential. Specialized cells in the nervous and muscular systems can use resting potential to conduct impulses or action potentials. These signals are sent to the organ systems, instructing specific physiological activity.

c. The *cytoplasm* is the fluid-filled region between the nucleus and the plasma membrane. It contains numerous small structures called organelles that in effect are the machinery performing the cell's specialized activities.

3. The plasma (or cell) membrane separates the cell into two areas:

a. Intracellular, and

b. extracellular.

4. *Interstitial fluid* is an extracellular fluid that bathes our cells. It is derived from our blood and contains the many substances needed for metabolism. Cells extract the nutrients they need from this fluid through a process known as selective permeability. The process of selective permeability allows needed nutrients to enter the cell while keeping out undesirable material.

5. *Diffusion* across a cell membrane occurs when ions and molecules scatter to equalize their concentration in an environment. Ions and molecules tend to move from higher concentrations to lower concentrations. This process is called diffusing down their concentration gradients.

a. *Simple diffusion* is one of two basic diffusions that occurs when substances are able to cross the cell membrane without having to use a channel. This happens with such things as oxygen and carbon dioxide. Oxygen concentrations are always higher in the blood than inside the tissue cell, so oxygen constantly enters the cell by diffusing down its concentration gradient. Carbon dioxide (CO_2) is one of the "waste products" produced by the cells and it is in higher concentrations inside the cell than outside. CO_2 diffuses down its concentration gradient by the process of simple diffusion.

b. Facilitated diffusion is the second basic diffusion. It involves the movement of substances across the membrane that are either too large to pass through passively, or, are lipid-phobic (meaning they are insoluble to the lipid bilayer that forms the cell membrane). Facilitated diffusion uses proteins that construct passageways or pores through the membrane.

c. Osmosis is a special type of diffusion. Osmosis is the net movement of a liquid (usually water) across a selectively permeable membrane when there is a difference in concentration of solutes on either side of the membrane. The liquid is driven by the difference in solute concentrations on the two sides of the membrane. A selectively permeable membrane is one that allows unrestricted passage of water, but not solute molecules or ions, so only the water moves from one side to the other.

The different concentrations of the solute results in different concentrations of "free" water molecules on each side of the semi-permeable membrane. On the side of the membrane with higher free water concentration (i.e., a lower concentration of solute), more water molecules are available to bounce around and hit the pores in the membrane. More hitting of the membrane results in more molecules passing through the pores, which in turn results in net diffusion (movement) of free water from the compartment with high concentration of free water to that with low concentration of free water.

6. *Active transport* is an important process to cell membranes. Sometimes substances cannot passively navigate through the cell membrane. This may be due to size, charge, or because it cannot dissolve through the bi-lipid (fatty) layers of material that make up the cell walls. Active transport uses proteins called *transport systems* to move ions "uphill" against their concentration gradient. One very important transport system is the sodium-potassium (Na+ - K+), which helps keep the proper concentration in intracellular and extracellular. The concentration gradients of sodium and potassium are essential for our muscle and nerve cells to function properly.

7. *Vesicular transport* is a process whereby large particles and molecules can be transported across cell membranes inside of small sacs called vesicles. This process is called exocytosis. One way cells communicate with one another is by the release of chemicals called neurotransmitters. The little sacs attach to the inside of the membrane, fuse with it, and spill out the neurotransmitter so it can contact the adjacent cell. The sacs are reabsorbed by the cell, and recycle themselves to be used again.

8. *Membrane potential*, or voltage, is the amount of electrical potential energy across a membrane. In cells, the plasma membrane separates oppositely charged particles. If there are more positively than negatively charged particles gathered on one side (e.g., the outside of the cell membrane), the difference results in *membrane potential*, much like a battery. If

there becomes a way for the charged particles to flow, a current will arise. All cells are said to be polarized because they establish a membrane potential with the inside of the cell membrane being more negatively charged than the outside of the membrane. Cells use this membrane potential to communicate by opening channels that allow current to flow in or out of the cell. This will be discussed later in the section on the nervous system.

9. *Chemical signaling* is a primary way cells in the nervous system, and hormones in the endocrine system, communicate using neurotransmitters. Different cells respond in different ways to the same neurotransmitter or hormone. Some transmitters can increase the activity in one cell and decrease the activity in another. The end result depends upon the receiving target cell.

B. TISSUE

1. *Tissue*- Groups of similar cells that combine to perform a related function are called tissue. There are four types of primary tissue that form the body: epithelial, connective, muscle, and nervous.

2. *Epithelia* – Epithelia forms the boundaries between different environments for an organism. Epithelium provides protection, absorption, filtration, excretion, secretion, and sensory pathways.

3. *Connective Tissue* – Connective tissue "connects" body parts. Functions of connective tissue include support, storage, and protection of the body. Skin, blood, bone, ligaments, and cartilage are all examples of connective tissue.

4. *Muscle Tissue* – Muscle tissue has the unique ability to shorten or contract. The three types of muscle tissues are skeletal, cardiac, and smooth. Smooth muscle is found in the walls of hollow organs like our blood vessels and stomach. It is called smooth because it has no striations or stripes. Smooth muscles can contract (constrict) or dilate (enlarge) and can be used to adjust the movement of substances. Smooth muscles are highly involved in the adjustment of blood pressure.

C. ORGAN and ORGAN SYSTEMS

1. *Organ*- An organ is a discrete structure that performs a specific function composed of different tissue types.

2. *Organ system*- Organ systems are composed of organs working together for a common purpose. There are 11 organ systems in the human body. They are: cardiovascular, respiratory, nervous, integumentary, muscular, skeletal, digestive, endocrine, lymphatic, urinary, and reproductive systems.

3. In PDD, we are primarily concerned with the respiratory, cardiovascular, nervous, and integumentary systems. These systems contribute to the physiologic measurements we collect during PDD exams. A basic understanding of the physiologic properties underlying the measurements is essential for a sound foundational knowledge base.

a. Respiratory system- (air movement through the nasal cavity, pharynx, larynx, trachea, bronchus, lung). This system removes carbon dioxide and continually supplies blood with oxygen.

b. Cardiovascular system- (heart, blood vessels). The heart pumps our blood and our blood vessels transport it throughout the body to all cells. Blood carries oxygen, carbon dioxide, nutrients, waste and more throughout the body.

c. Nervous system- (brain, spinal cord, nerves). This is the control system of the body. It responds to internal and external changes, and activates muscles and glands.

d. Integumentary system- (skin, hair, nails). This system forms the external body covering and protects deeper tissues from injury. It houses cutaneous receptors, sweat glands, oil glands, and synthesizes (makes) vitamin D.

D. ORGANISM

1. *Organism*- The living organism (animal or plant) that represents the sum total of all organ systems working together.

E. HOMEOSTASIS & ALLOSTASIS

1. *Homeostasis*- Homeostasis is a term used within the scientific community to describe

the maintenance of the internal viability of organisms. The word homeostasis is derived from the Greek homeo, which means “same,” while stasis means “stable;” thus, “remaining stable by staying the same.” American physiologist Walter Cannon coined the term “homeostasis” to refer to the processes by which constancy of the fluid matrix is maintained. It is used to describe the maintenance of internal parameters within a relatively narrow window. Homeostasis is maintained through the "integrated" actions of numerous body systems. For example, sufficient nutrients must be present in the blood and the cardiovascular system must be functioning properly to provide those nutrients to all of the cells in the body. Waste products, like CO_2, must not be allowed to accumulate in the cells and must be continuously removed. The core temperature of a healthy person is maintained within a relatively narrow band in spite of the changing climates.

2. *Homeostatic mechanism of actions*- Homeostatic reflexes adjust to maintain a constant set point or level, much like a thermostat in a home. Homeostasis involves a *negative feedback loop* because it waits for something to happen before acting. A feedback loop involves a central control module which receives input regarding a condition, processes it, and then sends an output signal to maintain a set point. The central control center in a negative feedback system sends a correction to reverse the change from a set point to maintain a constant or fixed state. Positive control feedback systems enhance a stimulus that is already present. The classic feedback control model of homeostasis in psychophysiology describes compensatory responses to restore detected imbalances rather than enhancing what is already there and thus is considered negative. Homeostasis describes the regulation of the body to a balance, by single point tuning such as blood pressure, blood oxygen level, blood glucose, or blood pH. Baroreceptor reflex in blood pressure is the classic, prototypic homeostatic system whose inputs, outputs, and controls are well characterized. But blood pressure set points can, and do, change depending on the circumstances. Additionally, blood pressure can be changed through a variety of ways, not necessarily through one simple negative feedback system.

3. *Allostasis*- Allostasis is the process of achieving stability, or homeostasis, through physiologic or behavioral change. This term is derived from the Greek: *allo* meaning change, and *stasis* meaning “stable”. That is, some changes are necessary to maintain stability or viability. These changes are presumed to be aimed at ensuring the overall viability of the organism. Allostasis encompasses both behavioral and physiologic processes directed towards maintaining adaptive states of the internal environment. One common example is the ever changing relative blood pressure in a person over the course of the day. Researchers have found mean arterial blood pressure will fluctuate to meet demands, or in an anticipation of a demand.

4. *Allostasis as a feed-forward regulatory process*- The allostatic model acknowledges the organism can use prior information to predict demand and adjust proactively before the demand is needed. Cannon recognized the body can respond in anticipation of a disturbance or agitation. For example, blood pressure typically rises slightly during the moments just before a person stands after having been sitting or relaxing. The anticipatory increase in blood pressure is adaptive, and serves to prevent lightheadedness by preventing the gravitational pull of blood to the feet by this positional change. The anticipatory increase in blood pressure is not in response to environmental or physiologic feedback, but can be thought of as a form of adaptive learning from past experiences with the action of standing. If a subject takes medication which blocks these blood pressure changes, the feed forward action can be blocked and the subject becomes dizzy.

F. ANATOMICAL NOMENCLATURE

1. The standard body position known as the *anatomical position*- A position in which the body is standing erect, feet slightly apart, palms facing forward with the thumbs pointing away from the body. The terms "right" and "left" are used with reference to the body being described and not the person observing that body.

2. *Sagittal plane*- A sagittal is a vertical plane that divides the body section being viewed into right and left. Mid-sagittal describes a sagittal

plane directly down the middle of the part viewed. Imagine splitting your body from the top of your head down through your crotch and then being able to look into either the left or right half of your body.

3. *Frontal* or *Coronal* plane- A frontal or coronal plane splits a body into anterior (front) and posterior (back) views. Imagine splitting your body from the top of your head through both shoulders, down to your feet and looking at the front half or back half of your body.

4. *Horizontal* or *Transverse* plane- A horizontal or transverse plane runs across and separates the body viewed into superior and inferior planes. These are sometimes referred to as cross-sectional planes. Imagine cutting straight across your stomach and being able to look at the upper or lower half of your body.

a. Superior (cranial)- A direction towards the head or upper end of the structure.

b. Inferior (caudal)- A direction away from the head end and towards the lower part of the structure.

c. Posterior (dorsal)- A direction towards the back or behind.

d. Anterior (ventral)- A direction towards the front or in front of something.

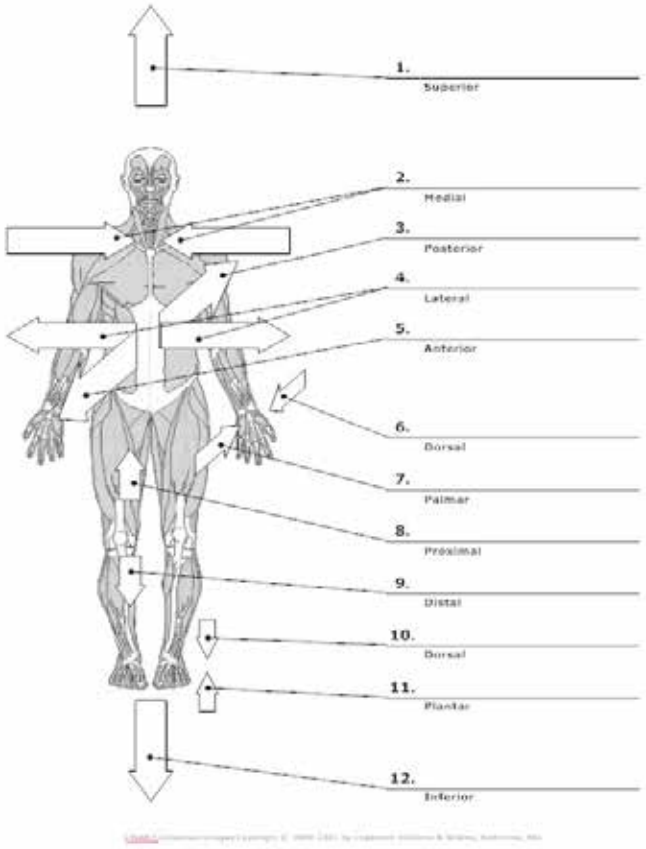
e. Medial- On the inner side or towards the center.

f. Lateral- On the outer side or away from the middle.

g. Proximal- Closer to the origin of the body part or the point of attachment.

h. Distal- Farther from the origin of the body part or point of attachment.

5. View orientation and anatomical planes below:



6. The *dorsal body cavity* and the two subdivisions- The dorsal body cavity encases the organs that comprise the central nervous system, the brain and the spinal cord.

7. The *ventral body cavity* and the two major subdivisions- The two major subdivisions of the ventral body cavity are the thoracic cavity and the abdominopelvic cavity.

8. The *thoracic cavity*- The thoracic cavity contains the pleural cavities which encase the lungs and the medial mediastinum. The mediastinum encloses the thoracic organs as well as the pericardial cavity, which surrounds the heart.

9. The *diaphragm*- The diaphragm is a dome shaped muscle that is extremely important for breathing. It separates the thoracic cavity from the inferior abdominopelvic cavity.

10. The *abdominopelvic cavity*- The abdominopelvic cavity contains two parts. The superior abdominal cavity contains the stomach, liver, spleen and intestines, as well as related organs.

11. The pelvic cavity lies inferior and contains some reproductive organs, the bladder, and the rectum.

IV. THE NERVOUS SYSTEM

A. The basic functions of the nervous system-

1. The nervous system monitors information about changes inside and outside of the body. It perceives or senses the information about change and forms decisions.

2. It causes muscles, glands, organs, and additional portions of the nervous system to respond (monitor, interpret and command). The nervous system is the master control/coordinator system in the body. Control/coordination is accomplished through:

   a. Monitoring changes inside and outside body sensory input

   b. Integrating sensory input and determining output

   c. Affecting responses (motor output)

3. The Nervous system partners with the endocrine system. Nervous system responses are quick and short lived, while endocrine responses are slower and longer lasting.

B. The structural and functional divisions of the nervous system-

1. The nervous system can be broadly separated into two primary divisions, the central nervous system (CNS) and the peripheral nervous system (PNS).

2. The CNS consists of the brain and spinal cord and can be considered the command center of the body. The CNS receives information, interprets the information, and then commands actions based on the interpretation. The PNS can be thought of as the system that carries messages to and from the CNS.

3. The *subdivisions of the PNS*-

   a. The PNS can be broken down into two subdivisions, one that carries information into the CNS (the sensory or afferent division) and one that carries the impulses away from the CNS (motor or efferent system).

      i. Sensory fibers from all over the body, such as the eyes, ears, nose, mouth, skin, joints, internal organs, and muscles send impulses to the CNS via the afferent or sensory division of the PNS.

   b. The motor or efferent division transmits commands from the CNS to all body parts, which are called effector organs, because nerve impulses affect them. Effector organs then respond to the commands of the CNS to perform functions the CNS has determined are necessary.

4. The *motor division of the PNS*-

a. The motor division can be thought of as having two major parts, the somatic nervous system and the autonomic nervous system (ANS).

b. The somatic nervous system is often called the voluntary nervous system because the nerve fibers control voluntary movement of skeletal muscles. For example, we use these nerves to command our fingers to type on a computer keyboard, or to pick up a book to study.

c. The ANS consists of nerves that regulate the activity of smooth muscles (like blood vessels, cardiac muscles, and glands). These activities are generally considered outside of our control and so this system is sometimes referred to as the involuntary nervous system. The ANS has two functional subdivisions, the sympathetic branch and the parasympathetic branch.

5. The historical view of the functional division of the ANS-

a. The purpose of *sympathetic* branch of the autonomic nervous system has been thought to be related to mobilizing the body systems for stressful or emergency situations; the fight or flight response. The *parasympathetic* branch has been proposed to support conservation of energy, nonemergency functions, "resting and digesting," etc.

i. These descriptions of function are often based on the seminal work of Walter Cannon in the first half of the 20th century. Cannon and others analyzed the function of the ANS in experimental animals and developed theories that drive our current conceptual approach to the ANS.

ii. Cannon coined the phrase "homeostasis," which he used to describe the coordinated physiological processes that maintain a steady state within the organism. Cannon believed the sympathetic nervous system was primarily responsible for maintaining homeostasis. Cannon also believed the sympathetic nervous system acted broadly (all at once and hence the name sympathetic) to restore imbalances in homeostasis. He believed there was a widespread and diffuse output aimed at returning the body's internal state to the narrow band needed to support life.

iii. In contrast, the parasympathetic branch functions were considered to be more discreet, having greater specificity. Cannon believed the effects of the sympathetic and parasympathetic nervous systems were generally opposite in the same organ and his ideas of an all or nothing sympathetic defense response and a specific restorative parasympathetic nervous system have influenced the conception of the functionality of the ANS.

6. A *current* view of the functional division of the ANS-

a. Wilfrid Janig, a modern physiologist, points to a number of inconsistencies in the historical functional separation of the divisions of the ANS. Janig makes a very convincing case for the idea that the separation between the sympathetic and parasympathetic branches of the ANS is anatomical as opposed to functional.

b. The parasympathetic outflows are cranial (from the head area) and sacral (from the lower spine area) while the sympathetic braches originate in the thoracolumbar (from the thoracic and lumbar parts of the spinal column).

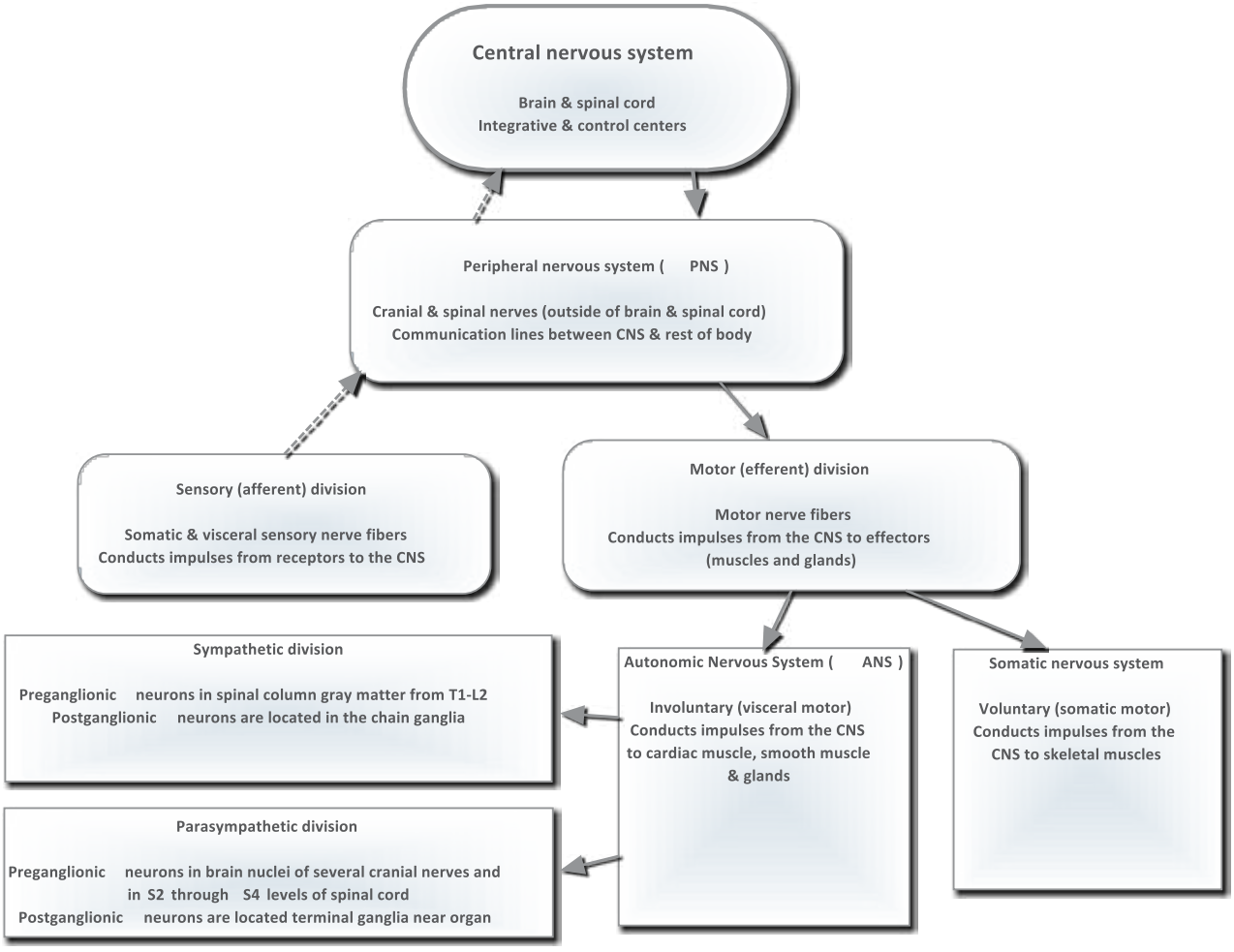
c. Some organs are "dually innervated" meaning they are innervated by both branches of the ANS and these innervation actions are antagonistic. The end result however is a coordinated, and conceivably larger or more "fine-tuned" response. Dual innervation allows the CNS to activate both the sympathetic and parasympathetic branches of the ANS, which can act synergistically to improve the response. Heart rate is an example. Parasympathetic activation may result in slowing the heart while sympathetic innervation will speed the heart. A coordinated (integrative) action comprised of a reduction of parasympathetic innervation and increase in sympathetic innervation can result in a potentially greater and faster response.

d. Janig points out that modern evidence more strongly supports a theory of integrative actions of the ANS, as opposed to a simple all or nothing action of one branch or the other.

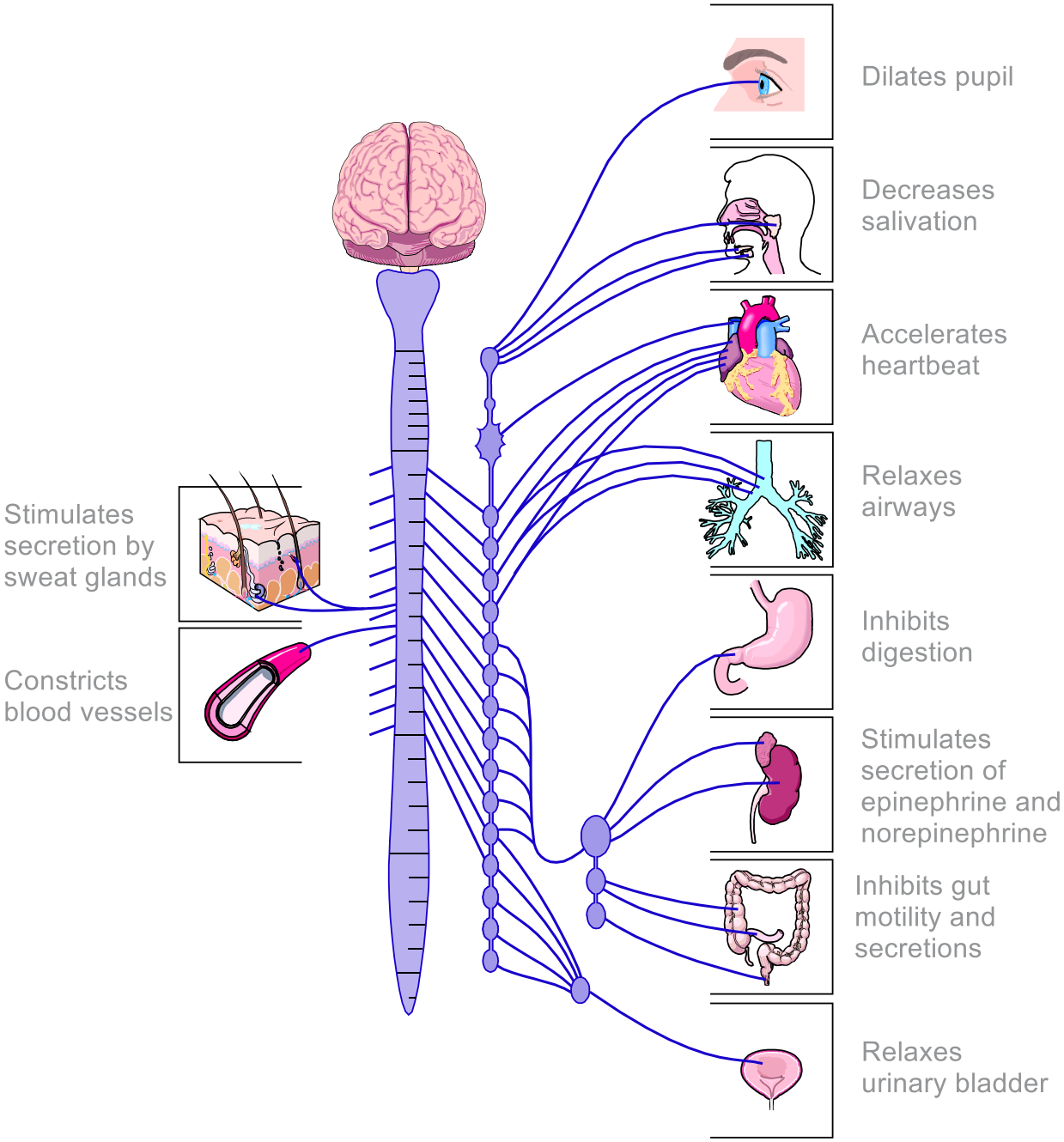
e. Berntson and Cacioppo have also questioned the historical doctrine of the two branches being functionally opposing systems. They point out that both branches can have similar effects on certain organs. They have shown that in some cases, one system activates at certain times, while the other system activates at other times. For example, at higher blood pressures, heart rate is controlled primarily by vagal (parasympathetic) activity, while at lower blood pressures, by sympathetic activity.

    i. Berntson and Cacioppo proposed a multidimensional model of autonomic regulation to account for conditions where the two systems are not reciprocal, but instead uncoupled (not acting at the same time) or coactive.

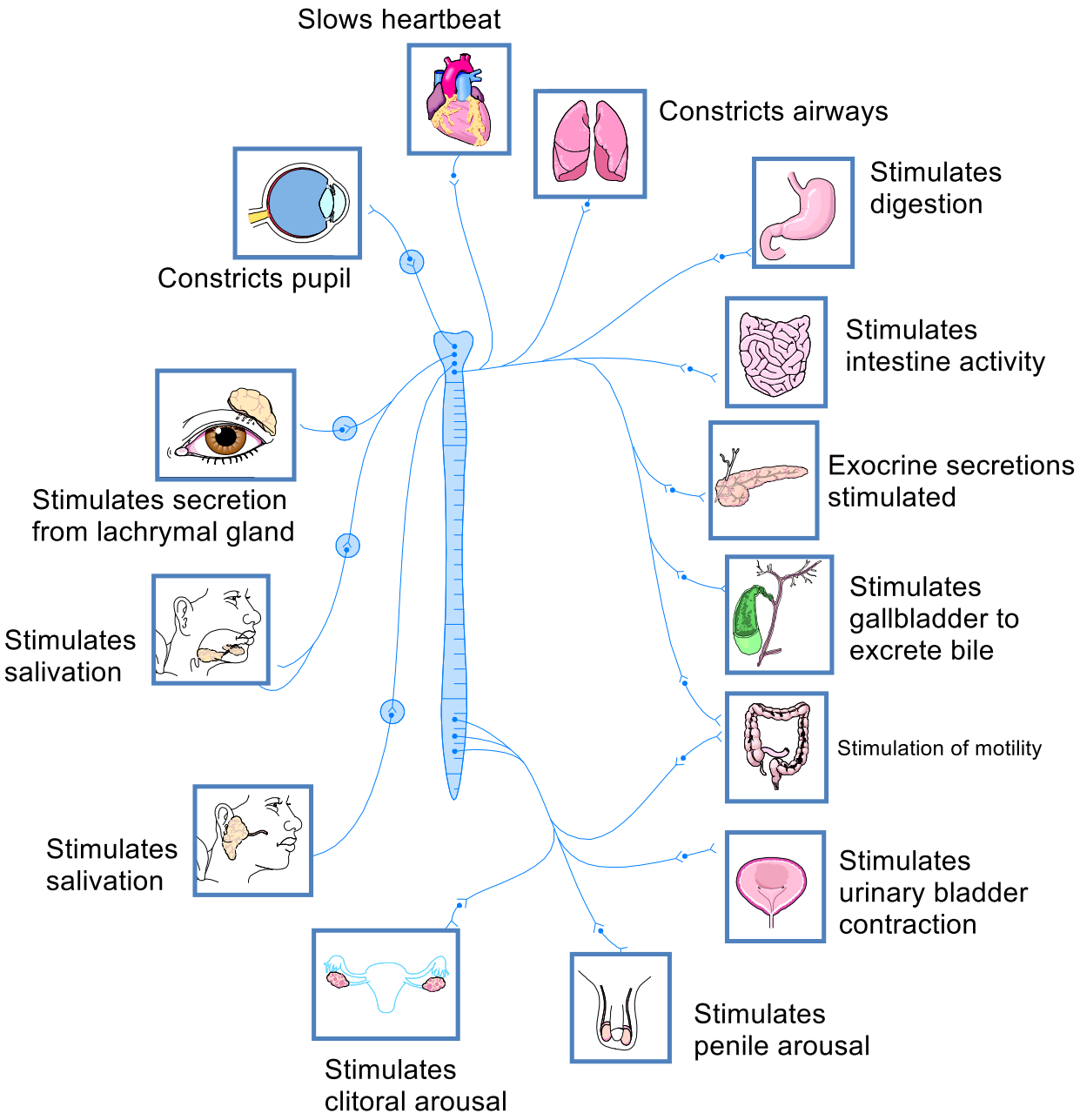
7. A general outline of the nervous system



8. Organs innervated by the parasympathetic nervous system.

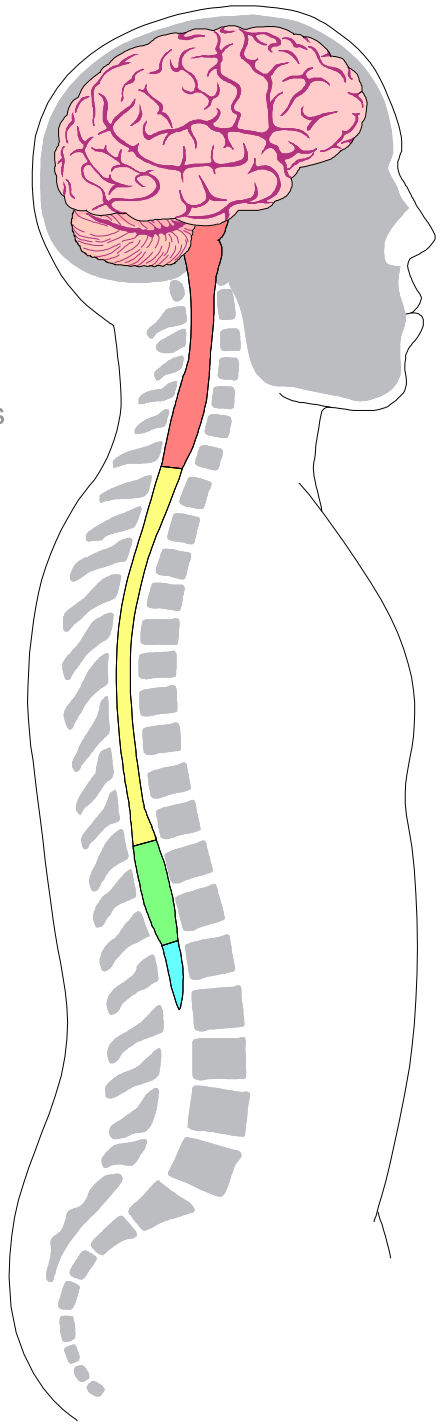


9. Organs innervated by the parasympathetic nervous system.



10. The location of the CNS-

Lateral view of figure showing central nervous system and its associated encasing skeletal structure.



11. The two principle types of nervous cells

    a. Nervous system tissue can be essentially divided into two main types of cells: neurons, the nerve cells that transmit signals, and neuroglia or supporting cells that surround, assist, and support the neurons.

    b. Some of the functions of neuroglia- Neuroglia or "glial" are support cells that make up about 85-90% of all brain cells. There are five main different types of neuroglia cells.

    c. In the CNS there are four different "glial" cells; astrocytes, microglia, ependymal, and oligodendrocytes.

    d. The glial cells of the PNS are Schwann cells. All glial have unique functions but one important purpose is to provide support for neurons by keeping them separate from one another. Also, some glial cells improve communication between cells by wrapping themselves around a portion of the neuron, thus insulating it. This results in faster conduction, much the same as wrapping a leaking garden hose with duct tape moves the water faster from one end of the hose to the other by reducing leakage.

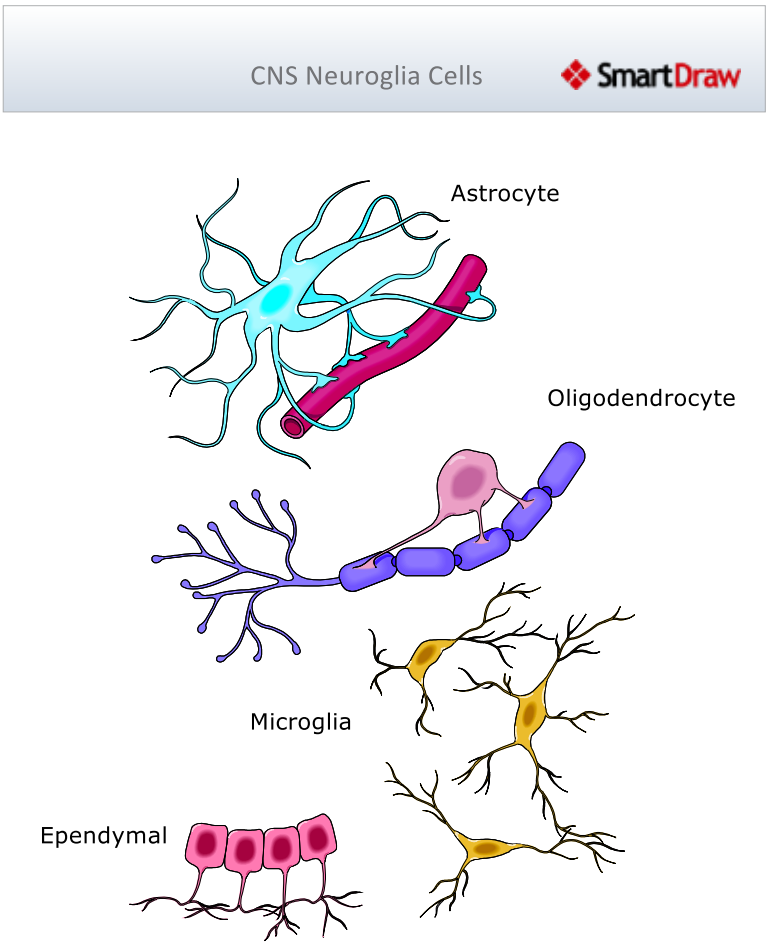


Image showing the four types of CNS neuroglia cells.

12. The basic parts of the neuron and a description of their purposes-

    a. Cell body- The cell body (or soma) contains the *nucleus* and other organelles involved in the biosynthetic activities to support cell life and function.

    b. Dendrites- The dendrites comprise the main input or receptive areas of the cell. They receive incoming information from numerous sources and convey this information on towards the cell body.

    c. Axons- Each neuron has a single axon that projects from a part of the neuron called the axon hillock. Once the axon leaves the axon hillock, it narrows to a relatively uniform diameter for the remainder of its length. Axons can range in length from non-existent to several feet. Axons are usually a single process for most of their length, though they can have branches or collaterals. At the end of axons, there are numerous (thousands) of terminal branches called axon terminals. Axons are the conducting component of the neuron during its communication with other neurons. Axons transmit nerve impulses away from the cell body to the axon terminals.

    d. Axon Terminals- Axon terminals are the knob-line bulbs at the terminal end of the axon. They contain the secretory component of the neuron. Upon reaching the terminals, an impulse causes chemicals (neurotransmitter) stored there to be released from the axon terminals. These neurotransmitters interact with adjacent cells and can cause those cells to become excited or inhibited.

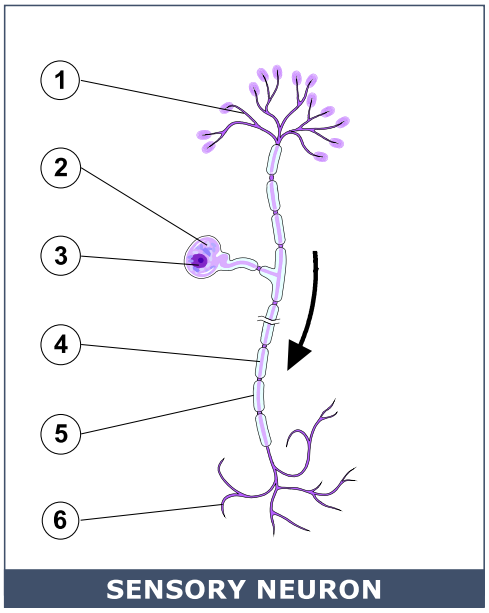
    e. Myelin- Myelin is a white colored, fatty tissue that covers some axons. Myelin protects the axon and insulates the axon from others. Myelinated fibers are able to conduct nerve impulses faster than those that are unmyelinated.

        i. Myelin in the PNS is composed of Schwann cells and myelin in the CNS is composed of oligodendrocytes. In the PNS, Schwann cells wrap around the axon but leave small gaps called Nodes of Ranvier. These gaps occur at regular intervals along the axon because of the size of the Schwann cell providing the myelination. The gaps contribute to the increased speed of conduction.

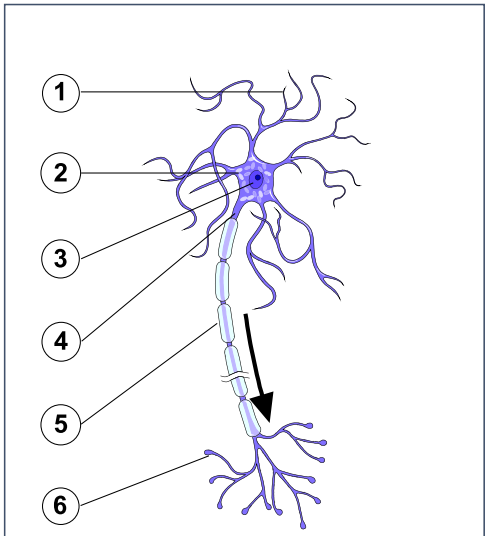
13. Major parts of the sensory or motor “model neuron”

NERVOUS SYSTEM

Types of Neurons



SENSORY NEURON



MOTOR NEURON

1. DENDRITE/RECEPTOR...
a slender, branched projection of a neuron, which conducts the electrical stimulation received from other cells to and from the cell body, or soma, of the neuron from which it projects.

2. CELL BODY (SOMA)...
the bulbous end of a neuron, containing the nucleus and is where most protein synthesis occurs.

3. NUCLEUS...
controls chemical reactions within the cytoplasm and stores information needed for cellular division.

4. AXON...
a long slender projection of a neuron which conducts electrical impulses away from the neuron's cell body.

5. MYELIN SHEATH...
an electrically insulating phospholipid layer that surrounds the axons of many neurons, composed of about 80% lipid fat and about 20% protein. It helps prevent the electrical current from leaving the axon and causing a short circuit in the brain.

6. AXON TERMINAL...
a specialized structure at the end of the axon that is used to release neurotransmitter and communicate with target neurons.

KMG Kurtsdale Medical Group

14. *Action potentials*- An action potential is the conductance of an electrical impulse along the length of an axon. The way most excitable neurons communicate is through action potentials.

    a. Recall our discussion about cells. The cell membrane has a potential (voltage difference) across it like a battery. This negative membrane potential (more negative inside the cell membrane compared to the outside of the cell membrane) results from the ion concentration. An action potential results in a brief (a couple of milliseconds or thousandths of a second) depolarization of the membrane and this continues along the axon until it reaches the terminals where the neurotransmitters are released.

    b. Action potentials are not graded; they keep the same strength from start to finish. If a neuron is sufficiently stimulated, it can transmit an action potential or nerve impulse. The propagation of the action potential comes from opening gates on the axon that are sensitive to voltage changes and that allow certain ions to pass through because of the decrease in voltage.

    c. Remember when we discussed sodium and potassium earlier and mentioned they were ions involved in neuronal communication. Changes in voltage open and close gates along the axon that allows ions to enter or leave. This lowers the voltage of the adjacent section of the axon and gates open and close there allowing more ion movement and this decreases the voltage of the next adjacent part of the axon. This "chain reaction" of depolarization and opening of gates allows a current to move down the axon to the axon terminals where it ultimately results in the release of the neurotransmitter from the terminal bulbs.

15. The two types of *gated membrane ion channels*- Plasma or cell membranes contain two basic types of gated ion channels: *chemically gated* and *voltage gated*. The term gated is used to describe the idea that there is a gate in the membrane that is open or closed.

    a. Chemically gated or neurotransmitter gated channels open or close when the appropriate neurotransmitter binds there. It can be visualized as a locked open or closed gate and only when the correct key (neurotransmitter) is used can the gate become unlocked and then change from opened to closed or visa-versa.

    b. Likewise, voltage gated ion channels open or close based on membrane potential.

        i. Each ion channel is generally selective for just which ion or ions it will allow to pass when open. Once opened, ions pass very quickly through the gate based on the electrical charge and chemical or concentration gradient. Ions will move away from an area of similar charge towards an area of opposite charge which is along their electrical potential. Ions will flow from areas of higher to lower concentration, which is called the concentration gradient. Together the electrical and concentration gradients are referred to electrochemical gradients and they are what effect ion movement across open

ion channels. Ions will tend to balance out based on the electrochemical gradients.

16. The action of neurotransmitters- Neurotransmitters are chemicals that neurons release that stimulate or inhibit other neurons or effector cells.

    a. Neurons use neurotransmitters and their electrical signals to communicate with other cells (neurons, glands, and muscle). The cell releasing the neurotransmitter is called the presynaptic cell and the cell upon which it acts is called the postsynaptic neuron.

    b. The neurotransmitter is released into a small fluid filled gap between the neuron and the effector cell which is called the synaptic cleft. This functional space or point of close contact between two neurons or between a neuron and an effector cell is called the synapse. Some neurons release only one neurotransmitter at a synapse but most make and/or release more than one neurotransmitter. Some of the neurotransmitters we will discuss are;

        i. Acetylcholine (ACh)- This was the first neurotransmitter to be identified and probably the most studied. ACh is released at neuromuscular junctions, which are where neurons synapse with muscle cells for movement. In the ANS, ACh is the presynaptic neurotransmitter for all preganglionic neurons both sympathetic and parasympathetic. ACh is the postsynaptic neurotransmitter for all parasympathetic postganglionic fibers. It is also the neurotransmitter for postganglionic fibers for the eccrine sweat glands which are a member of the sympathetic nervous system and are responsible for the electrodermal activity measured in polygraph.

        ii. Norepinephrine (NE) - An excitatory or inhibitory neurotransmitter, depending on the receptor. NE is found in the CNS and the PNS. In the PNS, NE is the main postganglionic cells of the sympathetic nervous system.

        iii. GABA- This is the principle CNS inhibitory neurotransmitter in the brain. Alcohol and antianxiety drugs of the benzodiazepam class enhance GABAs effect. GABA manifests its inhibitory effect on cells by opening chloride channels and allowing extra negatively charged chloride to enter the cell. This extra negative charge hyperpolarizes the cell, bringing it further away from threshold and making it harder for the cell to fire and initiate an action potential. It tends to make the cells less active.

        iv. Glutamate- This is a principle excitatory CNS neurotransmitter in the brain. Glutamate is very important for learning and memory because of its action in the medial tempo-

ral lobe of the brain. A little goes a long way, however, as excess glutamate leads to excitotoxicity. This occurs when neurons literally excite themselves to death, and is common during strokes. Some medical treatments for stroke now include drugs to combat the excessive glutamate released during strokes to prevent cell death in the brain.

17. The *spinal cord*- This bundle of nervous tissue runs from the base of the brain stem to somewhere between the first to the third lumbar region and it provides the afferent (to the brain) and efferent (away from the brain) conductance pathways.

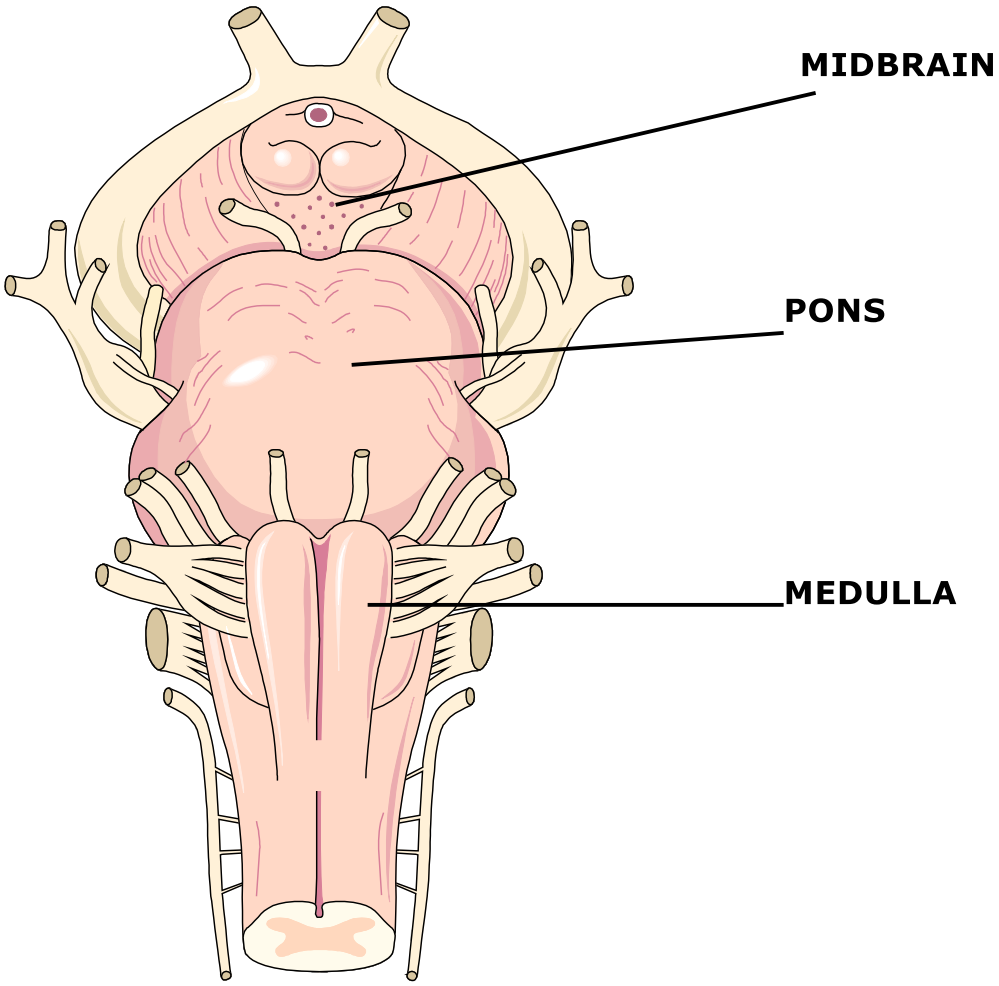
    a. The spinal cord is composed of *"white matter" and "gray matter."* The *gray matter* consists mostly of neuron cell bodies and neuroglia, and is shaped like a butterfly or the letter H. The gray matter can be divided into a dorsal half (in the back) which is generally the sensory input and a ventral half (in the front), which is generally the motor output.

    b. The sensory afferent fibers enter through the dorsal half where they connect to the sensory cell bodies in an area known as the dorsal root ganglion. The cell bodies for the motor output mostly lie in an area called the ventral horn, sending their fibers out through the ventral roots.

    c. White matter in the spinal cord is composed of nerve fibers, both myelinated and unmyelinated. There are fibers that ascend to the brain, carrying sensory input, and fibers that descend for motor output. Additionally, there are fibers that cross from one side of the spinal cord to the other called transverse or commissural fibers. The white matter is the communication transport section of the spinal cord, much like phone lines for telecommunication.

18. The *brain stem*- Working from an inferior to superior direction, the brain stem is comprised of the medulla oblongata, pons, and midbrain.

    a. The brain stem contains many important nuclear groups that result in the automatic behavior programs necessary for survival. The brainstem provides a pathway for fiber tracts running between the higher and lower brain center.



Anterior view of the brainstem. Midbrain (mesencephalon), pons, medulla oblongata and spinal cord are visible.

19. The functions provided by the *cerebellum*- The cerebellum is a large structure located dorsal to the pons and medulla. It processes inputs from the cortical areas responsible for motor actions, sensory receptors, and brain stem inputs. The cerebellum is concerned with coordination of movements.

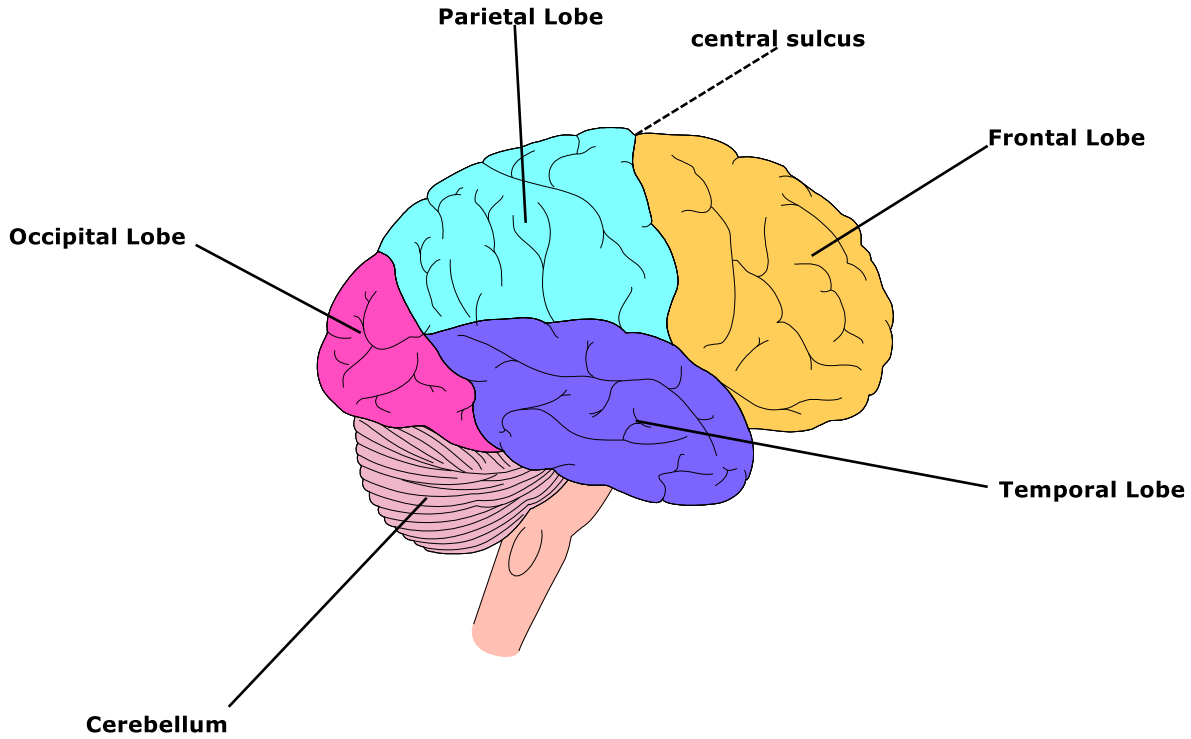
20. The *lobes* of the human brain- The hemispheres of the brain are subdivided into five major lobes on the basis of some of the major grooves.

    a. The *frontal lobe* consists of the area in front of what is known as the central sulcus and is the largest of all lobes. It contains important motor and language related areas in posterior part and many functions related to social behavior and higher mental activities towards the frontal part.

    b. The *parietal lobe* is located parallel to the central sulcus and contains much of the somatosensory related cortex.

    c. The *occipital lobe* is primarily related to visual functions and is located at the back of the brain.

    d. The *temporal lobe* contains many different regions including sensory areas for auditory and olfactory functions. This lobe contains two very important structures related to memory and emotion called the amygdala and the hippocampus.



Lateral view of the brain with the different lobes depicted with color.

21. The *diencephalon* and some functions - The diencephalon forms the central portion of the forebrain and consist of the thalamus, the hypothalamus, and the epithalamus.

    a. The thalamus is the largest part of the diencephalon and contains about fifty smaller nuclei which each have their own functional specialty. Thalamus is a Greek word meaning "inner room." It receives virtually all inputs to the brain including sensory, emotional, and motor related input. The only sensory input that bypasses the thalamus is the olfactory system. The *Thalamus* plays a key role in integrating and mediating motor activity, sensation, cortical arousal, learning, and memory. The thalamus is the means by which almost all information gets to the cortex to be processed.

    b. The hypothalamus is named for its position directly below the thalamus (hypo means lower). In spite of its small size, the *hypothalamus* is the grand conductor of homeostatic control of the body. Hypothalamus is part of the autonomic control center, the emotional response control center, and directs life supporting behaviors such as food and water intake and sleep. The hypothalamus controls the release of hormones from the endocrine system which also helps maintain homeostatic balance of the body.

    c. The *epithalamus* consists of the pineal gland, which helps regulate sleep, and the choroid plexus, which manufactures cerebrospinal fluid.

22. Psychophysiology concepts relating to the CNS. The concept of the *"limbic system"* from a historical, anatomical, and present day perspective-

    a. Around 1939, an American anatomist named James Papez proposed that the central parts of the brain including the hypothalamus, parts of thalamus, the cingulate gyrus, the hippocampus, and their interconnections, form a "harmonious mechanism" by which all emotion is generated, and from which emotional expressions result. Following Papez' proposal, the size and structures attributed to this "limbic system" have expanded to include a substantial portion of the brain. Modern neuroscientists seem to agree there is no scientific justification for a "limbic system." Many of the so-called limbic structures have multiple purposes that go beyond emotion. Indeed, some do contribute to generation and expression of emotion, but this poorly reasoned association does not justify a specific "system" of the brain dedicated solely to emotion.

V. EDA AND THE INTEGUMENTARY SYSTEM-

A. The Integumentary System

1. The skin consists of a complex set of organs called the integumentary system, which serves a protective function. We will limit our discussion of skin to predominately those aspects related to understanding the mechanisms of electrodermal activity (EDA).

    a. Skin protects the body from environmental threats such as temperature, chemical, mechanical, and infectious microorganisms.

    b. From a sensory standpoint, skin houses various receptors to provide afferent information related to touch, pain, and temperature.

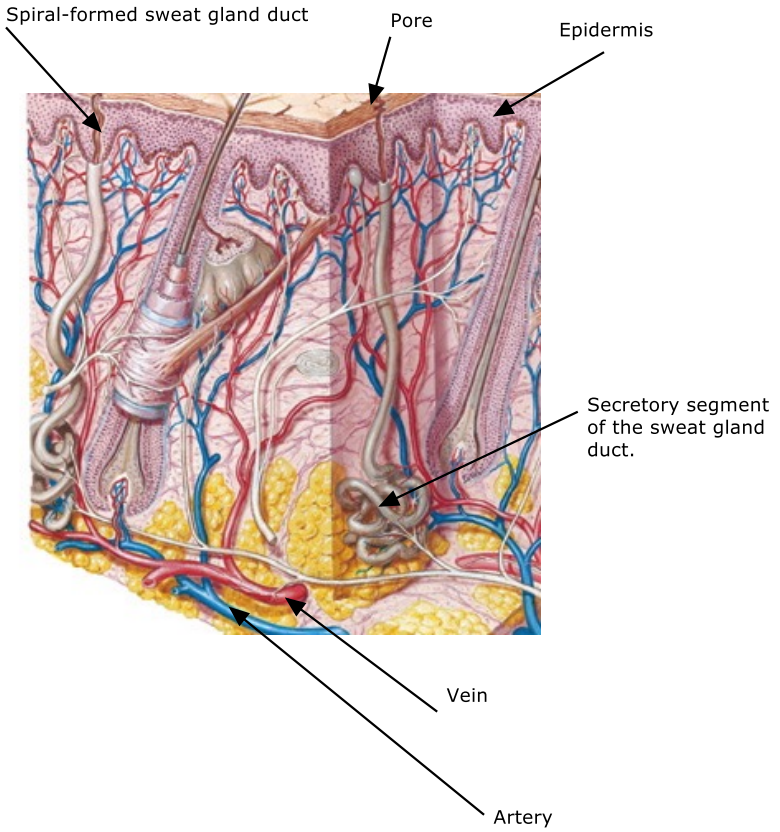
    c. Skin participates in

perspiration, which keeps the skin moist and allows the body to excrete fluids. Skin can be hairy or glabrous (hairless).

2. A typical cross section of the skin and some of the important features-

    a. Skin is composed of various characteristic layers, though all layers are not uniformly found in all skin. Skin essentially consists of two main layers; an outer layer called the epidermis, and a thicker lower layer, the dermis.

    b. The epidermis is composed of five layers with each layer becoming progressively hornier (tough and calloused). The outer layer of the epidermis is the stratum corneum. The epidermis, the layering most important to EDA, consists of regularly arranged cells that become drier as they move towards the stratum corneum. The glabrous skin found on the palms (palmer) and soles of the feet (plantar) has a thick epidermis and also a relatively thick stratum corneum. The stratum corneum has a very important role in producing the EDA we measure in polygraph.



3. The action of sweating of the *eccrine* sweat glands-

    a. Sweat glands secrete directly onto the skin surface. The greatest density of sweat glands is found on the forehead, the palms, and the soles.

    b. The sweat glands of the palm are considered eccrine sweat glands, which means the secretions do not contain something called cytoplasm.

    c. The sweat glands can be subdivided into the secretory portion and the duct. The secretory section is located deep within the skin and is comprised of an irregularly coiled duct. The duct extends from the secretory section to the sweat gland pore opening on the surface of the skin.

    d. Efferent fibers from the sympathetic nervous system innervate the eccrine sweat glands. These are referred to as sudorisecretory fibers. The sudorisecretory fibers use acetylcholine to innervate the secretory part of the sweat gland.

    e. The hypothalamus is generally regarded as the controlling center for all ANS function including sweat gland innervation. Hypothalamic sympathetic activity can be elicited by a number of brain structures, not the least of which includes the cerebral cortex. A variety of mental functions have been found to demonstrate the ability to activate the eccrine sweat glands and cause an EDA reaction.

4. A mechanism of sweating and how that contributes to EDA-

    a. Human sweat contains a certain amount of sodium and chloride ions. The precursor of sweat in humans has a considerably higher concentration of both. As sweat makes its way up through the duct, it loses some of the sodium and chloride ions. This is the theory behind NaCl reabsorption, that reabsorption may prevent excessive loss of NaCl. Sweat does not continuously flow out of the sweat duct but rather is ejected in pulses. Rhythmic contractions of the secretory and sweat duct portions are thought to be the source of pulses that are suspected of being the force that drives sweat up and out of the ducts.

5. *"Emotional sweating"*- Increased sweating as a result of mental activity, especially during emotional arousal, is referred to as "emotional sweating." Emotional sweating occurs primarily on the glabrous skin on the palmer and plantar surfaces of the body and is likely activated via the hypothalamus. EDA reactions during polygraph testing can be a result of emotional sweating.

6. Some of the putative CNS origins of EDA-

    a. EDA can be elicited by higher level CNS processes (cortical) but can also come from structures considered to be subcortical. The hypothalamus seems to be one of the primary initiators of EDA reactions from an emotional standpoint. A part of the brain called the basil ganglia may contribute to EDA responses in preparation for motor actions.

7. Some of the suggested biological roles of EDA-

    a. Sweating may be a biologically adaptive function that serves a number of purposes. Hydration provides optimal friction and tactile sensitivity. One is

able to feel and grip better when their hands are slightly moist. Footing is arguably better when the feet are slightly moist or tacky. Skin is also less likely to sustain injury when slightly moist.

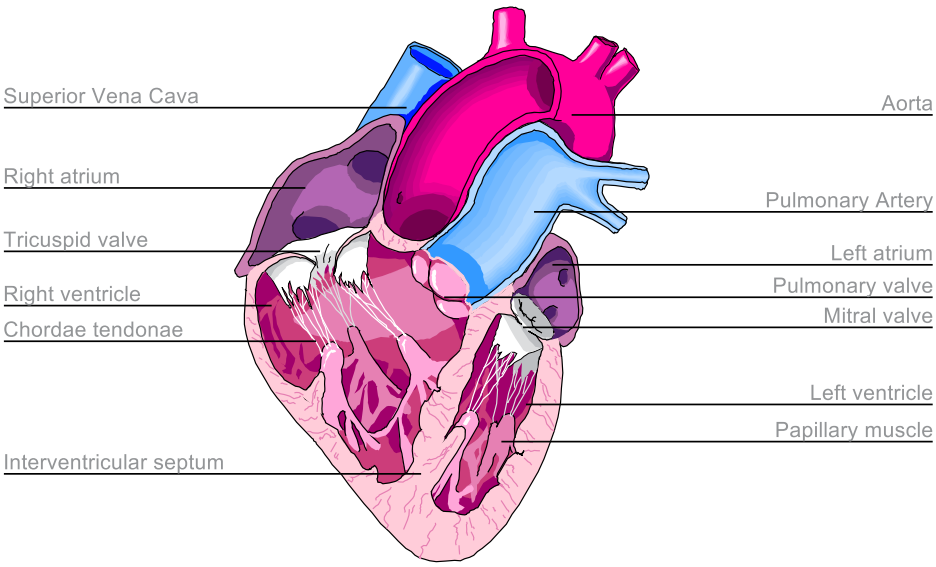
b. Skin is more resistant to abrasion and cutting when moist then when dry.

VI. THE CARDIOVASCULAR SYSTEM

A. The chambers of the heart-

1. The heart has four chambers, two ventricles and two atria. The ventricles are the discharge chambers and discharge blood to the body (left ventricle) or to the lungs (right ventricle). The atria are the receiving chambers for blood returning from the body (right atria) or the lungs (left atria).

Parts of the Internal Heart



B. The major heart valves-

1. There are two atrioventricular (AV) valves, one on each side of the heart, which separate the atria from the ventricle, preventing back flow.

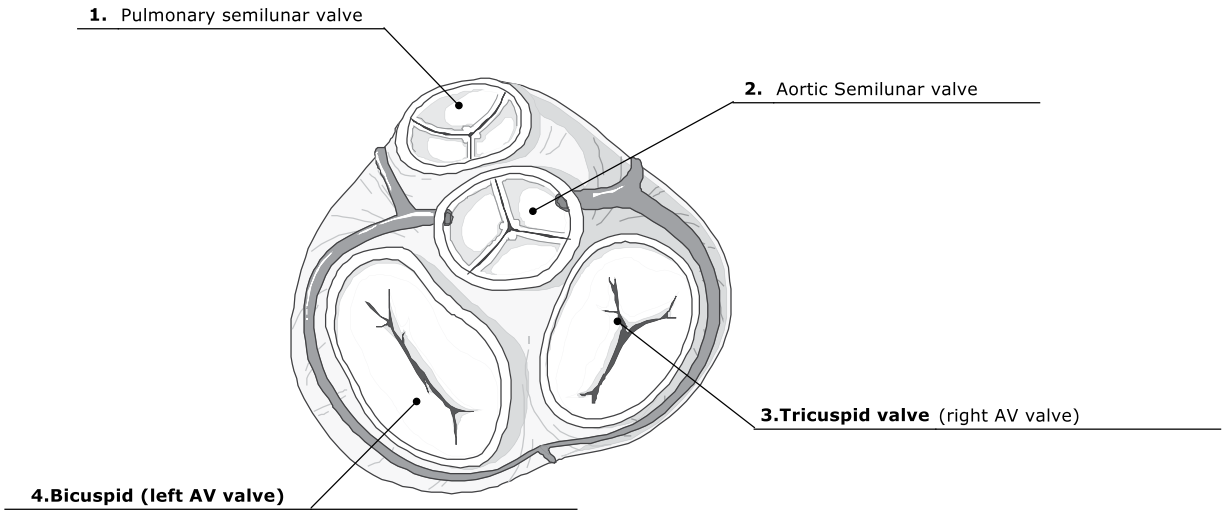
2. The right AV valve is called the tricuspid valve because it has three flexible cusps or flaps. The left AV valve is called the bicuspid valve because it has only two cusps or flaps.

a) The bicuspid valve is sometimes referred to as the mitral valve as it is said to resemble a miter, the hat worn by a bishop.

3. There are two semilunar valves (SL), one at the discharge site of each ventricle. The SL valves guard against backflow by flattening out and slamming shut when pressure is higher on the discharge side.

a) SL valves are so named because of their three crescent moon shaped cusps.

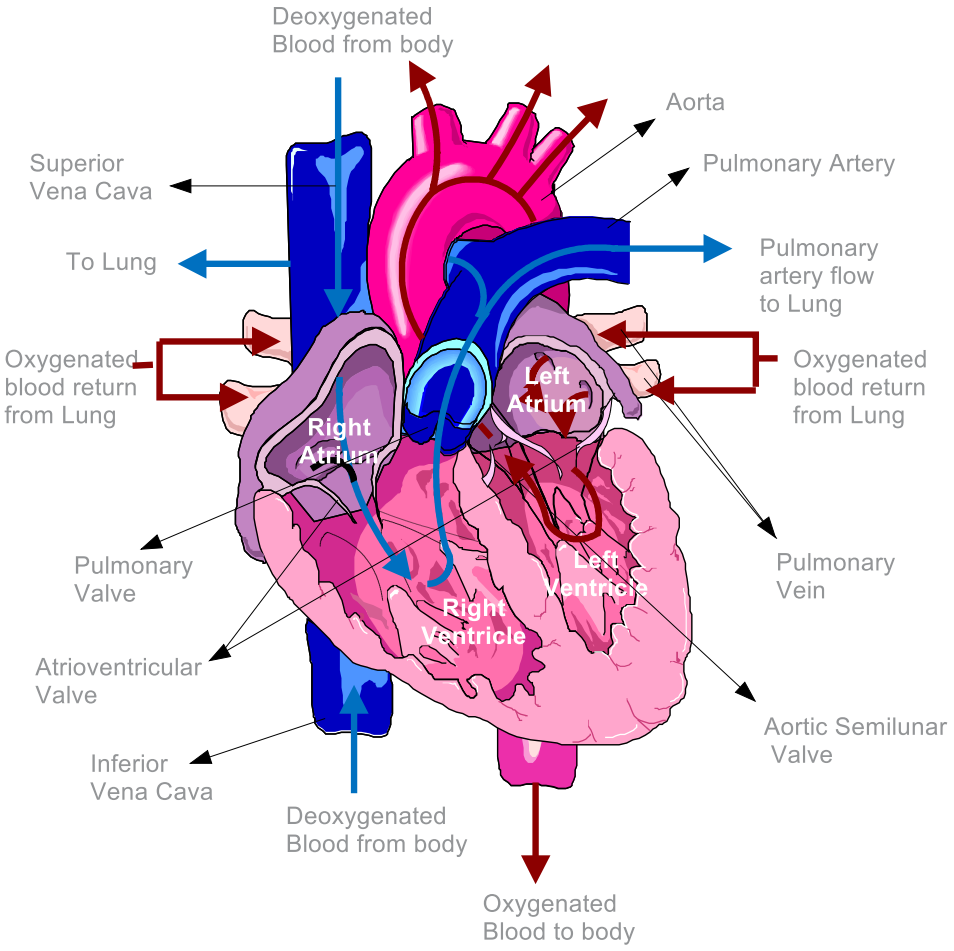
Heart Valves



C. The pathway of blood flow through the heart-

1. The right side of the heart is the *pulmonary circuit* which directs carbon dioxide rich blood to the lungs. Returning blood enters and fills the right atria. The right atria contracts, forcing blood through the tricuspid valve and into the right ventricle. The right ventricle compresses, sending blood out the pulmonary semilunar valve to the lungs via the pulmonary arteries. It is here that carbon dioxide is exchanged for oxygen.

2. The left side of the heart is the *systemic circuit* pump. It is responsible for transportation of blood through the cardiovascular system. The freshly oxygenated blood is returned to the left atria of the heart via the pulmonary veins. The left atria contracts and directs blood through the bicuspid or mitral valve to the left ventricle, which pumps blood out of the aortic semilunar valve into the aorta.



D. The purpose of the *cardiovascular system-*

1. The cardiovascular system is a completely closed structure consisting of the heart muscle, arteries, capillaries, and veins. A primary purpose of the cardiovascular system is to transport nutrients and oxygen to body tissues and remove metabolic wastes and carbon dioxide from the body tissues.

E. Blood pressure and how is it measured-

1. Blood pressure is a measurement of force per unit of area exerted on a blood vessel wall. It is typically expressed in units of millimeters of mercury, written "mmHg." Blood pressure is usually expressed medically in terms of systolic pressure over diastolic pressure.

2. In polygraph testing, the cardiograph waveform depicts changes in relative blood pressure throughout the examination. For the sake of our paper, when we discuss blood pressure, we refer to systemic blood pressure as measured at the monitoring site, unless otherwise stated.

F. Peripheral resistance-

1. Blood flow occurs within the body's closed circulatory system and is normally expressed in milliliters per minute, written as "ml/min." Peripheral resistance is a term used to describe the overall restriction to blood flow within the blood vessels and it is a function of blood viscosity, vessel length, and vessel diameter. Thicker blood, longer vessels, or smaller diameter vessels each increase resistance to flow.

G. How cardiac output and peripheral resistance effect blood pressure-

1. Blood pressure is determined by cardiac output and peripheral resistance. Cardiac output is the amount of blood the heart is pumping for a given time period. Cardiac output is a function of stroke volume times the number of beats per minute.

2. Stroke volume is how much the heart pumps (ml/beat) and is a function of how hard the heart beats (contractile force) and how much blood is available to pump (end diastolic volume, or EDV**).**

3. EDV is the volume of blood in a ventricle at the end of filling. The greater the EDV, the greater the distention (stretching) of the ventricle. An increase in EDV increases the preload on the heart. It increases the amount of blood ejected from the ventricle, during systole, through the Frank-Starling mechanism. EDV is generally controlled by venous return or the blood returned to the venae cavae prior to being delivered to the right atrium.

4. Additionally, a physiologist named Bainbridge observed that right atrial distention produced an increase in heart rate. Bainbridge found the reflex arc responsible for this tachycardia was mediated through an increase in sympathetic effect and a decrease in parasympathetic effect.

5. There are two primary factors that increase venous return: the respiratory pump and the muscular pump. The respiratory pump describes pressure changes in the venae cavae that result from breathing. As we inhale, chest pressure decreases, negative pressure is generated, and blood is "sucked" back towards the heart. The greater the depth or length of inhalation, the

greater the amount of negative pressure influence created for venous return. The muscular pump describes the manner in which the skeletal muscle contraction presses against veins to force blood back towards the heart.

6. Peripheral resistance affects blood pressure by increasing or decreasing the pressure against which the heart pumps. The greater the overall vasoconstriction, the greater the pressure. As vasodilation occurs, blood pressure decreases.

7. In summary, there are several factors affecting blood pressure. Cardiac output increases by accelerating the heart rate, contractile force, or end diastolic volume. Altering the diameter of the blood vessel increases or decreases peripheral resistance to flow. Any combination of these factors can result in a rise in blood pressure.

H. The *electrical conduction system* through the heart-

1. The heart is able to contract (beat) without influence from outside nervous systems. There is, however, a great deal of neural input to the heart, which coordinates the heart's activities with that of other systems that support life.

2. Electrical conduction begins at the sinoatrial (SA) node in the right atria, which intrinsically generates impulses at the rate of about 75 times per minute. This small mass is known as the "pacemaker," as it sets the cadence that is known as sinus rhythm.

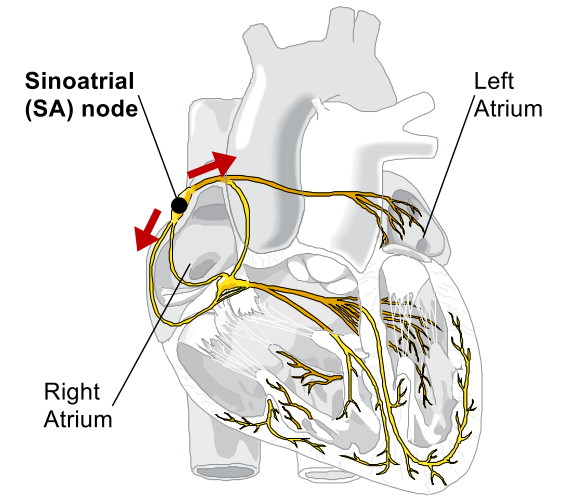
3. From the SA node, the signal is sent through intermodal fibers into both atrial muscle walls, and then into the atrioventricular node located near the tricuspid valve. This node holds the signal for a moment, allowing the atria to fully contract before it passes the signal on.

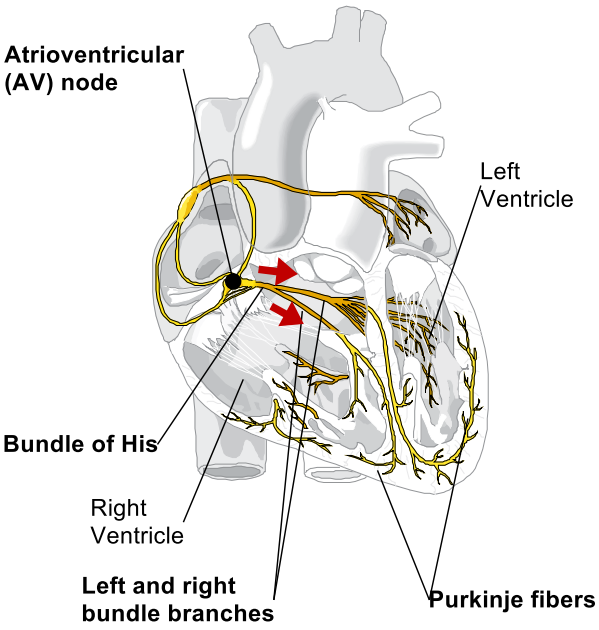
4. From the AV node, the signal progresses to the atrioventricular (AV) bundle, which is located in the upper portion of the septum that separates the ventricles. This is sometimes called the bundle of HIS, named after its discoverer.

5. From the bundle of HIS, the signal splits into the right and left bundle branches as they progress down the septum. The right and left bundle branches send the impulses to the Purkinje fibers that are located in the ventricles. The left ventricle has a thicker muscular wall due to greater pressure requirements needed to pump blood through the increased resistance of the entire body than the right ventricle has pumping just to the lungs.

Electrical Conduction System of the Heart

(cardiac conduction system)





The heart's electrical system controls all the events that occur when your heart pumps blood.
Each beat of your heart begins with an electrical signal from the sinoatrial node, called SA node.

The signal is generated as the two vena cavae fill your heart's right atrium with blood from other parts of your body. The signal spreads across the cells of your heart's right and left atria. This signal causes the atria to contract. This action pushes blood through the open valves from the atria into both ventricles.

The signal arrives at the AV node near the ventricles, where it slows for an instant to allow your heart's right and left ventricles to fill with blood. The signal is released and moves to the His bundle located in the walls of your heart's ventricles.

The signal is released and moves next to the bundle of His located in your heart's ventricles. From the bundle of His, the signal fibers divide into left and right bundle branches which run through your heart's septum.

The signal leaves the left and right bundle branches through the Purkinje fibers that connect directly to the cells in the walls of your heart's left and right ventricles.
As the signal spreads across the cells of your heart's ventricle walls, both ventricles contract, but not at exactly the same moment. The left ventricle contracts an instant before the right ventricle. This pushes blood through the pulmonary valve (for the right ventricle) to your lungs, and through the aortic valve (for the left ventricle) to the rest of your body.

As the signal passes, the walls of the ventricles relax and await the next signal.

Source: National Heart Lung and Blood Institute, National Institutes of Health. nhlbi.nih.gov

VII. THE RESPIRATORY SYSTEM

A. The function of *respiration*-

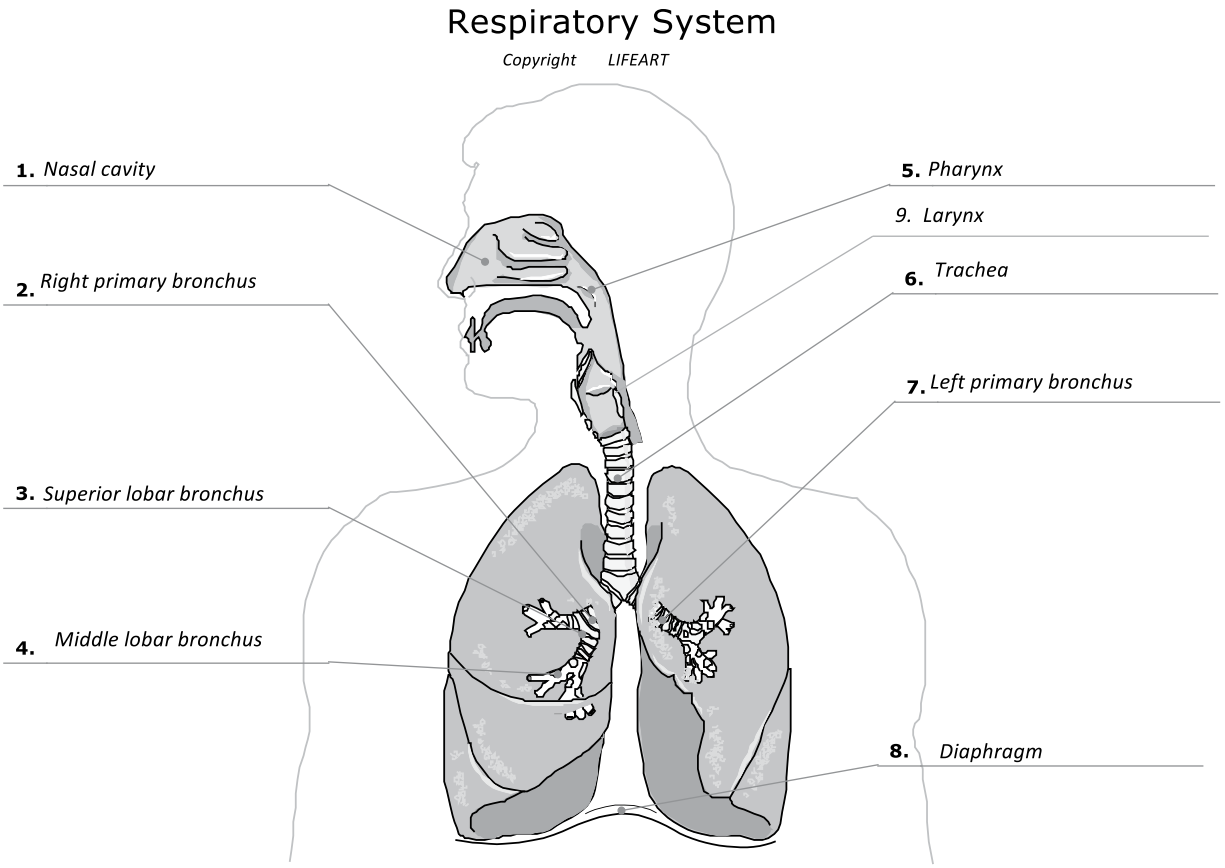
1. The primary function of the respiratory system is to supply the cells of the body with oxygen, and to vacate the body of carbon dioxide.

2. Pulmonary ventilation (breathing) describes the collective actions that move air into and out of the lungs.

3. External respiration describes the exchange of oxygen for carbon dioxide in the alveoli, the microscopic air sacs in the lungs.

4. Internal respiration describes the exchange of oxygen for carbon dioxide between blood and tissues.

5. Cellular respiration describes the cellular metabolic reactions that consume oxygen to produce energy molecules and carbon dioxide.



B. Describe *breathing*-

1. Breathing involves moving air through the airway (dead air space) composed of the nasal cavity, pharynx, larynx, trachea, bronchi bronchial tree, then into the lungs.

2. The airway, through which the air travels, warms, humidifies, and cleans the air before directing it to the lungs.

3. The nasal passageway contains olfactory receptors which are unusual in that their input bypasses the thalamus and is sent directly to cortical and limbic system areas of the brain that stimulate memory.

4. The pharynx connects the nasal cavity and mouth to the larynx.

5. The larynx is composed primarily of cartilage, vocal cords, and other connective tissue, and connects the pharynx to the trachea.

6. The trachea, composed of C shaped cartilaginous rings, is a flexible tube that connects the larynx to the bronchi.

7. The bronchi enter the lungs and branch out to form secondary and tertiary bronchi leading to terminal bronchioles and finally into alveoli air sacs.

8. Pulmonary capillaries surround the alveoli sacs providing the pathway for blood flow to and away from them. It is at this junction the exchange of oxygen for carbon dioxide takes place.

C. The mechanics of breathing-

1. The mechanics of breathing generates a pressure differential between the inside and outside of the lungs, causing air to move one direction or the other.

2. Air, as with fluids, moves from areas of higher pressure to lower pressure regions. Just before inspiration, the differential pressure between the inside and outside of the lungs (intrapulmonary pressure) is zero. At zero, there is no air movement.

3. The act of breathing causes the pressure inside of the lungs to be lower than that outside and thus air flows inward (Boyle's Law), similar to the concept of drawing a fluid up into a syringe. This negative intrapulmonary pressure is made possible by the expansion of the lungs resulting from the ventilation dynamics of the diaphragm and intercostal muscles.

4. The muscles of normal, quiet inspiration (eupnea) include the diaphragm and the external intercostals. The diaphragm is a large, domed shaped muscle that separates the abdominal cavity from the thoracic cavity. The diaphragm is attached to the sternum and is the muscle most responsible for eupneic breathing. During normal quiet breathing the diaphragm contracts, causing it to descend about one half inch into the abdominal cavity. This results in stretching the thoracic cavity downward, increasing its volume.

5. Simultaneously, contraction of the external intercostal muscles lift the rib cage and pull the sternum outward, like a handle on a bucket. The external intercostal muscles are innervated by nerves leaving the first through the eleventh thoracic segments of the spinal column.

6. The lungs are passive. They have no capacity to expand or contract on their own and are subject to external forces, much like a sponge absorbs and releases water. Each lung is encased by one continuous serous tissue folded over itself called the pleural membrane. The parietal pleura portion is attached to the outer wall of the thoracic cavity with the visceral pleura bonding directly to the lungs. This creates a small space between the two pleurae which is called the interpleural space, or pleural cavity. Both pleurae secrete a fluid into the cavity which reduces friction between them. Just prior to inspiration, the pressure within the pleural cavity is about 4mmHg below atmospheric pressure. This negative pressure between the pleura membranes keeps the lungs sucked to the chest wall thus preventing them from collapsing inward. As the thoracic cavity expands, the lungs are pulled into an expanded mode, reducing the pressure in the alveoli (intrapulmonic pressure), resulting in air being pulled into the lungs.

7. The combination of the contractions of the diaphragmatic and intercostal muscles results in an action that increases the thoracic cavity by approximately 500 milliliters. This increase causes a drop of intrapulmonary pressure of about 1-2 mmHg and air rushes into the lungs.

8. Expiration during eupneic breathing is passive and is accomplished through the elastic nature of the lungs and relaxation of the inspiratory muscles. As the muscles relax and the lungs recoil, the volume of the thoracic cavity decreases and there is no longer a difference in pressure between the inside and outside of the lungs. Additionally, alveoli ducts and bronchioles have elastic fibers that recoil inward, expelling air. Finally, inward pull resulting from the surface tension of water vapor in the alveoli also contributes to lung volume decrease. The intrapulmonary pressure rises to about 1 mmHg above atmospheric pressure to force air out of the lungs.

D. The regulatory control of breathing-

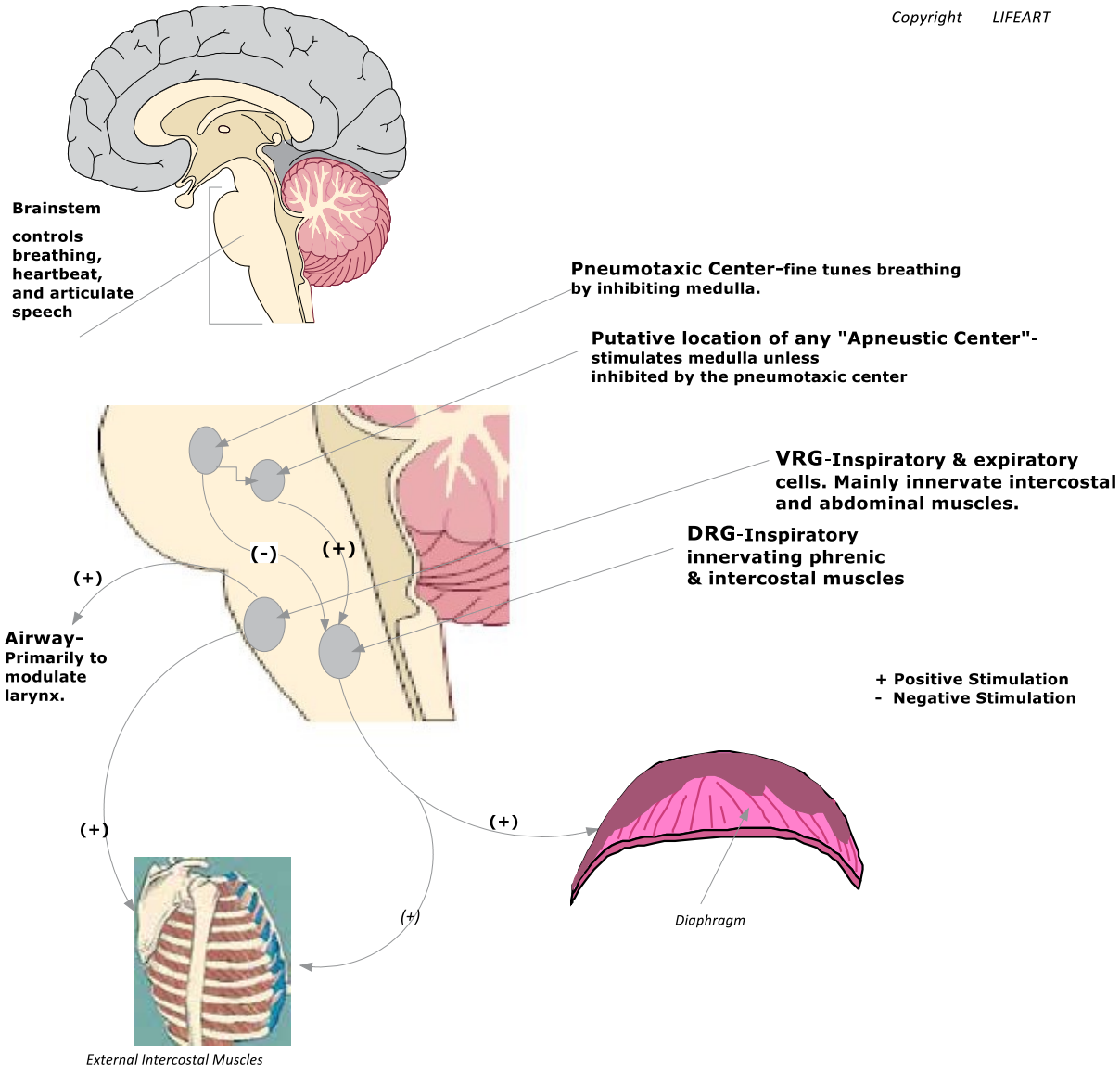
1. Vegetative regulations of visceral body organs, including breathing dynamics, are controlled in part by nuclei and centers in the brain stem.

2. The respiratory rhythmicity centers are located in the lower brain stem, medulla oblongata, with refining regulatory centers in the pons.

3. In the medulla, the rhythmic respiratory center is comprised of two distinct respiratory areas known as the dorsal respiratory group (DRG) and the ventral respiratory group (VRG). The DRG neurons are the primary innervators of the phrenic nerve and thus the diaphragm muscle.

4. The VRG, a column of individual nuclei stacked upon one another, contains mostly expiratory neurons and receives drive input from the DRG. The VRG is also involved in innervating the larynx and pharynx via vagal motoneurons, which assists in maintaining airway patency. During inhalation, the VRG innervates the external intercostal muscles and has some connection to the phrenic nerve. Expiratory neurons, originating in the VRG, project to the internal intercostal muscles and abdominal muscles. These muscles, however, function mostly during intense and rapid exhalation, such as during exercise when passive exhalation would take too long.

5. Modulatory centers such as the pontine respiratory group (formerly called the pneumotaxic) and a putative “apneustic center,” located in upper area of the pons, appear to be associated with phase-related activity. If nuclei exist that form an apneustic center it seems they may function as a “cut off switch,” terminating inspiration. While this center has not been positively identified, it is presumed to be located at about the same level as the pontine respiratory group. Investigators who have experimentally transected the brain stem at this level have been able to produce apneusis (inspiratory spasms or cramps), but only if they also serve the vagus nerve. This suggests any “apneustic center” that exists receives input via the vagus nerves in order to prevent apneusis. While not well defined, the function of the respiratory related neurons in the pons seems to be to “fine tune” the action of eupneic respiration, helping to provide a smooth transition between inspiration and expiration. The ponto-medullary respiratory rhythmicity center, however, can be influenced by the emotional limbic system centers as well as the cognitive cerebral cortical areas.



General locations of central nervous system nuclei responsible for rhythmic regulatory control of breathing. DRG and VRG generalized location and effects on the diaphragm and intercostal muscles during eupneic breathing. Copyright LIFEART and reprinted with permission of LIFEART and SmartDraw, Inc.

E. The major reflexes that affect the breathing cycle-

1. A number of reflexive (automatic) actions can have an effect of the depth and rate of breathing.

2. Stretch receptors within the airways have the potential to influence the respiratory cycle. One such stretch receptor reflex, known as the Hering-Breuer inflation reflex, can result in decreased respiration drive. As the lungs expand through pulmonary inflation, it activates the sensors of these stretch receptors, which project via the vagus nerve to the DRG and the pontine respiratory group. The end result is bronchial dilation and increased expiration time, resulting in a decrease in respiration rate. This seems to be a protective reflex, which has developed to prevent the lungs from over-expanding.

3. Irritant receptors are located throughout the airway and can be activated by certain chemicals, gasses, smoke, dust, and very cold air. Activation by these vectors is transmitted primarily by the vagus nerve and can result in bronchial constriction, which functions to protect the airways from the noxious agent.

4. Chemoreceptors are located centrally in the medulla and peripherally in the great vessels of the neck. The central chemoreceptors are exquisitely sensitive to carbon dioxide, which is the most tightly controlled chemical factor. Carbon dioxide diffuses into the cerebral spinal fluid and forms carbonic acid, which liberates hydrogen ions, resulting in a drop in the pH of the cerebral spinal fluid. It is these hydrogen ions that actually excite the central chemoreceptors in the medulla, which in turn stimulates ventilation. The peripheral chemoreceptors, however, are more responsive to oxygen levels in the blood. Chemoreceptors sensitive to oxygen are located in the aortic and the carotid bodies. If the circulating level of oxygen drops substantially, these act to stimulate respiration rate and depth. Under normal conditions, oxygen levels in the blood affects breathing only indirectly by enhancing the sensitivity of the central carbon dioxide sensors.

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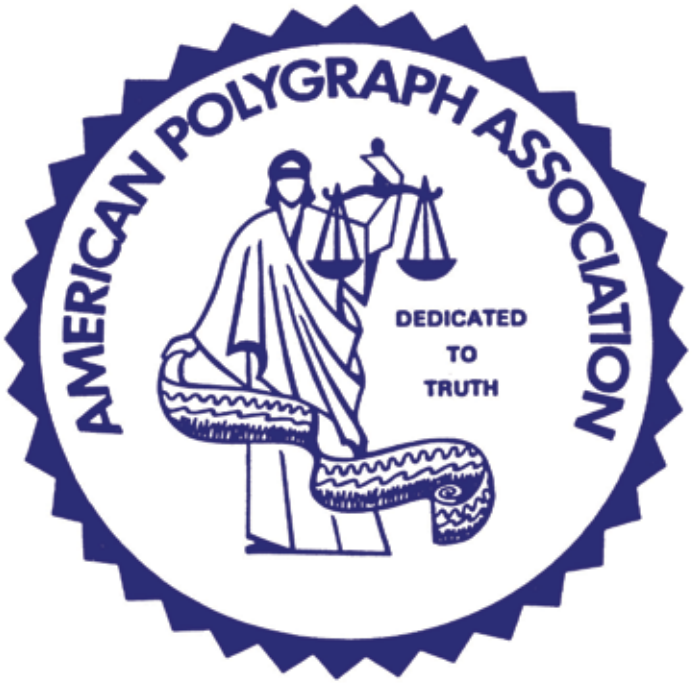
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