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ELECTROPHYSIOLOGY OF HEARING: EVERYTHING YOU NEED TO KNOW BEFORE STARTING YOUR ASSESSMENTS (PART I) – CHOOSING THE STANDARD DEVIATION

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ELECTROPHYSIOLOGY OF HEARING: EVERYTHING YOU NEED TO KNOW BEFORE STARTING YOUR ASSESSMENTS (PART I) - CHOOSING THE STANDARD DEVIATION

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The growing use of electrophysiological methods within the batteries of diagnostic procedures is evident and contumacious however, there is a gap in the knowledge of some professionals in the area about the theoretical and technical aspects of this important tool.

It is worth conceptualizing that the knowledge gap prevents an adequate and complete understanding of a given subject or matter, which can reflect on the quality of the collection and evaluation process and, consequently, on the diagnosis. In view of this point of view, a new special edition of our bulletins has been designed and designed to address important topics within electrophysiological diagnosis and will be presented in a clear, objective and elucidative way.

We invite you to join us on this journey of new knowledge and this bulletin will focus on elucidating an aspect that is still constantly discussed, but not completely understood by the evaluators, the standard deviation. To do so, it will be necessary to enter the universe of mathematics, more specifically, the world of statistics.

STANDARD DEVIATION: MATHEMATICAL CONCEPT

Standard deviation is **a statistical measure** that is related to the variation of responses in relation to a data mean. As the idea is to simplify the reasoning and correlate the data with the electrophysiological findings, in our explanations, when possible, we will attribute the correlations in this sense.

In a layman's way, the use of standard deviation in electrophysiology will allow us to understand whether the responses obtained in an electrophysiological evaluation of a given patient are within (responses within normal limits) or outside (responses outside the limits of normality) of the mean values expected for that given population.

In the evaluation of the Brainstem Auditory Evoked Potential with a click stimulus (BAEP-click), the use of the standard deviation is necessary and indicated, however, it is not uncommon for the evaluators to be unaware of how this calculation should be performed. In addition, there is a doubt as to the most suitable standard deviation value for each clinical population.

Therefore, we will present an example of how to perform this calculation in the analysis of wave I responses of the BAEP-click assessment of individuals over 2-3 years of age. It is worth mentioning that, in this evaluation model, there is a differentiation between the standard deviation values to be performed between children up to 2-3 years of age and individuals above this age group. However, we will return to this point, after understanding the mathematical calculations.

Table 1: Absolute latency values of BAEP-click wave I of 20 individuals (over 3 years of age) with hearing within normal limits. Database of the first author of this study.

Individual	Wave I latency value (BAEP – click)
1	**1,10 ms***
2	1,50 ms
3	1,54 ms
4	1,46 ms
5	1,38 ms
6	1,72 ms
7	1,23 ms
8	1,69 ms
9	1,48 ms
10	1,93 ms
11	1,11 ms
12	**1,98 ms****
13	1,51 ms
14	1,46 ms
15	1,55 ms
16	1,55 ms
17	1,58 ms
18	1,51 ms
19	1,27 ms
20	1,61ms

* individual with lowest absolute latency value (individual 1)
**Subject with lowest absolute latency value (Subject 12)

Table 1 presents the responses to wave I of the BAEP-click of 20 individuals over 3 years of age. With this data it will be possible to obtain some mathematical indicators, such as:

MINIMUM VALUE* [lowest response value among all evaluated patients.]

Example: Subject 1 (1.10 ms)

MINIMUM VALUE = 1,10 ms

MAXIMUM VALUE* [highest response value among all patients evaluated]

Example: Subject 12 (1,98 ms)

MAXIMUM VALUE = 1,98 ms

TOTAL VALUE (SUM) [the sum of all the responses of the patients evaluated] which will serve as a database for various calculations to be performed.

Example: Subject 1 (1.10 ms) + Subject 2 (1.50 ms) + Subject 3 (1.54 ms) + Subject 4 (1.46 ms) + Subject 5 (1.38 ms) + Subject 6 (1.72 ms) + Subject 7 (1.23 ms) + Subject 8 (1.69 ms) + Subject 9 (1.48 ms) + Subject 10 (1.93 ms) + Subject 11 (1.11 ms) + Subject 12 (1.98 ms) + Subject 13 (1.51 ms) + Subject 14 (1.46 ms) + Subject 15 (1.55 ms) + Subject 16 (1.55 ms) + Subject 17 (1.58 ms) + Subject 18 (1.51 ms) + Subject 19 (1.27 ms) + Subject 20 (1.61 ms).

TOTAL VALUE (SUM) = 30,16 ms

MEAN (M) [the sum of all the responses of the patients evaluated divided by the number of patients evaluated] which represents a set of data with a single value.

Example: Subject 1 (1.10 ms) + Subject 2 (1.50 ms) + Subject 3 (1.54 ms) + Subject 4 (1.46 ms) + Subject 5 (1.38 ms) + Subject 6 (1.72 ms) + Subject 7 (1.23 ms) + Subject 8 (1.69 ms) + Subject 9 (1.48 ms) + Subject 10 (1.93 ms) + Subject 11 (1.11 ms) + Subject 12 (1.98 ms) + Subject 13 (1.51 ms) + Subject 14 (1.46 ms) + Subject 15 (1.55 ms) + Subject 16 (1.55 ms) + Subject 17 (1.58 ms) + Subject 18 (1.51 ms) + Subject 19 (1.27 ms) + Subject 20 (1.61 ms) / 20 Subjects

MEAN VALUE = 1.508 ms

The mean (M) is useful when one wants to obtain a general idea of a specific set of data, in this case, the mean absolute latency values of BAEP-click wave I in normal individuals over 3 years of age. And with this measure, it is possible to check if the values are homogeneous or if there are individuals with very heterogeneous values (extremely high or reduced values) in relation to the rest of the group. These individuals with heterogeneous values are called outliers.

Média = (1,10+1,50+1,54+1,46+1,38+1,72+1,23+1,98+1,48+1,93+1,11+1,98+1,51+1,46+1,55+1,55+1,58+1,51+1,27+1,61)/20=30,16/20=1,508

STANDARD DEVIATION (SD) [depends on some specific steps that will be presented in detail below] represents how close or far the data from a set (in this case, all evaluated patients or a specific population) are to the mean. That is, it represents the variability or consistency of a data set or a specific population.

STANDARD DEVIATION VALUE = 0,23 ms

Steps to calculate standard deviation:

1. Calculate the average (already performed in the calculations above)
2. Subtract the mean from each value and square the difference (see calculations in table 2).
3. Add up all the squares of the differences (see calculation in table 2).
4. Divide by the number of elements (see calculation in table 2).
5. Take the square root of the result (see calculation in table 2).

Table 2: **Step 2 Calculations for Obtaining Standard Deviation**

Individual	Wave I values	Subtracting the value of wave I from the mean value of the group (calculation a)	(Calculation a) squared
	Valeu (xi)	xi - x-	(xi - x-)^{2}
1	1,10 ms	1,10 – 1,508 = -0,408	0,166464
2	1,50 ms	1,50 – 1,508 = -0,008	0,000064
3	1,54 ms	1,54 – 1,508 = 0,032	0,001024
4	1,46 ms	1,46 – 1,508 = -0,048	0,002304
5	1,38 ms	1,38 – 1,508 = -0,128	0,016384
6	1,72 ms	1,72 – 1,508 = 0,212	0,044944
7	1,23 ms	1,23 – 1,508 = -0,278	0,077284
8	1,69 ms	1,69 – 1,508 = 0,182	0,033124
9	1,48 ms	1,48 – 1,508 = -0,028	0,000784
10	1,93 ms	1,93 – 1,508 = 0,422	0,178084
11	1,11 ms	1,11 – 1,508 = -0,398	0,158404
12	1,98 ms	1,98 – 1,508 = 0,472	0,222784
13	1,51 ms	1,51 – 1,508 = 0,002	0,000004
14	1,46 ms	1,46 – 1,508 = -0,048	0,002304
15	1,55 ms	1,55 – 1,508 = 0,042	0,001764
16	1,55 ms	1,55 – 1,508 = 0,042	0,001764
17	1,58 ms	1,58 – 1,508 = 0,072	0,005184
18	1,51 ms	1,51 – 1,508 = 0,002	0,000004
19	1,27 ms	1,27 – 1,508 = -0,283	0,056644
20	1,61 ms	1,61 – 1,508 = 0,102	0,010404
Sum of All Values (Calculus a) Squared			0,97972
Calculation b = Division by the number of elements (minus 1 element) $\frac{0,97972}{n-1} = \frac{0,97972}{20-1} = \frac{0,97972}{19} =$			0,051564
Square root of result (calculation b) =s= $\sqrt{0,51564}$ =			0,22

GAUSS CURVE: UNDERSTANDING THE CURVE AND ITS MATHEMATICAL APPLICABILITY WITHIN ELECTROPHYSIOLOGY

One way to visualize mathematical information clearly and accurately is by analyzing the Gauss Curve. This graph model is also known as the normal distribution curve, that is, it allows us to ascertain how a given population behaves in a given procedure.

Again, directing this concept to the analysis of the absolute latency values of wave I of the BAEP-click, those same 20 patients, whose data were described in detail above, the Gauss curve will allow us to understand how the responses of the individuals evaluated were.

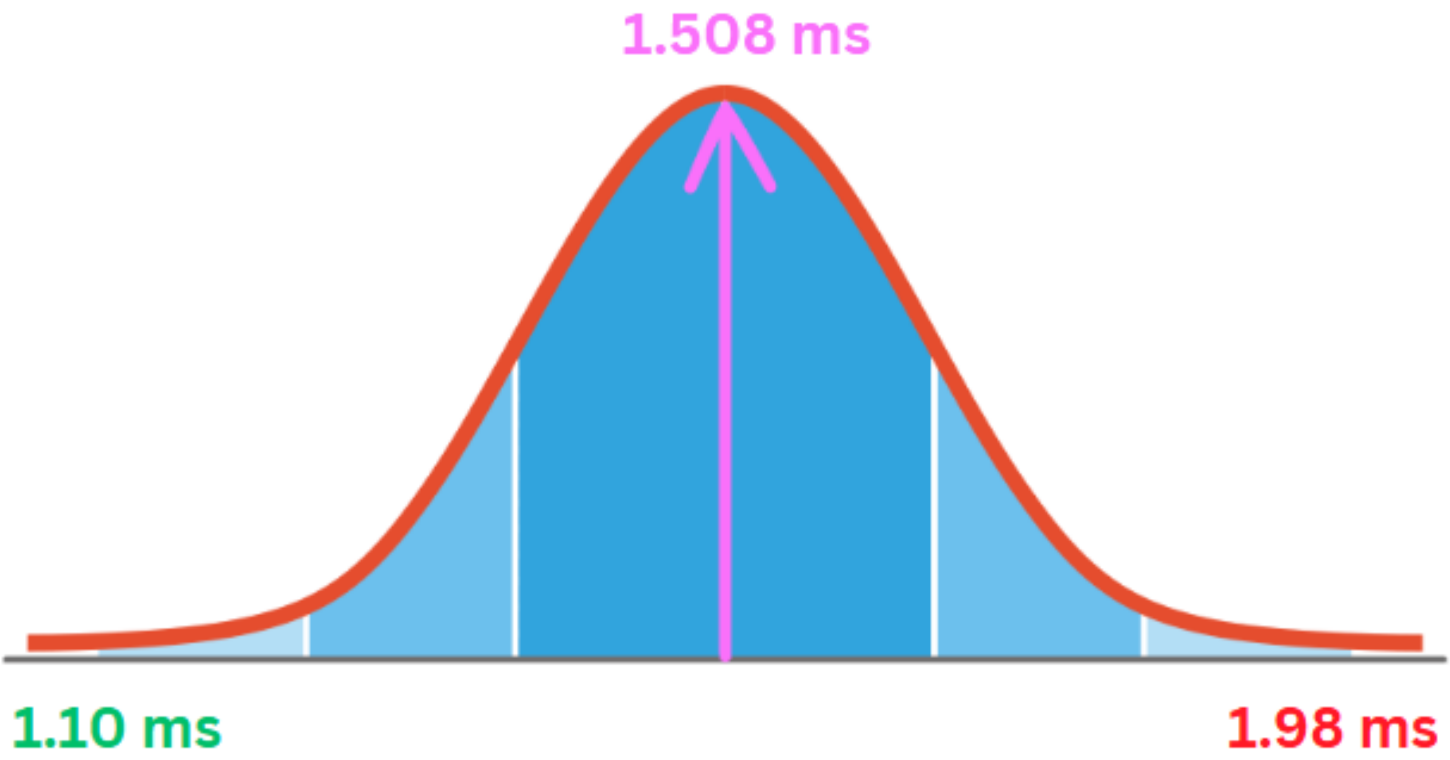


Figure 1: Degree curve with the representation of the minimum, mean and maximum values of wave I of the BAEP-click. Image developed by the authors (Sanfins et al, 2025)

In figure 1, at the beginning of the wave (in green) is the minimum value found in the collection that represents the response of individual 1, in the center of the curve is the average value of responses considering all the individuals evaluated (in pink) and at the end of the curve (in red) is the maximum value found in the collection that represents the response of individual 12. See Table 1.

The complementation of the curve will depend on the mathematical analysis of the standard deviation. The standard deviation, as the name implies, is a measurement that is dispersed from the center of the curve. When considering a dispersion of 1 standard deviation, it means that 68% of the people in the population studied have wave I latency values in this range of values. It is important to note that the vast majority of people will have wave I values (black area represented in the graph).

Using 1 standard deviation, individuals with BAEP-click wave I latency values between 1,288 ms and 1,728 ms would be considered normal. Table 1 would show that individuals 1, 10, 11, 12 and 19 (5 out of 20 individuals) would be altered.

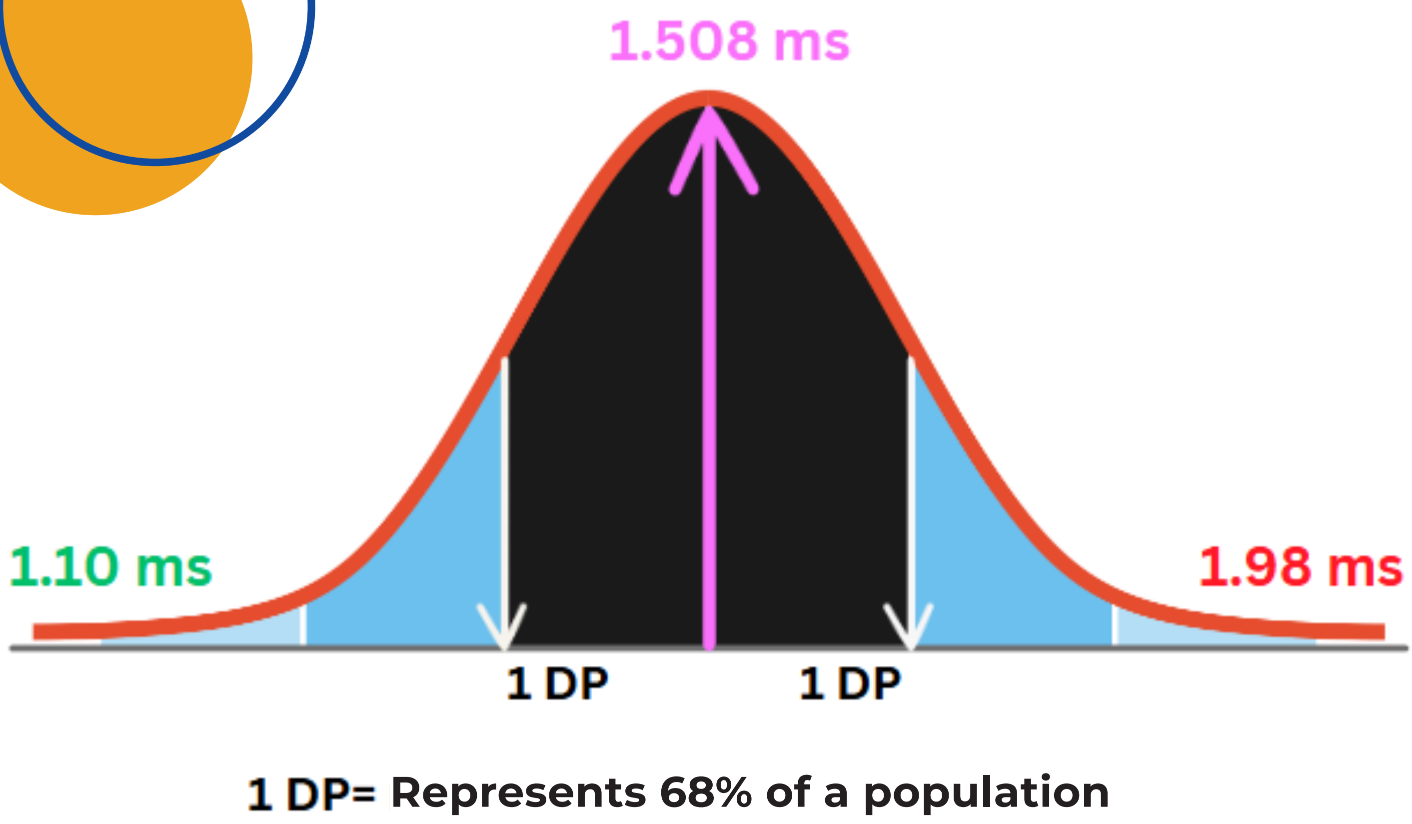


Figure 2: Degree curve with the representation of 1 standard deviation. Image developed by the authors (Sanfins et al, 2025)

However, there are people with values below or above 1SD and, even so, their values are considered to be within the expected values for a given population. For this reason, the calculation of 2 standard deviations is considered a good resource within the electrophysiological evaluations, since it will be taken into account that 95% of the people (black area + orange area represented in the graph) of a given population will have values within the limits of normality.

Using 2 standard deviations, individuals with absolute latency values of BAEP-click wave I between 1.07ms and 1.95ms would be considered normal. Analyzing Table 1, only individual 12 would be altered.

The use of 2 standard deviations allows the test to be more sensitive, which will allow the identification of individuals who are actually altered, and is therefore more reliable. In addition, individuals without alterations would not be erroneously diagnosed.

Individuals who present absolute latency values of wave I of the BAEP-click above or below 2 standard deviations (black area + orange area of the graph) will be considered "outliers", i.e., they are outside the expected normative values, therefore, with the presence of some type of impairment in the integrity of the auditory pathway.

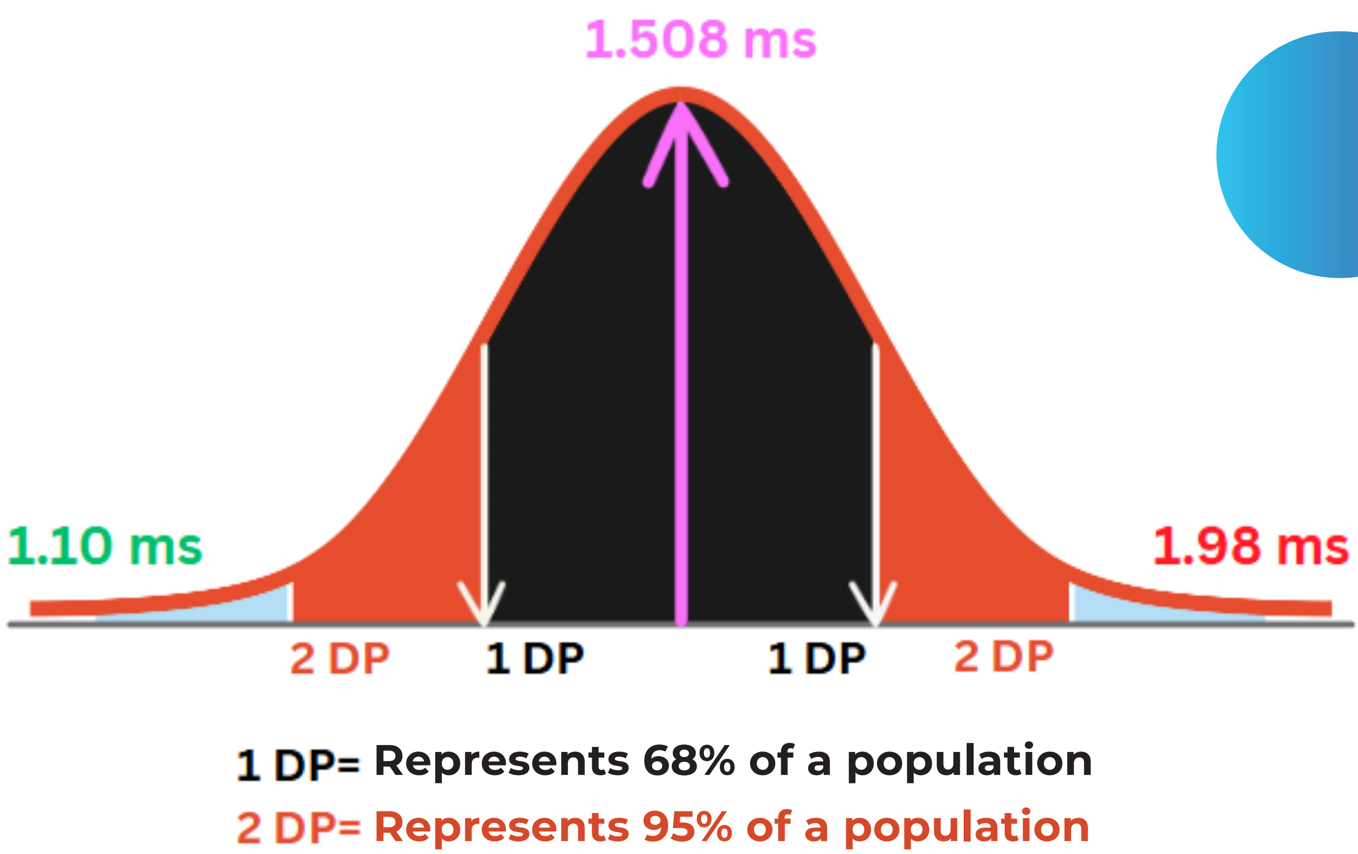


Figure 3: Degree curve with the representation of 1 standard deviation and 2 standard deviations. Image developed by the authors (Sanfins et al, 2025)

For a simple conference, in a normal distribution, 1 standard deviation represents 68% of a population, 2 standard deviations represents 95% of a population, and 3 standard deviations represents 99.7% of a population.

CRITERIA FOR CHOICE IN THE DEFINITION OF STANDARD DEVIATION

After clarifying the calculations necessary for the production of the standard deviation and how it could be applied within the context of electrophysiology, the objective at this point is to present what are the criteria for choosing standard deviation by different researchers.
A first aspect that should be noted is that there seems to be a certain homogeneity of responses among the researchers, with small discrepancies between the studies. To this end, some studies will be presented that focused on the production of normative criteria for the evoked potential, most used in clinical practice, the Brainstem Auditory Evoked Potential (BAEP) with click-type stimulus.

A common point among researchers is that the evaluation of BAEP-click in individuals over 2-3 years of age would use 2 standard deviations would be a viable alternative, whereas, below this age group, the most indicated would be the use of 3 standard deviations. This would be explained by the maturational process in the Central Auditory Nervous System (CNS) and whose maturation would be complete in the brainstem region around 18-24 months of age. For this reason, the application of 3 standard deviations in the evaluation of BAEP-click in the pediatric population would be of great value and excellent clinical applicability, since in this age group a greater variability in responses is expected between individuals.

A relevant aspect mentioned by Prof. James Hall III, a renowned researcher, is that special attention should be paid in cases of prematurity, since the variability can be even more pronounced and the use of 3 standard deviations would bring more precision in the analysis of the responses.

However, there are still studies that suggest the use of 2 to 2.5 standard deviations both in the detection of abnormalities in the integrity of the auditory pathway and in the investigation of auditory thresholds, especially when the evaluator is close to the electrophysiological threshold. Below, some studies, in chronological order, will be presented with information about the population studied, the equipment used in the research and the standard deviation value used.

RELATION OF NORMATIVE STUDIES BASED ON STANDARD DEVIATION VALUES

1. **Hecox e Galambos (1974)** - Auditory brainstem responses in humans
    - **Study Population:** adults.
    - **Standard Deviations:** 2 DP.
    - **Equipment:** Not specified.

2. **Picton et al (1977)** - Human auditory evoked potentials.
    - **Study Population:** adultos.
    - **Standard Deviations:** 2 DP.
    - **Equipment:** not specified.

3. **Musiek et al (1986)** - Auditory Brain Stem Response—Interwave Measurements in Acoustic Neuromas.
    - **Study Population:** adultos .
    - **Standard Deviations:** 2 DP.
    - **Equipment:** Nicolet.

4. **Gorga (1987/1989)** - Auditory brainstem responses from graduates of an intensive care nursey: normal patterns of response and Auditory brainstem responses from children three months to three years of age: normal patterns of response II.
    - **Study Population:** infants, infants and young children
    - **Standard Deviations:** the author presents the standard deviation value, but does not recommend which value should be used by age group.
    - **Equipment:** navigator Pro from Biologic.

5. **Schwartz (1989)** - Auditory brain stem responses in preterm infants: Evidence of peripheral maturity.
    - **Study Population:** preterm infants.
    - **Standard Deviations:**2,5 DP.
    - **Equipment:** Nicolet.

6. **Jerger and Hall (1980) -** Effects of age and sex on auditory brainstem response.
   - **Study Population:** adults.
   - **Standard Deviations:** 2 DP (adults).
   - **Equipment:** Nicolet.

7. **Kraus and Chee (1994) -** Auditory brainstem response and auditory processing disorder.
   - **Study Population:** children and adults.
   - **Standard Deviations:** 2 DP.
   - **Equipment:** navigator pro from biologic.

8. **Hood (1998) -** Clinical Applications of the Auditory Brainstem Response.
   - **Study Population:** children and adults.
   - **Standard Deviations:** 2 DP (adultos) / 3 DP (crianças).
   - **Equipment:** Nicolet.

9. **Stapells (2000) -** Threshold Estimation by the Auditory Brainstem Response: A Literature Meta-analysis.
   - **Study Population:** infants, toddlers, and normal adults.
   - **Standard Deviations:** 2 a 2,5 DP (general population).
   - **Equipment:** not specified.

10. **Sininger et al (2001) -** Auditory brainstem responses in infants and children.
   - **Study Population:** infants, toddlers, and adults.
   - **Standard Deviations:** 2 DP.
   - **Equipment:** not specified.

11. **Naftaliev et al (2003) -** Auditory brainstem responses in children and adults with hearing impairment.
   - **Study Population:** adults.
   - **Standard Deviations:** 2 DP.
   - **Equipment:** not specified.

12. **Stapells et al (2004) -** Threshold estimation by the auditory brainstem response in adults and children.
   - **Study Population:** young adults and children.
   - **Desvios Padrão:** 2 DP.
   - **Equipment:** not specified.

13. **Hall (2007) -** New Handbook of Auditory Evoked Responses.

- **Study Population:** adults and children.
- **Standard Deviations:** 2 DP (adults) / 3 SD (children).
- **Equipment:** Nicolet, Neurosoft and Cadwell.

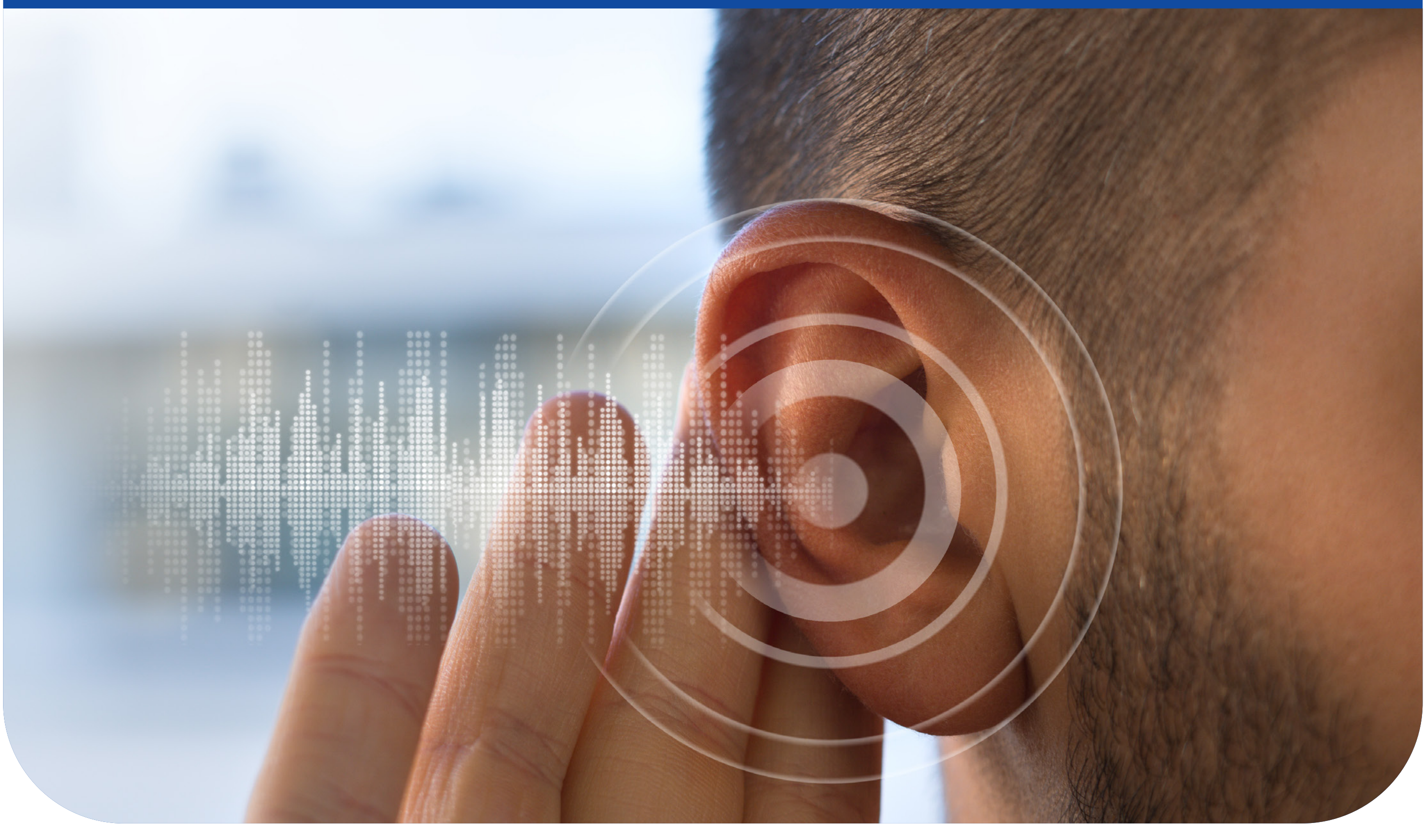
14. **Eggermont (2015) -** Auditory Brainstem Response Audiometry in Neonates.

- **Study Population:** adults.
- **Standard Deviations:** 2 DP (adults) / 3 DP (children).
- **Equipment:** not specified.

15. **Sanfins (2022) -** Latency and Interpeak Interval Values of Auditory Brainstem Response in 73 Individuals with Normal Hearing.

- **Study Population:** adults.
- **Standard Deviations:** 2 DP.
- **Equipment:** neuroaudio from neurosoft.

> **In a didactic and practical way, the studies show that the criterion for choosing the standard deviation should consider the variability among a group of individuals. Therefore, the greater the possibility of different responses among individuals of the same age group, the higher the standard deviation should be..**

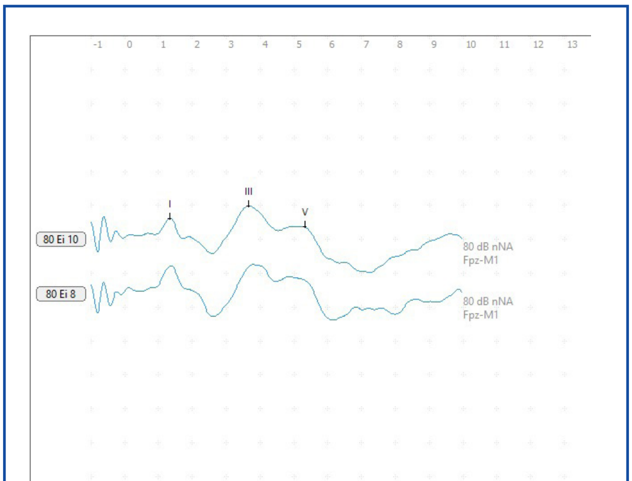


FOR A QUICK REFERENCE, SEE TABLE 3 WITH A SUMMARY TABLE OF THE FINDINGS.

Table 3: SUMMARY OF STANDARD DEVIATION CRITERIA – PEATE CLICK

Author	Equipment	Standard deviation	
		Infant, Infant or Child	Adult
Hecox e Galambos (1974)	Not specified	-	2,0
Picton et al (1977)	Not specified	-	2,0
Jerger e Hall (1980)	Nicolet	-	2,0
Musiek et al (1986)	Nicolet	-	2,0
Gorga et al (1987, 1989)	Navigator Pro - Biologic	-	-
Schwartz et al (1989)	Nicolet	2,5	-
Kraus e Chee (1994)	Navigator Pro – Biologic	2,0	2,0
Hood (1998)	Nicolet	3,0	2,0
Stapells (2000)	Not specified	2,0 - 2,5	2,0 - 2,5
Sininger et al (2001)	Not specified	2,0	2,0
Naftaliev et al (2003)	Not specified	-	2,0
Stapells et al (2004)	Not specified	2,0	2,0
Hall (2007)	Nicolet, Neurosoft and Cadwell	3,0	2,0
Eggermont et al (2015)	Not specified	3,0	2,0
Sanfins et al (2022)	Neuroaudio - Neurosoft	-	2,0

Image from Prof. Sanfins' personal collection



Neurodiagnostic evaluation using PEATE-click in a 1 year and 4 months old female child. **Personal collection of Prof. Sanfins.**

The graphical representation of the absolute latency values of wave I of the BAEP click will be shown in Figure 4, and it is possible to identify the different normative values considering 1, 2 or 3 standard deviations.

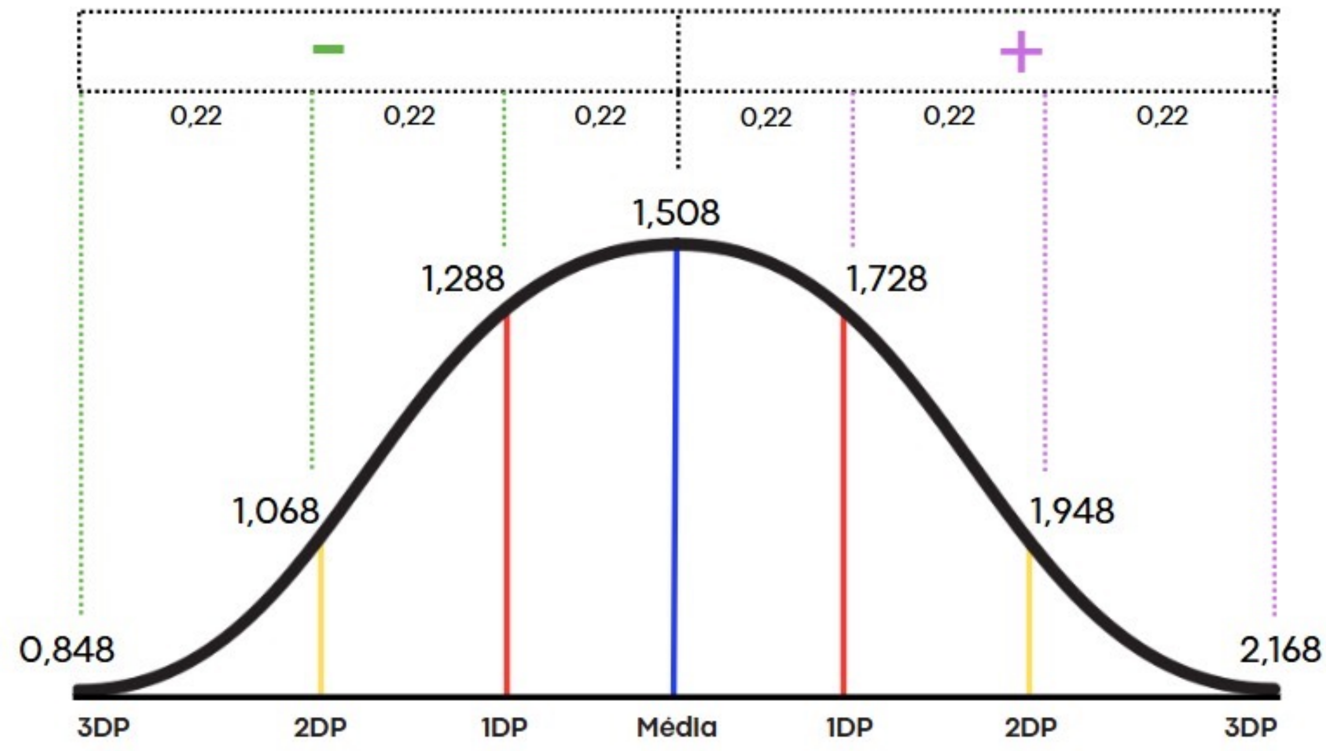


Figure 4: Degree curve with the representation of 1 standard deviation, 2 standard deviations and standard deviations for the absolute latency values of the BAEP-click wave I. Image developed by the authors (Sanfins et al, 2025).

WHAT IS THE IMPORTANCE OF USING STANDARD DEVIATION IN ELECTROPHYSIOLOGICAL EVALUATIONS?

The use of standard deviation is essential within the diagnostic process through electrophysiological evaluation of hearing, since it provides reliability and precision in the analysis of the answers obtained. Basically, it allows individuals with some type of dysfunction to be correctly identified, while allowing individuals without alterations not to be wrongly identified with some type of dysfunction.

> **The studies presented converge in suggesting the use of 2 to 2.5 standard deviations for the population over 3 years of age (children, adolescents, adults and the elderly), while the pediatric population, more specifically, up to 2 to 3 years of age, should use a wider standard deviation, that is, 3 standard deviations, which will provide greater assertiveness in the diagnostic process. considering the variabilities, the maturational process and the natural differences of this age group.**

It should also be noted that the evaluator is responsible for choosing the criteria to be followed and applied in his clinical performance. Thus, it is of fundamental relevance that the professional has knowledge about basic pre-assessment aspects. One of these aspects is the understanding and importance of the standard deviation, so the evaluator will have discernment to determine the value to be used and how this choice can influence the diagnostic process.

The definition of rigorous diagnostic criteria based on scientific evidence is essential within neurodiagnosis. And it is up to the evaluator to be up to date and on top of all the bases of the evaluation process.

We invite you to join us on this journey of understanding the technical and theoretical aspects that govern the electrophysiology of hearing. Our next topic will be about the polarities of sound stimuli and their importance and applicability in evaluation. See you there!

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-President-elect of International Advisory Board of AAOHNS, member of Congress and Meeting Department of EAONO, Regional Representative of Europe of ISA, VicePresident of HearRing Group, Auditor of EFAS, member of the Facial Nerve Stimulation Steering Committee;
-Board Secretary of the Polish Society of Otorhinolaryngologists, Phoniatrists and Audiologists. Member of Hearing Committee (2018–19);
-Goodwill Ambassador representing Poland at the AAOHNSF 2021 Annual Meeting & OTO Experience, and since 2021 a member of Implantable Hearing Devices Committee and Otology & Neurotology Education Committee of AAOHNS;
-Consultant Committee of International Experts of CPAM-VBMS (by special invitation), honorary member of ORL Danube Society, and honorary member of Société Française d'Oto-Rhino-Laryngologie;
-Member of the Council of National Science Center;
-Expert and member of numerous national organizations.