Baseline Shift and Gain Asymmetry in the Caloric Test

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Introduction

In the standard bithermal caloric test, right warm and left cool irrigations are expected to generate right-beating nystagmus while left warm and right cool irrigations are expected to generate left-beating nystagmus. In a normal individual, the intensities of all four caloric responses are approximately the same and therefore, there is no significant difference between right-beating and left-beating responses. Some patients however, have directional preponderance (DP) in which responses in one direction are significantly greater than the responses in the opposite direction. DP is defined as the normalized (scaled) difference between the peak nystagmus slow-phase velocities (SPVs) from irrigations that are expected to generate right-beating nystagmus and those from irrigations that are expected to generate left-beating nystagmus. Mathematical formulas for calculating DP and other caloric parameters are provided in the Appendix.

Interpretation of DP

The normal limits reported for DP from different studies have ranged from as low as 20% to as high as 50%. Currently, most laboratories consider DP of less than 30% to be within normal limits (Sills et al., 1977).

There has been a controversy about the interpretation and clinical value of abnormal DP. Initially, abnormal DP was considered a central finding but this conclusion was reached based on caloric responses that were obtained in the presence of fixation (Fitzgerald and Hallpike, 1942). Therefore, what was considered...
to be abnormal DP was actually related to asymmetric failure of fixation suppression. Subsequent studies in which the caloric test was performed in the absence of fixation found DP in both peripheral and central pathologies (Coats, 1966; Baloh et al., 1977). Therefore, abnormal DP in its current form is considered a non-localizing finding. Abnormal DP has also been reported in normal individuals, which further casts doubt on its clinical value (Coats, 1965).

Due to its low sensitivity to pathologies and lack of specificity to central versus peripheral abnormalities, some laboratories do not include DP in the interpretation of the caloric test. However, it has now become clear that DP can be caused by two different types of abnormalities. Therefore, the low clinical value of DP should not come as a surprise because the current method of calculating DP does not distinguish between these two abnormalities. It seems worthwhile to define new parameters that can separately quantify these abnormalities.

Different types of DP

Figure 1 shows two different types of DP. In Figure 1A, caloric responses are shifted in one direction indicating presence of nystagmus at the beginning of all four irrigations. The caloric stimulus in an ear with an intact tympanic membrane does not reach the labyrinth for at least 10 seconds from the onset of the irrigation. Therefore, this baseline shift represents a pre-existing nystagmus in the standard caloric position. That is, this patient has some form of spontaneous nystagmus. This nystagmus is added to the caloric-induced nystagmus when they are in the same direction and subtracted from it when they are in opposite directions. As a result, significant DP is generated because the peak caloric responses for two irrigations (right cool and left warm, in this case) are greater than those for the other two irrigations (right warm and left cool, in this case). This type of DP is called Bias or Baseline Shift (BS).

Figure 1. Different types of DP: A) BS, B) GA. For clarity of presentation, simulated caloric responses are used instead of actual patient test results.
Figure 1B shows a different type of DP in which the caloric responses in one direction are truly stronger than the responses in the opposite direction. There is no spontaneous nystagmus as the SPVs at the onset of all four caloric irrigations are zero. This type of DP has been described in the literature but it is an extremely rare finding (Sills et al., 1977). Halmagyi et al. (2000) found this type of DP in less than 1% of patients who underwent vestibular testing whereas BS constituted the remaining 99% of the cases with clinically-significant DP. They termed this type of DP, Gain Asymmetry (GA).

Quantification of BS and GA

Although the caloric responses in Figure 1A and 1B represent two different abnormalities, UW and DP parameters are the same. In order to differentiate between these two cases, new parameters are needed to quantify BS and GA.

The formula for DP can be partitioned into two components with the first component related to spontaneous nystagmus and BS and the second component related to GA. However, the representation of BS in this form has a major shortcoming as the intensity of spontaneous nystagmus is divided by the sum of four caloric responses (Barin and Stockwell, 2002). Because spontaneous nystagmus is independent of the caloric irrigations, it does not seem logical to scale or normalize its intensity based on the caloric responses. The consequence of normalizing the intensity of spontaneous nystagmus is shown in Figure 2. The same level of spontaneous nystagmus can generate a wide range of values for DP that can be normal (Figure 2A) or abnormal (Figure 2B). That is, the caloric test parameters are different despite the fact that underlying abnormality is the same in Figures 2A and 2B.

Figure 2. The effect of normalizing the intensity of spontaneous nystagmus or BS on DP: A) Strong caloric responses, B) Weak caloric responses. For clarity of presentation, simulated caloric responses are used instead of actual patient test results.
The most appropriate method for quantifying BS appears to be the SPV of spontaneous nystagmus. This can be accomplished in different ways. First, the intensity of spontaneous nystagmus can be calculated from the supine position in the static position testing because this position is similar to the standard caloric test position (Figure 3B). A better alternative is averaging of the nystagmus SPVs from the first few seconds of each irrigation. This will account for any potential calibration change from the position test to the caloric test. The averaging of SPVs can be done computationally but a graphical approach simplifies the process. It involves finding a best-fitting horizontal line that passes through the SPV points at the beginning of each irrigation (Figure 3A). The intersection of this line with the vertical axis represents BS.

The intensity of spontaneous nystagmus (and by extension, BS) depends on the gaze position and the level of alertness. That is the reason in actual patient testing (Figure 3) the BS levels from different irrigations are approximately the same but they are not exactly the same as in the idealized responses (Figure 1 and 2). Using a best-fitting line or averaging of the SPVs addresses this issue. On the other hand, the direction of spontaneous nystagmus does not change in a single head position. Therefore, any difference in the direction of BS from one irrigation to another usually represents a technical error (such as not waiting long enough between irrigations). In very rare cases, periodic alternating nystagmus, which represents a central abnormality, can cause changing of nystagmus direction in a single head position. If the direction of BS is different in different irrigations and technical errors have been ruled out, the presence of periodic

Figure 3. A) Graphical method for estimating BS. The green line represents a best-fitting horizontal line for the SPV points within the first few seconds of each irrigation (dotted black boxes). B) The static position test result for the same patient showing left-beating nystagmus in the supine position with an average SPV of 10 deg/sec.
Alternating nystagmus can be verified by repeating the position test in a single head position and recording the nystagmus for an extended period of time (typically, 5 minutes or longer).

The true asymmetry in the intensity of right-beating versus left-beating nystagmus can be quantified using the same formula for the DP after removing the contribution of the spontaneous nystagmus from each of the peak caloric responses. This is indeed the definition of GA. Note that dividing of the difference between right-beating and left-beating nystagmus intensities by the total caloric responses is appropriate because after removing the contribution of the spontaneous nystagmus, all of the parameters in the formula for GA represent caloric-induced SPVs.

One more note on the somewhat confusing terminology for expressing BS and GA. BS is usually expressed with respect to the direction of stronger slow phases whereas GA is usually expressed with respect to the direction of stronger fast phases. For example, BS in Figure 1A is to the right whereas GA in Figure 1B is to the left.

**Interpretation of BS and GA**

Because BS and GA are independent parameters, they should be interpreted separately. BS and spontaneous nystagmus represent the same abnormality and therefore, their normative limits and interpretation are the same. Most laboratories use SPVs of less than 4-6 deg/sec as the normal limit for spontaneous nystagmus, which can be used directly as the normal limit for BS.

In many cases, abnormal BS occurs concurrently with abnormal UW, which indicates an acute or uncompensated peripheral vestibular lesion. In the absence of an abnormal UW, abnormal BS and spontaneous nystagmus indicate a non-localizing finding involving peripheral or central vestibular pathways.

The normative values and the interpretation of GA are not well-established because there are very few studies that have examined GA independent of DP. Halmagyi et al (2000) used values of greater than 40% for abnormal GA but again, that limit was based on their normal limits for DP. In our laboratory, we use a somewhat arbitrary limit of less than 25% for normal GA. More studies are needed to establish the normal limits of GA in a more definitive manner.

Abnormal GA is an extremely rare finding. Halmagyi et al (2000) found less than 1% of the patients who underwent vestibular testing demonstrated abnormal GA. Baloh and Honrubia (2001) have suggested that abnormal GA denotes a central lesion. Halmagyi et al (2000) did not address this issue directly but found abnormal GA in a variety of both central and peripheral lesions. In their study of patients with abnormal GA, the majority of those with peripheral vestibular lesions had a diagnosis of either benign paroxysmal positional vertigo or Meniere’s disease. In a companion paper, Cartwright et al (2000) suggested that abnormal GA was due to a dynamic asymmetry in the secondary vestibular neurons. They further suggested that such an asymmetry in peripheral vestibular lesions was brought on by a faulty compensation mechanism in response to fluctuations of vestibular function. If we accept this notion, the concept of abnormal GA representing a central lesion is still plausible because both the secondary vestibular neurons and the compensation mechanisms reside within the central vestibular pathways. However, further studies are needed to determine the value of GA in identifying the site of lesion.

**Summary**

There are two distinct abnormalities that can cause a significant DP in the caloric test. Because the current method of calculating DP does not distinguish between these two abnormalities, new parameters were defined that can separately quantify these abnormalities. Further studies are needed to determine whether GA and BS are clinically more useful than DP. Nonetheless, identifying the distinct components of DP is a logical step and addresses major shortcomings of DP.
Appendix

The method for quantifying GA is presented here. The conventional formula for $DP$ is:

$$DP = \frac{TotRB - TotLB}{TotRB + TotLB} \times 100,$$

where $TotRB$ represents total responses from the irrigations that are expected to generate right-beating nystagmus and $TotLB$ represents total responses from the irrigations that are expected to generate left-beating nystagmus. The parameters in the above formula are determined from the peak nystagmus SPVs for right warm ($PeakRW$), left warm ($PeakLW$), right cool ($PeakRC$), and left cool ($PeakLC$) irrigations:

$TotRB = -PeakRW - PeakLC,$

$TotLB = PeakRC + PeakLW$

Note that the above formulas are algebraic operations and peak values are signed numbers with positive numbers representing rightward slow-phase or left-beating nystagmus and negative numbers representing leftward slow-phase or right-beating nystagmus (Figure 4). Sometimes caloric irrigations produce nystagmus in the opposite direction of what is expected (usually due to presence of strong spontaneous nystagmus). The above formulas are still applicable as long as the correct signs are used for the peak values of those responses. The common terminology for $DP$ is to express it with respect to the direction of stronger fast phases.

When there is spontaneous nystagmus, the caloric response is a combination of the caloric-induced nystagmus and the spontaneous nystagmus. That is,

$$PeakXX = CalXX + SN,$$

where $Cal$ is the maximum SPV of caloric-induced nystagmus, $SN$ is the average SPV of spontaneous nystagmus and $XX$ stands for $RW$ (right warm), $LW$ (left warm), $RC$ (right cool), and $LC$ (left cool) irrigations. If we apply this concept to $UW$, the contribution of spontaneous nystagmus completely disappears from the formula for $UW$. That is, $UW$ is defined as the relative difference

Figure 4. Signed values of SPV: A) Positive numbers for rightward slow-phase or left-beating nystagmus, B) Negative numbers for leftward slow-phase or right-beating nystagmus.
between the peak caloric responses of the right and left ears and quantified by:

\[
UW = \frac{\text{TotRE} - \text{TotLE}}{\text{TotRE} + \text{TotLE}} \times 100.
\]

TotRE represents total responses from the right ear and TotLE represents total responses from the left ear:

\[
\text{TotRE} = \text{PeakRC} - \text{PeakRW},
\]
\[
\text{TotLE} = \text{PeakLW} - \text{PeakLC}.
\]

Replacing the peak values:

\[
\text{TotRE} = \text{PeakRC} - \text{PeakRW} = \text{CalRC} + \text{SN} - \text{CalRW} - \text{SN} = \text{CalRC} - \text{CalRW},
\]
\[
\text{TotLE} = \text{PeakLW} - \text{PeakLC} = \text{CalLW} + \text{SN} - \text{CalLC} - \text{SN} = \text{CalLW} - \text{CalLC}.
\]

Therefore, \(UW\) is appropriately based on the caloric-induced nystagmus alone without any contamination by spontaneous nystagmus:

\[
UW = \frac{(\text{CalRC} - \text{CalRW}) - (\text{CalLW} - \text{CalLC})}{(\text{CalRC} - \text{CalRW}) + (\text{CalLW} - \text{CalLC})} \times 100.
\]

In fact, the rationale for performing bithermal caloric testing is to cancel out the effect of spontaneous nystagmus in calculating \(UW\). In the above formula, the difference between the responses of right and left ears is divided by the total of all four caloric responses to scale or normalize \(UW\). This is logical in view of the fact that there is considerable variability among the individual caloric responses from one person to another.

Replacing the peak values in the formula for \(DP\) yields:

\[
\text{TotRB} = -\text{PeakRW} - \text{PeakLC} = -\text{CalRW} - \text{CalLC} - 2 \times \text{SN},
\]
\[
\text{TotLB} = \text{PeakRC} + \text{PeakLW} = \text{CalRC} + \text{CalLW} + 2 \times \text{SN},
\]
\[
DP = \left(\frac{-4 \times \text{SN}}{(-\text{CalRW} + \text{CalLC}) + (\text{CalRC} + \text{CalLW})}\right) \times 100.
\]

The first component in the \(DP\) formula is related to spontaneous nystagmus and was discussed earlier. The second component represents the true asymmetry in the intensity of right-beating versus left-beating nystagmus after removing the contribution of the spontaneous nystagmus. Therefore, the appropriate quantification for \(GA\) is:

\[
\text{GA} = \frac{(-\text{CalRW} - \text{CalLC}) - (\text{CalRC} + \text{CalLW})}{(-\text{CalRW} - \text{CalLC}) + (\text{CalRC} + \text{CalLW})} \times 100.
\]

where \(\text{CalXX}\) can be calculated by subtracting the BS from the corresponding \(\text{PeakXX}\). Note that dividing of the difference between right-beating and left-beating nystagmus intensities by the total caloric responses is appropriate because all of the parameters in the above formula represent caloric-induced SPVs.
References


Technical Note

ICS Chartr software versions 6.0 and higher are capable of calculating BS and GA.