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Baseline Shift and Gain Asymmetry in the Caloric Test

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Abstract

The caloric test is quantified using two parameters: unilateral weakness (*UW*) and directional preponderance (*DP*). The clinical usefulness of *UW*, also known as canal paresis, is well established but there is considerable debate about the value of *DP*. Some laboratories choose not to include *DP* in the interpretation of the caloric test. One reason for the low clinical value of abnormal *DP* may be the fact that it can be caused by two distinct pathologies. The first is a static asymmetry in the peripheral or central vestibular pathways and the second is a gain asymmetry in the secondary vestibular neurons within the vestibular nuclei. Because the current formula for calculating *DP* combines both abnormalities into a single parameter, it is possible that important information is being lost. This article reviews the abnormalities that can cause *DP* and offers computational methods for separating the contribution of each abnormality.

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*).

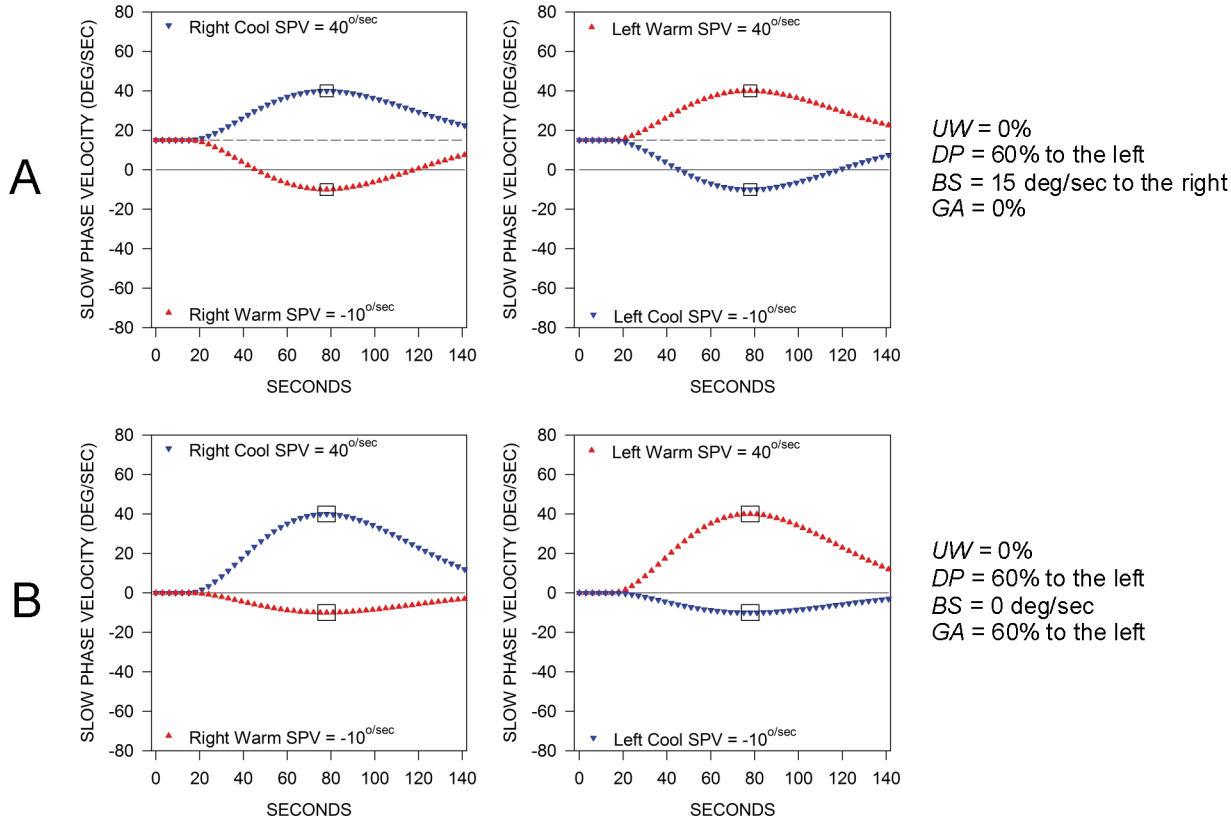


Figure 1. Different types of DP: A) BS, B) GA. For clarity of presentation, simulated caloric responses are used instead of actual patient test results.

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***.

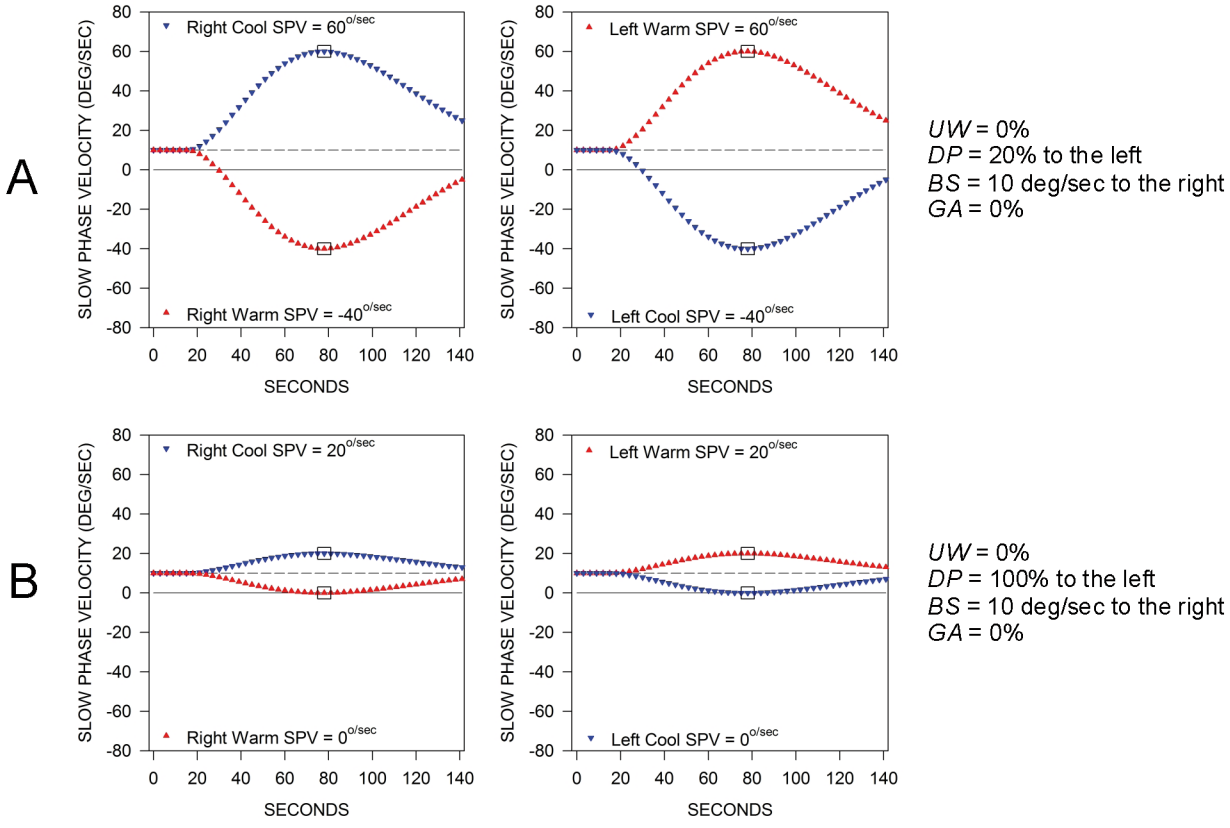
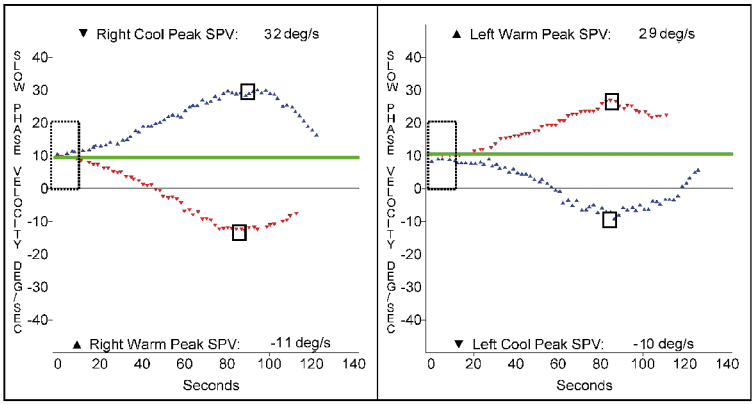


Figure 2. The effect of normalizing the intensity of spontaneous nystagmus or BS on DP: A) Strong caloric responses, B) Weak caloric responses. For clarity of presentation, simulated caloric responses are used instead of actual patient test results.

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

A



UW = 5% in the left ear
DP = 49% to the left
BS = 10 deg/sec to the right
GA = 0%

B

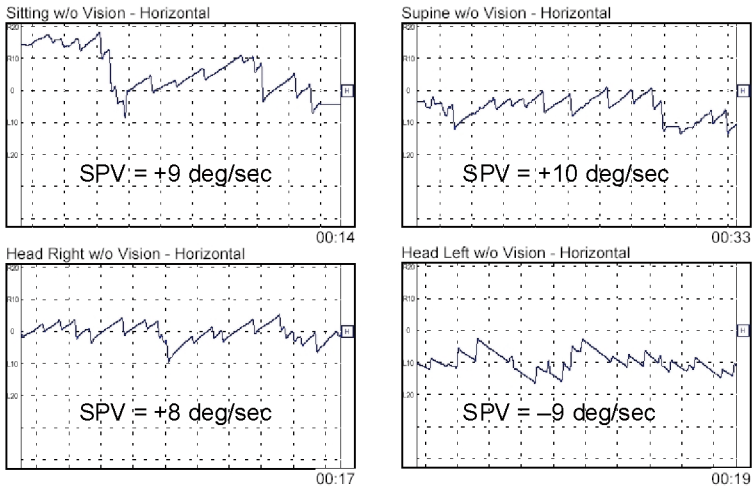


Figure 3. A) Graphical method for estimating BS. The green line represents a best-fitting horizontal line for the SPV points within the first few seconds of each irrigation (dotted black boxes). B) The static position test result for the same patient showing left-beating nystagmus in the supine position 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

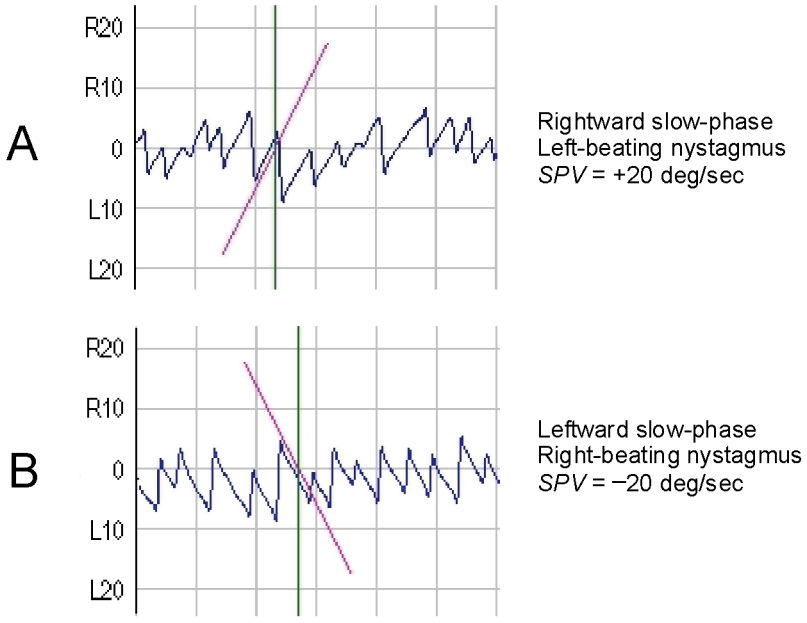


Figure 4. Signed values of SPV: A) Positive numbers for rightward slow-phase or left-beating nystagmus, B) Negative numbers for leftward slow-phase or right-beating nystagmus.

between the peak caloric responses of the right and left ears and quantified by:

$$UW = \frac{TotRE - TotLE}{TotRE + TotLE} \times 100.$$

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

$$TotRE = PeakRC - PeakRW,$$
$$TotLE = PeakLW - PeakLC.$$

Replacing the peak values:

$$TotRE = PeakRC - PeakRW = CalRC + \cancel{SN} - CalRW - \cancel{SN} = CalRC - CalRW,$$

$$TotLE = PeakLW - PeakLC = CalLW + \cancel{SN} - CalLC - \cancel{SN} = CalLW - CalLC.$$

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

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

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:

$$TotRB = -PeakRW - PeakLC = -CalRW - CalLC - 2 \times SN,$$

$$TotLB = PeakRC + PeakLW = CalRC + CalLW + 2 \times SN,$$

$$DP = \left(\frac{-4 \times SN}{(-CalRW - CalLC) + (CalRC + CalLW)} + \frac{(-CalRW - CalLC) - (CalRC + CalLW)}{(-CalRW - CalLC) + (CalRC + CalLW)}\right) \times 100.$$

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:

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

where *CalXX* can be calculated by subtracting the *BS* from the corresponding *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.

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Technical Note

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