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Use of ice water stimulation in suspected bilateral vestibulopathy

Mariah Jule Skinner
Washington University School of Medicine in St. Louis

USE OF ICE WATER STIMULATION IN SUSPECTED BILATERAL VESTIBULOPATHY

by

Mariah Jule Skinner

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Approved by:
Belinda Sinks, Au.D., Capstone Project Advisor
Maureen Valente, Ph.D., Secondary Reader

Abstract: The aim of this study was to investigate the incidence of patients with unilateral vestibular dysfunction on ice water testing as well as the presence of correlations with rotary chair test results and their diagnosis. All patients reviewed for this study had what appeared to be a bilateral vestibular loss before ice water testing was performed.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

ABBREVIATIONS

cc	Cubic centimeter
deg/s	Degrees per second
Hz	Hertz
REDCap	Research electronic data capture
SAS	Statistical analysis software
SD	Standard deviation
VNG	Video Nystagmography
VOG	Video oculography
VOR	Vestibular Ocular Reflex

INTRODUCTION

Bithermal caloric testing is an integral part of the Video oculography (VOG) test battery. It is used to determine whether a peripheral lesion exists, discern the site of lesion, and quantify the lesion. Bithermal caloric testing is one of the few vestibular tests that provides ear specific information. The procedure is able to provide ear specific information by stimulating one ear at a time while the patient is in a supine position with the head elevated at roughly a thirty-degree angle. This is known as the standard caloric position. Bithermal caloric testing is able to assess function of the horizontal semicircular canal. When the head is in the thirty-degree angle the horizontal semicircular canal is in the same plane as gravity, leaving gravity to have no effect. In addition, no responses can be evoked without an induced change to the vestibular system, due to cupula and endolymph densities being the same and not being affected by gravity (Jacobson & Shepard, 2008). The underlying purpose of the bithermal caloric test is to induce either an inhibitory or excitatory change to the vestibular system, which allows a nystagmus response to be recorded.

The bithermal caloric test stimulates the ear with either air or water at varying temperatures through the external auditory canal, inducing a change to the vestibular system. The temperature of the water for irrigation is either warm (excitatory) at 44 degrees Celsius, or cool (inhibitory) at 30 degrees Celsius (Katz, Medwestsky, Burkard, Hood, 2009). Air irrigation temperatures are 50 degrees Celsius for warm and 24 degrees Celsius for cool (Jacobson & Shepard, 2008). More specifically, the temperature is representative of 7 degrees Celsius above or below normal body temperature for water and 13 degrees Celsius above or below for air (Jacobson & Shepard, 2008). The change in temperature in the external auditory canal causes the density of fluid closest to the site of irrigation to change, thus moving the endolymph within the canal due to the effect of gravity (Katz et al., 2009). Warm and cool irrigations have different effects on the stimulated ear, which induce different nystagmus responses. The standard acronym for remembering the nystagmus response that should be seen from the different temperatures is COWS: cold opposite, warm same. This means that when cool water is presented to an ear the nystagmus will beat toward the opposite ear and when warm water is presented the nystagmus will beat toward the same ear. Robert Barany was the first to document what changes bithermal caloric testing has on the vestibular system to result in nystagmus responses.

The following is a representation of Robert Barany's description of what causes a nystagmus response. The warm irrigation causes the endolymph to become lighter and rise, resulting in deflection of the cupula towards the ampulla, which causes an excitatory response where the nystagmus fast phase beats toward the irrigated ear (Barany, 1907). On the other hand, cool irrigations cause the endolymph to become heavier and sink, resulting in an inhibitory response from the irrigated ear and the nystagmus fast phase beats toward the non- irrigated ear (Barany, 1907). Robert Barany's description is commonly described as gravity-dependent. For this publication on the nystagmus response Robert Barany won the 1914 Nobel Prize. Since his initial description of bithermal caloric testing, other explanations for the nystagmus response have emerged.

The most accepted description of bithermal caloric testing is a description by Coats and Smith, which includes two components. One of these components is the same as Barany's description related to a change in endolymph gravity (Coats & Smith, 1967). The second component introduced by Coats and Smith is that the vestibular nerve is also directly stimulated, unrelated to any effects of gravity. These investigators' two component description is commonly used in current clinical settings.

Although the bithermal caloric test has been established for many years there are still limitations that need to be addressed. The first limitation is that there is no calibration for the test. There is a lack of calibration due to individual differences of the labyrinths within and between patients (Stockwell, 1997). Differences between labyrinths can be present as a result of normal variability or anatomical anomalies. When there is normal anatomy of the ear, it is best to compare the patient's left and right ear to each other in order to reduce this variability. It is important to compare within the individual when possible because variability can be increased if compared to another patient. Secondly, the bithermal caloric test is a test of the horizontal semicircular canals and their afferent neural pathways, omitting the anterior and posterior canal function in most cases, as well as otolith function (Aw, Haslwanter, Fetter, Heimberger, & Todd, 1998). The anterior and posterior canals are often not stimulated, due to their increased distance from the external auditory canal. The last limitation is that it is a low frequency stimulation of the vestibular system, 0.003 Hertz (Hz), which is below the optimal operational range of the vestibular receptors (Jacobson & Shepard, 2008). Even though there are limitations for the bithermal caloric test, it is still an important part of the VOG test battery due to its ability to obtain ear specific information.

If bithermal caloric results are confounding in that they are bilaterally reduced or absent, ice water irrigation is a method further used to extract a response. There are essentially two outcomes that can be seen from the results of ice water testing. The first is to observe no change from the bithermal caloric test results. The second is that there could be a present response, likely indicating a severe but not complete loss of peripheral vestibular function (Jacobson &

Shepard, 2008). If a response is present, it can be either a unilateral or bilateral response. Ice water testing is a protocol in the audiologist's vestibular evaluation that can be used when bithermal caloric testing does not yield a sufficient response. However, a literature review has revealed a dearth of literature on the topic.

The use of ice water stimulation will sometimes reveal a stronger response than what was initially found using bithermal caloric testing as the extreme change in temperature is more stimulating than that used for standard cool bithermal caloric testing. There are three reasons for bithermal caloric results to be bilaterally reduced or absent including bilateral peripheral vestibular dysfunction, temperature transfer issues, or unilateral peripheral vestibular dysfunction with central inhibition. In the case of bilateral vestibular dysfunction, the results of ice water stimulation will also be reduced or absent. Secondly if temperature transfer issues are present it is possible for ice water results to be much more robust than the bithermal caloric results and the results are often more robust bilaterally. Temperature transfer issues can be seen as a result of temporal bone thickness, adipose tissue, or tortuous canals. Lastly, in the case of unilateral vestibular dysfunction with central inhibition the ice water results will be more robust on one side when compared to the other. This latter finding suggests an asymmetry in the peripheral labyrinthine input with one side being weaker than the other. This is what prompted the idea for this study.

Schmal, Lubben, Weiberg, and Stoll (2005) compared the ice water test to the bithermal caloric test in their study of 22 healthy subjects. The study also addressed reasons why ice water testing may not be as thoroughly investigated as other vestibular tests. These researchers found that ice water testing is rejected at times due to seemingly producing pseudocaloric nystagmus, as well as being an unpleasant and painful experience for the patient. However, none of their patients reported pain or discomfort during the ice water stimulation. The researchers defined pseudocaloric nystagmus as an activation of latent spontaneous nystagmus, thus not a true response. Benefits of the ice water test in this study were a stronger nystagmus response with a longer duration than the bithermal caloric response. The investigators also found that there was a higher sensitivity and specificity in detection of canal paresis based on the Jongkee's formula favoring the ice water test. The Jongkee's formula is used to determine the percentage of reduced vestibular response and whether a unilateral deficit is present. The criterion for unilateral deficit is a clinic specific measurement and depends on the normative data collected at the clinic. For this particular study when the result was a 25% or more difference between ears there was one ear significantly reduced compared to the other (Schmal et. al, 2005). The study concluded that the ice water test is a reliable test and it needs to be further investigated.

A study by Batuecas-Caletrio, Montes-Jovellar, Boleas-Aguirre and Perez-Fernandez (2009) aimed to review the findings obtained with the ice water test. The authors further tested patients with ice water when they noted a unilateral vestibular weakness greater than 90%, maximum slow phase velocity of nystagmus after bithermal caloric testing, or a total eye speed less than 15 degrees per second (deg/s). Slow phase velocity of nystagmus is the vestibular component of the response, which is used to obtain a measurement of the response in deg/s. The patients were tested in both the standard caloric supine position and also the prone position. The prone position, with the patient lying face down, was used because it further tested the effects gravity had on the responses. There were a total of 71 patients in this study, which was conducted at a university hospital. Each patient demonstrated a unilateral hypofunction based on the results from the bithermal caloric test. The same ear that showed a weakness on the bithermal caloric test was further tested using ice water stimulation. There can be different causes of unilateral vestibular hypofunction including vestibular schwannomas, vestibular neuritis, and vestibular labyrinthitis. The results of the ice water testing for the same patients who were found to have a unilateral hypofunction on bithermal caloric testing were categorized into three categories: normal response (n=24), gravity-independent response (n= 31), and no response (n= 14). A gravity-independent response was categorized as a weak nystagmus response beating away from the irrigated ear (Batuecas-Caletrio, et al., 2009). Two of the patients had results that were considered inconclusive and therefore could not be included in one of the three main categories. Overall, the study found that the ice water stimulation is a reliable test to further test patients who show a unilateral vestibular weakness on bithermal caloric testing.

Rotary chair is another test used to assess the horizontal semicircular canals for peripheral function. Prior studies have been completed to compare rotary chair testing to bithermal caloric testing. A study by Ahmed, Goebel, and Sinks (2009) found that bithermal caloric testing was more sensitive than rotary chair testing in distinguishing peripheral from central vestibular dysfunction. However, when multiple rotary chair subtests are combined it is a suitable vestibular diagnostic test to use when bithermal caloric testing is not attainable (Ahmed et al. 2009). Another study found that the bithermal caloric test had a 80.7% higher percentage of diagnostic accuracy than the rotary chair test (Maes et. al, 2011). Both of the studies agreed that when feasible, bithermal caloric testing and rotary chair testing should be used together to provide the most accurate diagnosis for patients; however, the bithermal caloric test remains the most effective diagnostic test for peripheral vestibular dysfunction.

The aims of this study were as follows: 1) to determine the incidence of patients who appeared to have a bilateral vestibular dysfunction on bithermal caloric testing prior to ice water testing, which then revealed a unilateral dysfunction with ice water testing 2) to investigate correlations between said patients who were discovered to have a unilateral vestibular dysfunction after ice water testing. Correlations were determined from patient data including rotary chair testing results and diagnosis.

METHODS

Participants

A descriptive retrospective study of patient medical files was completed using the Washington University School of Medicine Dizziness and Balance Center's database between 2001 and 2013. The Institutional Review Board reviewed the protocol, granting study approval and a waiver of informed consent. Collected unidentified data were entered into a database constructed using Research Electronic Data Capture (REDCap). A total of N= 445 patient medical files (male= 294, female= 151) were reviewed who were aged between 14-91 years (mean= 57, SD=15.9). Inclusion criteria for the study were patients who were suspected of having bilateral vestibular dysfunction as indicated by a total eye speed of 20 deg/s or less on bithermal caloric testing. Exclusion criteria were patients with a total eye speed greater than 20 deg/s on bithermal caloric testing and those who did not have the ice water test.

Bithermal Caloric Testing

Bithermal caloric testing is used to induce a change to the vestibular system in order to test its function. There are multiple ways to administer a change to the system by changing the temperature of the external auditory canal and thus the vestibular system as well. The bithermal caloric testing for the patients whose files were reviewed for this study was conducted utilizing the Brookler-Grams closed loop caloric irrigator. Nystagmus was recorded using the Visual Eyes™ VNG System. The method of closed-looped water irrigations involves a silicone balloon barrier attached to the end of the irrigator, which is then filled with either the warm or cool water after being placed inside of the external auditory canal. Using a closed-looped water method allows for there to be a barrier between the water and the external auditory canal. The water is delivered to the balloon through a hose attached to the water reservoir, which regulates the temperature and duration of the water (Jacobson & Shepard, 2008). This method of irrigation allows for some control of the variability that can be seen in patients by not solely relying on the test administrator to have proper insertion and placement of irrigator (Jacobson & Shepard, 2008).

There are also open-looped water irrigators and air irrigators. The open-looped water method delivers water to the ear canal through a hose typically attached to two water reservoirs with either warm or cool water. There is a timer used for this method to stop the flow of water. When this method is used, a container is also used to catch the water as it flows out of the external auditory canal. The tip of open-looped water hoses can be a simple tube or similar to an otoscope which allows for the external auditory canal to be illuminated. The air irrigator method is very similar to the open-looped water method. Air is delivered to the external auditory canal from an irrigator that regulates the temperature. An air pump is used to move the air through a tube that has an otoscope tip attached. A timer that is activated by a switch, typically a foot pedal, is used as well. There are mixed findings as to which irrigator is the best; however, all three irrigation methods are sufficient to provide the caloric stimulation needed to record responses and attain good test-retest reliability (Jacobson & Shepard, 2008).

Ice Water Testing

To administer the ice water test according to the protocol set forth by Jacobson and Shepard, the audiologist allows ice to sit in water for a few minutes until the water is cold. The water is then inserted into the patient's external auditory canal using a syringe while the test ear is placed in the horizontal plane. The volume of water used should be 2 cubic centimeters (cc) because that is the average volume of an adult external auditory canal (Jacobson & Shepard, 2008). After an average of 20 seconds, the patient should return to the standard caloric position and remain in the position for an additional 30 to 60 seconds (Jacobson & Shepard, 2008). The patient's nystagmus should be recorded from the time that the water is inserted into the external auditory canal until after the patient has returned to the standard caloric position for a duration of 60 seconds. Once the test is completed the water should be allowed to drain naturally out of the patient's ear.

The ice water testing protocol at the Washington University School of Medicine Dizziness and Balance Center, where the patients' files were obtained for this study, is unique and yet similar to that reported in the literature. To administer the ice water test, the patient is placed in a supine position with the head elevated to a 30-degree angle. The water used is stored in a refrigerator to keep it at a constant temperature, which is approximately 18 degrees Celsius. This standardization helps reduce potential result variability, due to the temperature of the water. The patient must have otologic clearance, meaning no perforation in their tympanic membrane or other external ear abnormality that could cause potential harm to the patient when the ear is irrigated with the ice water. The water is inserted into the patient's external auditory canal using a syringe with plastic tubing attached to the tip. This device is used to maintain a continuous flow of water for approximately 25 seconds. A continuous flow of water is important in order to prohibit standing water from being warmed by the external auditory canal. The nystagmus response of the patient is recorded from the time the irrigation begins until the nystagmus subsides. The protocol allows for the ear that is first irrigated to return to room temperature before proceeding with the next. The ice water testing protocol described by Jacobson and Shepard (2008) varies slightly from the protocol used for the patients in this study.

Rotary Chair Testing

An additional test that can be used to distinguish between a bilateral and unilateral vestibular loss is rotary chair testing, thus it was investigated for correlations in this study. There were 135 patients in this study that also had rotary chair testing performed as a part of their vestibular test battery. The rotary chair system used for these patients was the Micromedical™ Technologies System 2000 rotational chair. Specifically, rotary chair testing can measure the peripheral vestibular system's presence or lack of asymmetry for frequencies ranging from 0.01 Hz to 1.28 Hz. This is a useful test because it can measure frequencies higher than what is measured by bithermal caloric testing or ice water testing. The frequency of interest for this study was 0.025 Hz. This specific frequency was chosen for this study because it is the lowest rotary chair frequency used for testing the vestibular ocular reflex (VOR) at this clinic site, thus the most sensitive to showing dysfunction. Rotary chair testing can also use VOR gain to assess whether an individual labyrinth is functioning within normal limits. The normative data for VOR gain ranged from 0.42 deg/s to 0.85 deg/s. Rotary chair is used to provide supplemental information about the status of the peripheral system and whether any central inhibition or compensation is occurring. It can also be used as an alternative to bithermal caloric testing if irrigations cannot be performed or results are inconclusive; however, bithermal caloric testing is the gold standard for ear specific information.

Statistical Analysis

Standard descriptive statistics were used to describe study population and distribution of test scores and confirmed diagnosis. Mean and standard deviation were used for continuous level variables, while frequency and relative frequency were used for categorical level variables.

Scatter plots were used to explore correlation between rotary chair VOR gain at 0.025 Hz and ice water testing. The Pearsons product moment correlation test was used to quantify the potential correlations. The statistical analysis was performed using the Statistical Analysis Software (SAS) 9.3 package (SAS Institute). A formal power analysis could not be completed in that no previous studies could be located.

RESULTS

Incidence

Adopting the approach used in bithermal caloric testing the percent difference in ice water was calculated as the ratio of difference over the total measurement of the two ears multiplied by 100%. Based on the absolute value of this percent difference patients were categorized into ten groups that were representative of sequential 10% differences between patients' ears. Table 1 shows groups categorized by sequential 10% difference between ears on ice water testing. The groups were as follows: group 1 (0-9.9%), group 2 (10-19.9%), group 3 (20-29.9%), group 4 (30-39.9%), group 5 (40-49.9%), group 6 (50-59.9%), group 7 (60-69.9%), group 8 (70-79.9%), group 9 (80-89.9%), and group 10 (90-100%). The distribution of patients in the different groups, as shown in Table 1, were as follows: group 1 = 97 patients (21.8%), group 2 = 76 patients (17.1%), group 3 = 54 patients (12.1%), group 4 = 56 patients (12.6%), group 5 = 47 patients (10.6%), group 6 = 33 patients (7.4%), group 7 = 22 patients (4.9%), group 8 = 28 patients (6.3%), group 9 = 30 patients (6.7%), and group 10 = 2 patients (4%). The established normative data for bithermal caloric asymmetry at Washington University School of Medicine Dizziness and Balance Center is a difference of 30% or greater. If this criterion is used as a reference for this study it is observed that 49% of patients had a difference of 30% or greater between ears on ice water testing.

The distribution of the study population diagnoses was also determined. Patients were categorized as peripheral pathology (n= 219), central pathology (n= 47), unavailable (n= 173), or both (n=6), meaning peripheral and central. These categories were based on their medical diagnosis in their patient file.

Correlations

The scatter plot shown in Figure 1 helped to determine if there was any correlation between rotary chair VOR gain at 0.025 Hz and ice water testing. There was no significant correlation shown between rotary chair VOR gain results at 0.025 Hz and the difference in deg/s between ears after ice water testing was performed ($p= 0.938$).

The correlation between unilateral vestibular dysfunction after ice water testing and diagnosis was explored as well across the four main diagnosis groups: peripheral pathology, central pathology, unavailable, and both. As can be clearly seen from Figure 2 there is no significant difference among the four diagnosis groups.

DISCUSSION

The current study investigated the incidence of patients with unilateral vestibular dysfunction as elicited by ice water testing as well as the presence of correlations with rotary chair results and their diagnoses. All patients reviewed for this study had what appeared to be a bilateral vestibular dysfunction, as indicated by the bithermal caloric test, before ice water testing was performed. Results for incidence had to be interpreted in a creative manner due to no normative data on ice water testing, which resulted in a population distribution. There were no significant correlations shown between the ice water test results and the 0.025 VOR gain rotary chair test results. Also no significant difference was found among the diagnosis groups with respect to the ice water test results.

Ice Water Unilateral Vestibular Dysfunction

Although this study was a pilot study without any preliminary data, valuable insight was obtained as a result. Without normative data for ice water testing, the investigators were unable to determine magnitude of difference between ears that could be classified as a statistically significant unilateral vestibular difference. Data were analyzed in terms of 30% difference between ears as being the cutoff point for asymmetry. This numerical difference was chosen because it is representative of a unilateral vestibular dysfunction on bithermal caloric testing for the Washington University School of Medicine Dizziness and Balance Center. The results of this study showed that 49% of the patients had a difference between their ears that either met or exceeded the 30% difference criterion when tested with ice water. Interestingly, when the population distribution results are compared to a previous study of 71 patients, the percent of patients who were determined to have unilateral vestibular deficits is similar. Batuecas-Caletrio et. al (2009) confirmed that 63% of their patients had an absent or weak unilateral vestibular response after ice water testing was performed. These findings support the use of ice water testing to clinically assess whether a patient has a unilateral vestibular dysfunction and provide a numerical reference until normative data are present.

When interpreting the data as presented in the sequential categories of 10% difference between ears on ice water testing, there are three outcomes that need to be addressed. The first is that as the difference between ears increases, it is more likely that the patient has an asymmetry in labyrinthine input. Secondly, even when the percentage difference is low, i.e. less than 30%, these responses can be either reduced or robust depending on the input from the individual labyrinths. The last outcome that needs to be addressed is that even if the results indicate that there is lack of symmetry, the results cannot be interpreted as normal or abnormal, due to the lack of normative data.

Additionally, the sheer number of patients (n= 445) that appeared to have a bilateral vestibular dysfunction on bithermal caloric testing before ice water testing was performed during this time period of 12 years is astounding. Whether this is due to temperature transfer issues, true bilateral vestibular dysfunction, or unilateral vestibular dysfunction with central inhibition is uncertain. However, it is likely a number of these individuals have a unilateral vestibular dysfunction with central inhibition. This finding supports the ideology that the brain is able to adjust so that the individual labyrinthine inputs are recognized as being similar. The phenomenon known as central inhibition occurs when the brain depicts the asymmetric signals and suppresses one in order to restore balance within the system. This allows the patients to not feel an overwhelming sense of vertigo or dizziness.

Rotary Chair Correlations

Correlations with rotary chair were limited to only one data point. This data point, 0.025 Hz VOR gain, showed no significant correlation on scatter plots when compared to the difference between ears on ice water testing. Specifically, patients who had results that were considered abnormal gain did not have any trend in differences between ears on ice water testing. The number of patients who had rotary chair testing was small compared to the total population in this study; however, the smaller number of patients was not the reason for lack of correlation.

Diagnosis Correlations

There was high variability within the diagnosis groups. The group categorized as "both" displayed less variability when compared to the other three groups; however this group also had the smallest sample size (n=6). Due to the high variability, there was no significant difference found among the four diagnosis groups.

Limitations

There were three main limitations of this study. The first and most crucial was that there are no normative data for ice water testing. Therefore, statistical analysis could not be computed in terms of being statistically significant. A second limitation was that 173 patients' diagnoses were not available in their medical files. If this data would have been available, analysis may have provided more statistical information. Lastly, not all patients included in this study had rotary chair testing completed. Although only one data point was investigated in this study, it would have been interesting to investigate further subtests if more patients had undergone rotary chair testing.

Future Studies

The current study generated questions for further research of ice water testing. First and foremost, normative data would be invaluable both clinically and for research. Although normative data would be very beneficial, it is difficult to obtain due to the robust stimulation individuals with normal vestibular function experience when undergoing ice water stimulation. Another area for further research could be to investigate the outcomes of ice water testing with more data points of rotary chair testing, such as different frequencies as well as symmetry and step velocity time constants. Lastly, correlations with other vestibular subtests for peripheral vestibular pathologies could be investigated, such as the vestibular evoked myogenic potential test.

CONCLUSIONS

This study revealed that ice water stimulation is a reliable and useful test within the VOG test battery. A statistically significant difference between individual ear responses could not be determined to directly investigate incidence. However, when a 30% difference between ears on bithermal caloric testing is used as the cutoff point for asymmetry, it seems that the greater the asymmetry above 30% would increase the suspicion for clinically significant differences regarding ice water stimulation. There was no correlation found for VOR gain at 0.025 Hz during rotational chair testing compared to the percent difference between ears after ice water irrigations. Also there was no significant difference found in ice water results among the four diagnosis groups. Further studies focusing on ice water testing are needed and normative data should ideally be established.

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Table 1

Distribution of the study's population into groups categorized by sequential 10% difference between ears on ice water testing.

Group	Percent difference in ice water	N	Percent
1	0-9.9	97	21.8
2	10-19.9	76	17.1
3	20-29.9	54	12.1
4	30-39.9	56	12.6
5	40-49.9	47	10.6
6	50-59.9	33	7.4
7	60-69.9	22	4.9
8	70-79.9	28	6.3
9	80-89.9	30	6.7
10	90-100	2	0.4

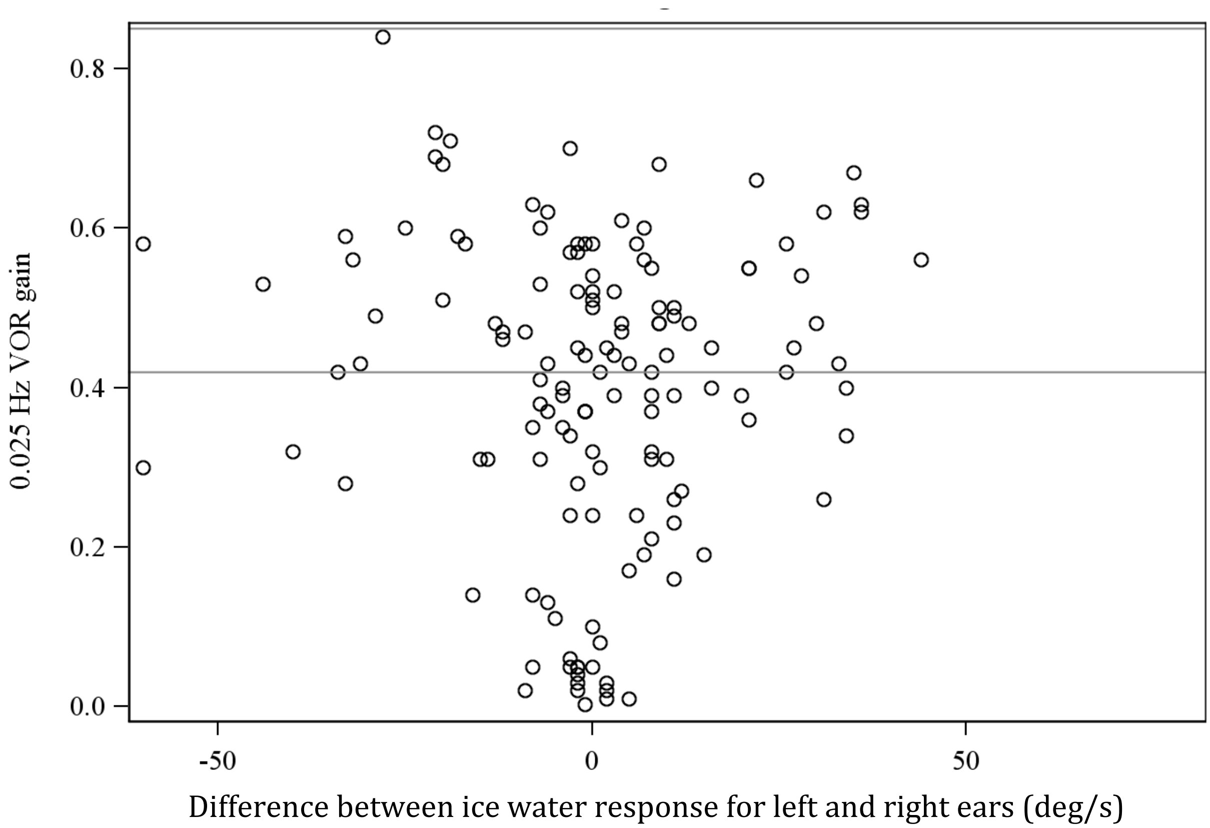

Figure 1. 0.025 Hz VOR gain (deg/s) compared to difference in deg/s of ears for ice water testing.

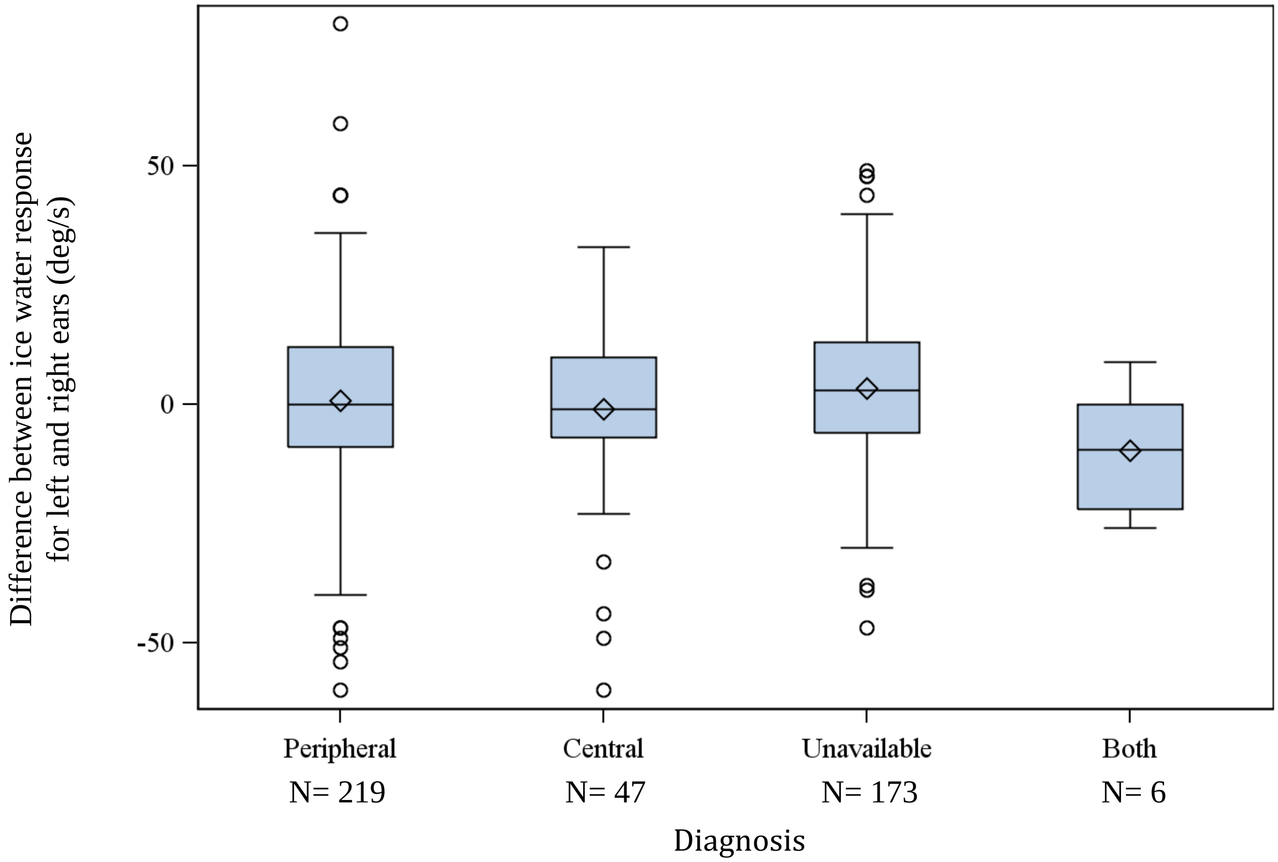

Figure 2. Diagnosis compared to difference in deg/s of ears for ice water testing.