Monothermal Caloric Testing in the Screening of Vestibular Function

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Shupak A, Kaminer M, Gilbey P, Dror T. ***Monothermal caloric testing in the screening of vestibular function.*** **Aviat Space Environ Med 2010; 81:369–74.**

Introduction: The alternate binaural bithermal caloric test (ABBT) is the standard test for evaluation of the dizzy patient. Monothermal caloric testing (MT) has the potential benefits of reducing the administration time and patient discomfort. The goal of the present study was to investigate the role of MT screening in the prediction of ABBT results. ***Methods:*** ABBT results of 218 patients having normal otoneurological examination, normal hearing, and normal electronystagmography (ENG) were retrospectively analyzed to generate norms for all subtests. These norms were then employed to calculate the sensitivity and specificity of MT for predicting normal ABBT in a group of 197 consecutive dizzy patients who were referred for vestibular testing. ***Results:*** The best predictions of ABBT by MT results were achieved when ENG testing showed oculomotor integrity and no spontaneous, positional, or positioning nystagmus. Under these conditions, warm MT lateralization $< 32\%$ had 90% sensitivity and 92% specificity for the prediction of normal ABBT. ***Discussion:*** When no pathology is detected in the other parts of the ENG, warm MT lateralization $< 32\%$ can indicate normal ABBT with a 10% probability for a false-negative result. This false negative rate precludes the routine use of warm MT in the clinical realm and its application as a screening tool for possible vestibular deficits in a generally healthy population like aviation or diving candidates. Higher sensitivity may be achieved by lowering the cut-off point of the response asymmetry required for the diagnosis of MT screening failure and the omission of directional preponderance diagnosis from the goals of the screening.

Keywords: electronystagmography, projections and predictions, flight safety, vertigo, spatial disorientation.

AVIATORS ARE COMMONLY exposed to vestibular illusions that might result in spatial disorientation, endangering flight safety. These are related to the lack of peripheral visual cues, linear and angular vection misperceptions, and to somatogyral and somatogravic illusions, where the input from the semicircular canals and otolith organs secondary to prolonged, high acceleration leads to misjudgment of rotation and altitude (4,9). Pilot spatial disorientation is a leading factor contributing to many fatal flying accidents. U.S. Air Force statistics of major aircraft accidents from 1980 through 1989 report 356 mishaps caused by operator error, with spatial disorientation accounting for 81 of these (23%) (9). Spatial disorientation is not restricted to military aviation alone. Of the 4012 fatal general aviation accidents occurring between 1970 and 1975, 627 (15.6%) involved spatial disorientation. It is of note that 90% of mishaps in which disorientation was a cause or factor were fatal (13) and that the reason no corrective action was taken by the pilots in most cases was because they failed to recognize the disorientation episode which led to the accident (5). The importance of normal function of the vestibular system is mentioned in the aviation medical literature as being a prerequisite for flying (20).

Standard evaluation of the vestibular system includes the alternate binaural bithermal caloric test (ABBT), which was originally described by Fitzgerald and Hallpike (8). ABBT is the only test available for detecting the side of peripheral vestibulopathy. By stimulating each ear separately, it contributes to the diagnosis of bilateral vestibular involvement when all responses to cold and warm stimuli are reduced and adds to the differentiation of peripheral from central vestibular involvement by measuring the fixation-induced inhibition of the caloric response. In spite of these benefits, ABBT is the most time-consuming part of the electronystagmography (ENG) test battery and frequently causes significant inconvenience to the subject due to the repeated vestibular stimuli. A shorter caloric test protocol with less extreme vestibular stimulation would reduce the examination time and patient discomfort and would be of special benefit when large and generally healthy populations like pilot candidates are screened for potential vestibular deficits. The monothermal caloric test (MT), which involves only single temperature irrigation in each ear, was suggested as such a screening tool (2). Previous studies investigating MT have reported contradictory findings. MT has been criticized as an invalid screening modality by several authors reporting high false negative (3,6,12,17) and false positive rates (3,17). A number of authors have documented low false negative and variable false positive rates mainly when MT screening was limited to patients satisfying one or more conditions in the ENG results (7,10,14). When MT was considered as a screening tool, most studies advocated warm water testing (10,14,16) while an advantage for cold air was found in only a single study (7).

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This manuscript was received for review in August 2009. It was accepted for publication in December 2009.

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DOI: 10.3357/ASEM.2651.2010

The conflicting results reported and the inconsistent conclusions arising from these results may be due to variations in test procedures and stimulus type, different sample sizes, different failure criteria for the ABBT pathology and MT side difference, and the use of additional ENG criteria to support the validity of MT screening. In view of these contradictory results, the aim of this study was to reinvestigate the diagnostic performance of MT compared to ABBT. Specifically, we looked for possible correlations between MT and ABBT test results and studied the prediction of ABBT abnormalities by MT screening.

METHODS

ABBT data were retrospectively collected from 218 patients (81 men and 137 women ranging from 19 to 83 yr of age; mean = 53.4 yr, SD = 14.6 yr) having nonvestibular dizziness, normal bed-side otoneurological examination, and normal pure tone, speech, and impedance audiometry. These patients who were referred for ENG to rule out vestibulopathy had normal ENG evaluation (Norm group). The ENG results of this group were used to determine the normal range of the caloric nystagmus slow phase velocity (SPV) for each of the fourv ABBT subtests and left and right ear differences for warm and cold water irrigation. A prospective study including 197 consecutive patients (69 men and 121 women ranging from 20 to 82 yr of age; mean = 55.6 yr, SD = 14.8 yr) suffering from spontaneous or postural vertigo with typical symptoms and signs that were referred for vestibular testing was conducted in order to determine the sensitivity and specificity of warm and cold MT in the prediction of ABBT results (Study group).

The horizontal and vertical eye movements were registered by conventional silver/silver chloride ENG electrodes that were applied bitemporally and above and below one eye. A ground electrode was applied to the forehead. The skin-electrode interface was of impedance below 5000 Ω. The electrodes were connected via a junction box to a commercially available ICS CHARTR 200 ENG system (GN Otometrics Inc., Taastrup, Denmark). The ENG battery included tests for oculomotor systems integrity (saccadic, gaze, optokinetic, and pursuit systems), tests for spontaneous, positional, and positioning nystagmus (Dix-Hallpike maneuver), and ABBT (1). The ABBT is performed with the subject supine with 30° head flexion using cold (30°C) and warm water (44°C) to irrigate each ear at a time. The water irrigation induces thermal gradient across the horizontal semicircular canal and the developed convection current stimulates the vestibular end organ. Caloric stimulations were performed using an open loop water irrigation unit (Water Calorics NCI 480, GN Otometrics Inc., Taastrup, Denmark). Water irrigations were carried out over a 40-s time period for a total volume of 250 ml. An alternating ear sequence was used and a minimum interval of 5 min was allowed to elapse between the caloric subtests. Recalibration was carried out before each individual irrigation. The maximal SPV of the resulting nystagmus was calculated as the average of the three strongest consequent nystagmic beats. To compare the responsiveness of one ear to that of the other ear the percent lateralization of the vestibular response was computed using Jongkees's formula (11). The maximal SPV were summed for each ear and then subtracted from the sum of responses to irrigation of the opposite ear. The difference was normalized by dividing by the sum of the four responses and then multiplying by 100 to get a measure of vestibular response lateralization in percent. Directional preponderance (DP) expresses numerically whether the amount of right-beating nystagmus exceeds the amount of left-beating nystagmus or vice versa. To calculate DP, the SPV sum of left warm and right cold irrigations were subtracted from the SPV sum of left cold and right warm irrigations. The difference was normalized by dividing by the sum of the four responses and then multiplying by 100 to get a measure of DP in percent.

The nystagmus SPV in response to the cold and warm water irrigations, which were obtained as part of the ABBT protocol, were used to evaluate MT side differences. These were calculated according to the following formula (2):

$$\text{Side difference} = [(\text{Maximal SPV Lt} - \text{Maximal SPV Rt}) / (\text{Maximal SPV Lt} + \text{Maximal SPV Rt})] * 100.$$

The study protocol and testing procedures were approved by the local Institutional Review Board.

The mean age and gender distribution of the Norm and Study groups were compared by the simple *t*-test and the Chi square test, respectively. The similarity of the Norm group caloric test results to normal distribution was examined by the Shapiro-Wilk test. Pearson's product-moment coefficients were used to examine the correlation between ABBT lateralization and DP and MT side differences. Abnormal ABBT results were defined as either unilateral weakness > 25% or directional preponderance > 30%. The upper limit of MT side difference, as calculated from the normal patient group data, was defined as the mean plus two standard deviations. The lower limit of the nystagmus SPV for each of the four ABBT subtests was defined as the mean SPV minus two standard deviations. The sensitivity, specificity, false negative, and false positive rates of warm and cold MT side differences toward the prediction of ABBT results were calculated. Statistical analysis was performed using SPSS software (SPSS, Inc., Chicago, IL) on a personal computer.

RESULTS

The mean age and gender distribution did not differ between the Norm and Study groups (simple *t*-test, Chi square test). The Shapiro-Wilk test showed normal distribution of the caloric test results in the Norm group. This result concurred with previous publications (1,7) and supported the assumption that the range of 2 SDs above and below the mean included 95% of the Norm

TABLE I. DESCRIPTIVE STATISTICS OF THE NORM GROUP DATA AND NORMAL LIMITS CALCULATED FROM THE MEAN ± 2 SD.

	Mean	SD	Range	Normal limit
Caloric stimulation SPV (degrees/second)				
Right cold	26	11	11-74	4
Right warm	25	10	11-60	5
Left cold	26	10	11-82	6
Left warm	24	10	11-54	5
MT side difference (%)				
Warm MT	13	9	0-47	32
Cold MT	13	9	0-38	30

MT – monothermal caloric testing. SPV – maximal slow phase velocity.

group data and represented the normal limits. **Table I** details the means, standard deviations, and normal limits for the nystagmus SPV of the four caloric stimulations and warm and cold MT side differences calculated from the Norm group data.

Of the 197 patients participating in the Study group, 72 (37%) had pathological and 125 (63%) normal ABBT results. The most frequent ABBT abnormality noted in 58 (29%) cases was directional preponderance, of which 44 recordings (76%) were not associated with pathological lateralization. Pathological lateralization was found in 28 (14%) patients and was not accompanied by significant directional preponderance in 14 (50%) of these cases.

Fig. 1 shows ABBT lateralization as a function of MT side difference for the warm and cold MT in the Study group. A Pearson product-moment correlation analysis indicated a strong positive correlation between ABBT

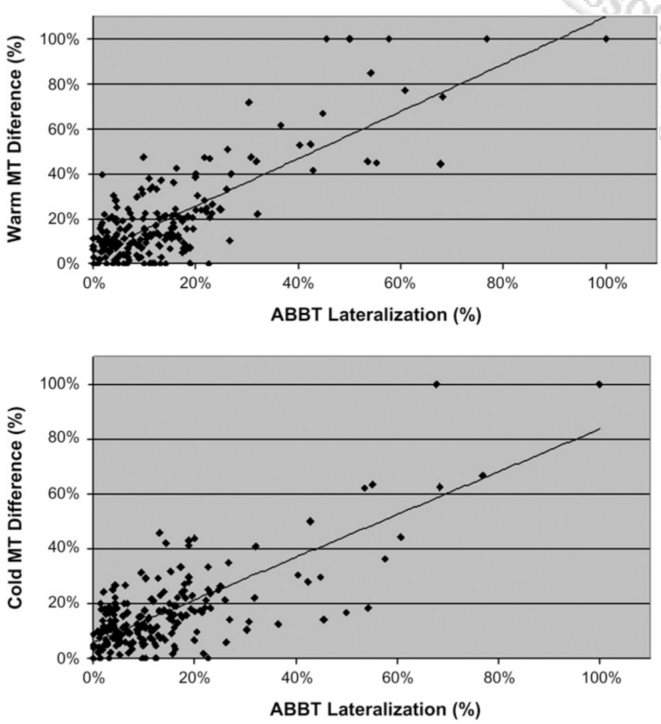

Fig. 1. ABBT lateralization as a function of the side difference for the warm and cold MT in the Study group. ABBT – alternate binaural bithermal caloric test MT - monothermal caloric test.

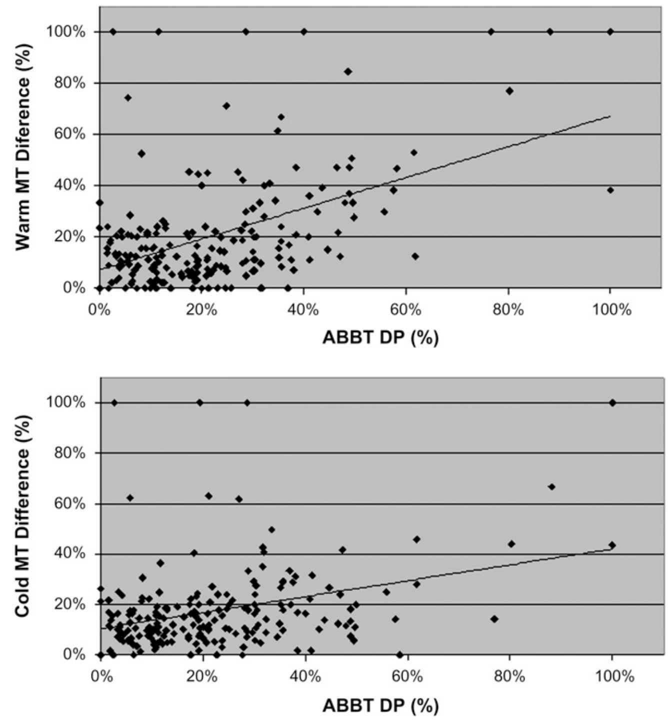

Fig. 2. ABBT DP as a function of the side difference for the warm and cold MT in the Study group. ABBT – alternate binaural bithermal caloric test. DP- directional preponderance. MT - monothermal caloric test.

lateralization and MT side difference for both the warm and cold MT (r = 0.82, $P < 0.0001$; r = 0.80, $P < 0.0001$, respectively). **Fig. 2** indicates only a moderate correlation between ABBT DP and MT warm and cold asymmetry (r = 0.49, $P < 0.001$; r = 0.33, $P < 0.005$).

The prediction of normal ABBT (lateralization < 25% and DP < 30%) by normal warm and cold MT was examined under the following conditions: 1) the whole study group was included in the analysis; 2) subjects with ENG findings of ocular motility disorders or spontaneous, positional, and positioning nystagmus were excluded from the analysis; 3) subjects with SPV values below the lower normal limits in any of the four caloric stimulations were excluded from the analysis; 4) subjects with SPV values below $11° \cdot s^{-1}$ in any of the four caloric stimulations were excluded from the analysis (3,7,8,12); 5) exclusion of subjects with ENG pathology in any of the pre-caloric tests and SPV values below the lower normal limits in any of the four caloric stimulations (conditions 2 and 3 combined); and 6) exclusion of subjects with ENG pathology in any of the pre-caloric tests and SPV values below $11° \cdot s^{-1}$ in any of the four caloric stimulations (conditions 2 and 4 combined). **Table II** details the findings of this analysis, showing that the highest sensitivity (thus lowest false negative rate) for the screening test was achieved for the warm MT when patients with ENG findings of ocular motility disorders or spontaneous, positional, and positioning nystagmus were excluded from the study. The sensitivity value of 90% (10% false negative) was associated with a specificity of 92% (8% false positive). The addition of either SPV criteria did not increase MT screening sensitivity while small

TABLE II. PREDICTION OF NORMAL ABBT RESULTS (LATERALIZATION < 25% AND DIRECTIONAL PREPONDERANCE < 30%) BY MT SCREENING.

	True Negative§ (*N*)	False Positive* (*N*)	False Negative† (*N*)	True Positive‡ (*N*)	Sensitivity (%)	Specificity (%)
Warm MT						
All Subjects	114	11	8	64	89	91
A	74	7	4	37	90	92
B	112	10	10	18	64	92
C	95	6	3	8	75	94
D	72	5	3	15	86	93
E	63	3	5	5	50	96
Cold MT						
All Subjects	120	5	33	39	54	96
A	77	4	13	28	69	95
B	118	4	18	10	36	97
C	99	2	7	3	26	98
D	75	2	13	5	29	97
E	65	1	5	5	50	98

A: Subjects with normal ENG; B: SPV > mean − 2 SD; C: SPV > $11° \cdot s^{-1}$; D: Both A and B; E: Both A and C. ENG criteria for exclusion included ocular motility disorders and spontaneous, positional, or positioning nystagmus.
ABBT - alternate binaural bithermal caloric test. MT – monothermal caloric test. ENG – electronystagmography. SPV – maximal slow phase velocity.
§ MT and ABBT normal.
* MT pathological, ABBT normal.
† MT normal, ABBT pathological.
‡ MT and ABBT pathological.

increments in specificity were observed. **Table III** summarizes the sensitivity and specificity of warm and cold MT in the prediction of normal DP ABBT. False negative rates of more than 50% were demonstrated in all examined conditions both for the warm and cold MT.

DISCUSSION

A good screening test should differentiate patients with pathology from healthy individuals with high sensitivity (or low false negative rate) and acceptable specificity (or false positive rate). The most important measure for MT screening is the false negative rate. In the context of ENG screening the specificity might be less crucial in determining the cost-effectiveness of the test because those who fail the screening would continue on the same occasion with the gold standard four caloric irrigations of the ABBT.

The best MT screening results achieved in this study were for the warm stimulation in patients having no ocular motility abnormalities or spontaneous, positional, or positioning nystagmus with a sensitivity of 90% (false negative rate of 10%) and specificity of 92% (false positive rate of 8%). Several studies have reported higher sensitivity for the warm MT, ranging from 91 to 100% (7,10,14,16). One possible explanation for the lower sensitivity found in this study is the inclusion of directional preponderance as indicating pathological ABBT in addition to unilateral weakness, a criterion that was not employed in some of the previous studies (2,10,15). While strong positive linear correlation was found between warm MT and ABBT lateralization (Fig. 1), only moderate correlation was demonstrated between MT lateralization and ABBT DP (Fig. 2). In the presence of DP the warm MT might not always indicate ABBT pathology as defined in the present study as detailed in Table III. When DP on the ABBT is associated with side lateralization, most of the time the preponderance would be directed away from the hypoactive side and warm irrigation

TABLE III. PREDICTION OF NORMAL ABBT DIRECTIONAL PREPONDERANCE RESULTS (< 30%) BY MT SCREENING.

	True Negative§ (*N*)	False Positive* (*N*)	False Negative† (*N*)	True Positive‡ (*N*)	Sensitivity (%)	Specificity (%)
Warm MT						
All Subjects	126	13	31	27	46	91
A	91	11	16	15	48	90
B	130	2	29	17	37	98
C	113	2	23	9	27	98
D	83	4	20	11	34	95
E	73	2	19	3	14	97
Cold MT						
All Subjects	128	11	46	12	20	92
A	92	8	25	8	23	92
B	127	5	41	5	12	96
C	114	1	28	3	10	99
D	84	3	28	3	10	96
E	73	1	22	1	5	99

All abbreviations and notes as in Table II.

would augment it. However, when the preponderance is toward the hypoactive side, the warm irrigation would conceal it. Also, in our study 76% of cases with DP had no abnormal lateralization. For example, we consider a case in which the responses to the warm irrigations are similar in both ears, but the response to the right cold stimulus is higher than the response to right ear warm stimulus and the response to the left cold stimulation is lower than that of the left warm response. Under these circumstances the warm MT would indicate normal response in the face of left DP. Although a recent study has suggested that the exclusion of individuals with spontaneous nystagmus would screen out most cases of directional preponderance (14), another study reported that a significant proportion of patients with directional preponderance had no spontaneous nystagmus (7). When compared to previous studies we have used a higher cut-off point for the inter-ear side difference definition of pathological warm MT (2,14,15,17). In our normal population, side difference of less than 32% was expected in 95% of individuals and the adoption of this parameter, on the condition that a low false negative rate would be found, should yield low false positive rates. Lower cut-off values for MT asymmetry, which have been employed by other investigators, were associated with higher sensitivity at the expense of lower specificity. Enticott et al. (7) used a side difference of 5% for air MT screening to yield a sensitivity of 98% and a specificity of 22%. A unilateral weakness criterion of 15% was associated with a sensitivity of 98% and a specificity of 70% (15), while a value of 10% resulted in a sensitivity of 94% and a specificity of 52% (17). A recent study using receiver operating characteristic analysis recommended the use of MT asymmetry below 15% to obtain a sensitivity of 95% with 71% specificity (14). A too-low specificity would curtail the potential benefits of the screening test as a significant number of the subjects would fail the MT and proceed to have a complete ABBT.

Our results agree with previous studies of water MT screening that have shown higher sensitivity for the warm over the cold water stimulation (7,10,14,16). It has been suggested that this higher sensitivity may be related to the production of a stronger excitatory response by the warm stimulation than the inhibitory cold water response, according to Ewald's second law (16,19). While abnormal ABBT might be found in the asymptomatic patient when central compensation of a vestibular deficit has occurred, the presence of ocular motility disorders or spontaneous, positional, or positioning nystagmus in the ENG point to an active disease that requires complete laboratory evaluation (18). This is the reason why it is acceptable to include normal findings in the pre-caloric ENG tests as a prerequisite for the conduction of MT screening (7,10,14). However, the employment of the 32% MT side difference criterion together with strict ENG parameters for MT screening candidacy only marginally lowered the false negative and false positive rates (from 11 to 10% and from 9 to 8%, respectively).

The presence of symmetrical MT response in the face of a bilateral vestibular deficit might potentially increase the false negative rate of the screening test. Several studies advocate the use of minimal SPV values of the nystagmic response as an additional condition for the performance of MT screening (7,10,14,15). We have set the Norm group calculated values of the mean SPV minus two standard deviations as the lower limit of the normal response. The exclusion of patients having SPV below these values or with the previously suggested SPV $< 11° \cdot s^{-1}$ (10,15) did not reduce the false negative rate of MT screening in this study.

The 10% false negative rate of warm MT in our patient population precludes its routine use in the clinical realm and its application as a screening tool for possible vestibular deficits in a generally healthy population like aviation or diving candidates. However, warm MT might be useful in patients who cannot tolerate the repeated caloric stimulation of ABBT. For this reason the warm stimulations should be performed first; thus MT asymmetry results may be considered in the clinical decision on further evaluation for patients who cannot complete the standard ABBT.

ACKNOWLEDGMENT

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