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The dependency of air caloric stimulus effectiveness on delivery tip characteristics

Key Words

Caloric test
Caloric stimulus
Air
Effectiveness
Speculum diameter
Air speed

Abbreviations:

RLUH: Royal Liverpool University Hospital
SPV: Slow phase velocity (of nystagmus)
VNG: Video nystagmography

Abstract

This brief study investigates the extent and origin of the apparent dependency of air delivery speculum size on the effectiveness of air used as a stimulus in the bi-thermal caloric test, using water as a reference stimulus. Eleven normal volunteers served as subjects. Six caloric stimulus delivery conditions included air with two speculum sizes, speculum only and with a rubber tube extension, and water. The resulting nystagmus was used as an index of stimulus efficiency. The effectiveness of the air stimulus was found to be dependent on the diameter of the speculum used for air delivery. The narrower speculum generated nystagmus that was typically twice that generated by the wider speculum. Users of air caloric equipment whose design includes a speculum that influences the effectiveness of the stimulus should be aware of this dependency and ensure their clinical interpretation of results is made with reference to appropriate normative data.

Sumario

Este breve estudio investigó la dimensión y el origen de la aparente dependencia del tamaño de la punta de estimulación, en la efectividad del aire que se usa como estímulo en la prueba calórica bitermica, usando agua como estímulo de referencia. Once voluntarios normales sirvieron como muestra. Seis condiciones de estimulación incluyeron aire con dos tamaños de espéculos, un espéculo aislado o con un tubo de extensión de hule, y agua. El nistagmo resultante se usó como índice de la eficiencia del estímulo. Se encontró que la efectividad del estímulo con aire es dependiente del diámetro del espéculo usado para el envío del aire. El espéculo más estrecho, generó un nistagmo que fue típicamente del doble que el generado con el espéculo más ancho. Los usuarios de equipo calórico con aire, cuyo diseño incluye un espéculo, deben estar concientes de esa dependencia y estar seguros de que sus interpretaciones clínicas de los resultados, se hagan con referencia a datos normativos apropiados.

The bi-thermal caloric test requires the temperature of the external canal of the patient's ear to be raised or lowered using a defined thermal stimulus. Guidelines published by the British Society of Audiology (BSA), (2010) suggest the following stimulus parameters:

Water irrigation: 30°C & 44°C (nominal body temperature ± 7°C) for 30 s at 500 ml/minute
Air insufflation: 24°C & 50°C (nominal body temperature ± 13°C) for 60 s at 8 litres/minute

Though not overtly stated, the inference is that these two sets of stimulus parameters give rise to broadly equivalent stimulus effectiveness in terms of the slow phase velocity (SPV) of the resulting nystagmus within the same individual.

At the Royal Liverpool University Hospital (RLUH) water is the standard stimulus used in most patients undergoing the bi-thermal caloric test. The water system conforms to BSA guidelines, whilst a recently obtained air caloric stimulator system has a fixed flow rate specified as 8.5 litres/minute and limits the maximum temperature to 48°C. Note that the manufacturer has imposed this limit in the belief that higher temperatures may be hazardous. Flow rate calibration with an air rotameter at 22°C indicated a flow rate of 10.5 litres/minute. The air stimulator (Coolstar, Difra Instrumentation, Belgium) is provided with an otoscope-type delivery head and is supplied with two sizes of otoscope specula: 4 mm and 2.5 mm. The speculum diameter did not influence the measured flow rate and there was no suggestion in the equipment user manual that speculum size might influence stimulus effectiveness.

Initial calibration checks using an artificial ear canal with a calibrated thermocouple located some 3 mm in front of the end wall (simulating the tympanic membrane) suggested that the air stimuli were on average 1°C cooler than indicated by the equipment, which monitors temperature at a point within the speculum. Following appropriate corrections to the requested temperatures the air system was put into clinical service using delivered temperatures of 24°C & 48°C. The first three patients to receive an air caloric test were adults and were therefore tested with the larger (4 mm diameter) speculum. They had normal external and middle ear anatomy and had expressed a preference for being tested with air. The caloric test results did not suggest any asymmetry (canal paresis) or directional preponderance using Jongkees' formula (Jongkees et al, 1962). However when the absolute SPV results were interpreted in the context of reference data derived from our water stimulus, all appeared to exhibit a bilateral sub-total canal paresis, i.e. caloric responses were low on both sides for both warm and cool stimuli. This prompted a pilot study to examine the efficiency of the air insufflator using the water stimulus as the reference standard.

Method and Subjects

The RLUH water caloric irrigation system employs a locally manufactured delivery tip featuring a disposable soft rubber tube of 3 mm internal diameter fitted to a handpiece designed to limit the insertion depth of the tube to 20 mm (measured from the most lateral aspect of the patient's tragus). This ensures the comfortable, non-traumatic delivery of water to the innermost third of the external canal thus minimizing the risk of an ineffective irrigation caused by trapping a pocket of air in the canal. We chose six caloric stimulus test conditions for the study:

1) Warm air using a standard 4-mm speculum
2) Warm air using a standard 2.5-mm speculum
3) Warm air using a 2.5-mm speculum modified to accept a 3-mm rubber delivery tube

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4) Cool air using a 2.5-mm speculum modified to accept a 3-mm rubber delivery tube
5) Warm water (with 3-mm rubber delivery tube)
6) Cool water (with 3-mm rubber delivery tube)

These test conditions were chosen in order to facilitate the investigation of the effect of air delivery tip diameter and insertion depth (conditions 1, 2, & 3), the warm/cool air difference for air and water (conditions 3 & 4; conditions 5 & 6), and air/water difference (conditions 3 & 5; conditions 4 & 6) on stimulus efficiency. It was assumed that any differences seen with warm air between conditions 1, 2, and 3 would be applicable to the delivery of cool air (i.e. that there would be no interaction between temperature and the physical characteristics of the delivery tip).

The air insufflation and water irrigation delivery options are illustrated in Figure 1.

The six caloric conditions were applied in a fixed order as listed above. Whilst a random or balanced order would be ideal to ensure freedom from any order effect, it would have been inappropriate to use an air stimulus in a wet canal since this would confound the effectiveness of the air stimulus because the air would evaporate the moisture in the canal and induce an unwanted cooling effect. This is the effect, sometimes referred to as caloric perversion, in which nystagmus initially beating in the 'wrong' direction is sometimes observed when warm air is used in a moist mastoid cavity or ear with a large perforation. Thus, the water irrigations in our study had to follow air insufflations. Further, there is reason to believe that there is no significant caloric order effect providing that video nystagmography (VNG) is used to record the induced nystagmus (Lightfoot, 2004). Care was taken to ensure that the speculum insertion depth into the subjects' canal was the same in conditions 1 & 2. We also included in the initial calibration check a measurement of the air flow rate with the rubber delivery tube arrangement used in conditions 3 & 4. The same flow rate of 10.5 litres/minute was recorded for both temperatures.

Subjects were 11 otologically-normal young adult volunteers (eight females, three males, mean age 27 years) with no history of balance disorder, who received the six test conditions in one ear only, chosen by subject preference. All subjects had normal middle-ear function as assessed by tympanometry. The caloric procedure complied with the BSA recommendations (1999) with nystagmus being recorded by VNG in total darkness (VNG Ulmer System, Synapsys SA, Marseille, France). No subject exhibited any nystagmus in the pre-caloric practice condition and a mental alerting regime was employed during the recording period. The time between the start of one stimulus and the start of the next was typically seven minutes (minimum 6.5 minutes). The caloric stimulus was undertaken by the same operator (GL) with meticulous attention paid to the minimization of any potential sources of error in stimulus delivery and nystagmus recording. Statistical tests were applied to log transformed data (to correct for a skewed distribution) using ANOVA with contrasts and paired two-tail t-tests with appropriate Bonferroni corrections. A criterion of $p < 0.05$ was applied for significance.

Results

The mean and standard deviation of the maximum SPV recorded in the six test conditions are detailed in Table 1 and illustrated in Figure 2. Also shown in Table 1 is the mean SPV expressed as a percentage of the SPV recorded with warm water, our reference stimulus. ANOVA with all six test conditions showed a significant effect of test condition ($p < 0.001$). ANOVA on the first three conditions (delivery geometry) was also significant ($p = 0.003$).

It is clear from Figure 2 that the effectiveness of the air stimulus with a 4-mm speculum (condition 1) was substantially lower than that with a 2.5-mm speculum (condition 2) or water (condition 5), confirming our original observation and suspicion that the low SPV recorded in the first three patients on whom the air stimulus was used was the result of an ineffective stimulus rather than vestibular hypofunction.

Next the effect of the 3-mm rubber delivery tube was examined. Comparing conditions 2 and 3 reveals that the tube is associated with a somewhat lower (21% less) efficiency than the 2.5-mm speculum alone, but this difference does not reach significance with only 11 subjects ($p = 0.56$).

Pooling conditions 3 and 4 (warm and cool air with a 2.5 mm speculum with rubber delivery tube) and conditions 5 and 6 (warm and cool water with rubber delivery tube) allowed the comparison of air and water with the same delivery arrangement. No significant difference was observed ($p = 0.28$). Inspection of Figure 2 illustrates that condition 3 (warm air) was the least efficient of the four using the 3-mm delivery tube, but this deficiency will in part be attributable to the inability of the air stimulator to deliver warm air at nominal body temperature + 13°C, as suggested in the BSA recommended procedure.

Finally is worth noting the relative efficiency of the warm and cool stimuli. With water the warm stimulus was more effective than

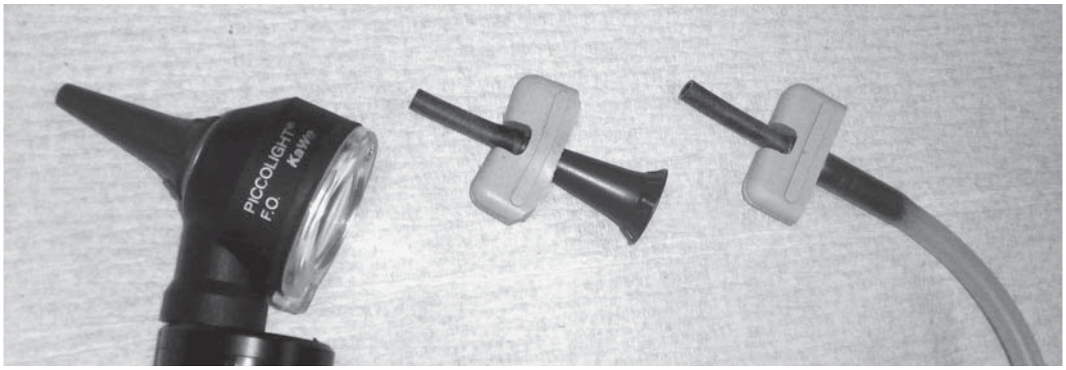

Figure 1. The different caloric delivery options used in the study. From left to right: (1) speculum alone, in position on the otoscope head (conditions 1 & 2); (2) 2.5-mm speculum with soft rubber tube and depth limiter (conditions 3 & 4); and (3) soft rubber tube with depth limiter used for water irrigations (conditions 4 & 5).

Table 1. Mean SPV (°/s) in the six test conditions. WA 4 = warm air with 4-mm speculum; WA 2.5 = warm air with 2.5-mm speculum; WA 2.5t = warm air with 2.5-mm speculum and tube; CA 2.5t = cool air with 2.5-mm speculum and tube; WWt = warm water with tube; CWt = cool water with tube.

	WA 4	*WA 2.5*	*WA 2.5t*	*CA 2.5t*	*WWt*	*CWt*
Mean SPV (°/s)	8.9	17.9	14.2	16.3	20.9	16.8
Standard deviation (°/s)	4.8	8.1	4.8	7.0	6.5	5.2
% Re: warm water	42.6	85.6	67.9	78.0	100	80.4

the cool ($p = 0.02$) whereas with air the cool stimulus was the more effective, but not significantly so ($p = 1$). Again this will in part be attributable to the limited (48°C) warm air temperature, but this medium-dependent warm-cool difference has been noted before with different equipment (Zapala et al, 2008; Lightfoot et al, 2009) and is beyond the scope of this study. Its origin has yet to be identified.

Discussion

There is a considerable literature on the air versus water debate and whilst there is a common perception that the responses to an air stimulus are probably more variable than those to a water stimulus (e.g. Zangemeister & Bock, 1980; Maes et al, 2007), some studies have shown that when an otoscope is used to carefully position the air delivery tip the two stimuli offer results of similar reproducibility (e.g. Munro & Higson, 1996), and others favour air as the stimulus providing a more reproducible response (Zapala et al, 2008). It is not the purpose of this technical report to further this debate but rather to identify our main finding: that with the equipment under study the effectiveness of air caloric stimuli is crucially dependent on the physical characteristics of the delivery tip, particularly the diameter of the speculum. This effect was unexpected, and as such, no criticism is made of the manufacturers of this stimulator. The narrower speculum generated slow phase nystagmus velocity that was typically twice that generated by the wider speculum. Delivery of the air stimulus to the innermost part of the canal did not improve effectiveness. Indeed the 3-mm delivery tube was associated with slightly less effectiveness compared to the standard 2.5-mm speculum, an effect that appears to be associated with diameter of the column of air entering the ear canal. Since the flow rate of the air caloric stimulator system was shown to be unaffected by speculum diameter, the speed of the column of air as it exits the speculum and enters the patient's canal must be influenced by speculum diameter. Assuming non-turbulent laminar flow and a rate of 10.5 litres/minute a 4-mm speculum produces an air speed of 14 m/s, whereas a 2.5 mm speculum produces an air speed of 36 m/s (129 km/hour or 80 mph). This ratio is about two and a half to one. It is therefore tempting to link the efficiency of air caloric stimulation to air delivery speed. The mechanism whereby the speed of the column of air influences stimulus effectiveness is uncertain but may be associated with mixing of air within the canal (Zangemeister & Bock, 1980). There may be areas of flow stasis (or low velocity) within the canal when the air speed is low; with higher air speed (but similar overall air flow rate), greater mixing would be expected to lead to a more uniform temperature distribution and correspondingly more efficient heat transfer.

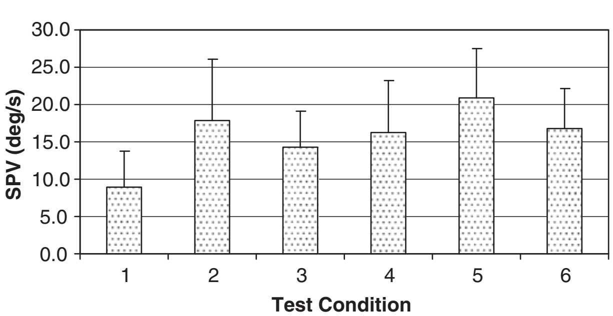

Figure 2. Mean SPV (°/s) in the six test conditions (see text).

The design of the air stimulator we investigated is such that speculum diameter will influence air speed. However this is not the case with all air insufflators; some have a fixed diameter delivery tube extending into the canal just beyond the tip of the speculum whilst others have a delivery tube only, with no speculum. We would not expect such designs to exhibit a stimulus effectiveness dependency on speculum size.

It is important that manufacturers and users of air caloric stimulators are aware of the possible dependency of caloric stimulus effectiveness on speculum diameter/air speed, and ensure that normative data accounting for this effect is collected and used. National and local protocols for the caloric test should acknowledge this effect. One simple solution for the air system under study is to use only the narrower speculum regardless of ear canal size.

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