



## **Recommended Procedure**

### **Tympanometry**

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## General foreword

This document presents a Recommended Procedure by the British Society of Audiology (BSA). A Recommended Procedure provides a reference standard for the conduct of an audiological intervention that represents, to the best knowledge of the BSA, the evidence-base and consensus on good practice given the stated methodology and scope of the document and at the time of publication.

Although care has been taken in preparing this information, the BSA does not and cannot guarantee the interpretation and application of it. The BSA cannot be held responsible for any errors or omissions, and the BSA accepts no liability whatsoever for any loss or damage howsoever arising. This document supersedes any previous recommended procedure on tympanometry by the BSA and stands until superseded or withdrawn by the BSA.

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## 2. Introduction

This document combines and revises recommendations made previously by the British Society of Audiology (BSA, 1992) and the Newborn Hearing Screening Programme Clinical Group (2008); see Appendix A for details. Its purpose is to describe recommended procedures for conducting tympanometry as a means of analysing middle-ear function for subjects of all ages, from birth to adulthood. The recommendations are deemed suitable for routine clinical measurements applicable to most types of instruments measuring aural acoustic impedance/admittance using a nominal probe frequency of 226 Hz for subjects whose corrected age is equal to or greater than 6 months (i.e. at least 6 months from the child's due date), and 1000 Hz for subjects below 6 months corrected age. (Recommendations regarding acoustic reflex testing will now be provided in a separate document.) Basic guidance is also provided on test precautions and interpretation. However, it is essential that the competent person carrying out the test (i.e. the 'tester'), or responsible for it, uses his/her professional judgement when deciding on the particular approach to be used with each 'subject' (i.e. the person who is being tested), given the specific circumstances and the purposes of the test, and the tester's level of competency.

Unless stated otherwise, the procedure described here represents the status of the current evidence base, taking into account other factors that influence desirable procedure, as interpreted by the Professional Practice Committee of the BSA in consultation with its stakeholders (see Appendix A). The document was developed in accordance with BSA (2003).

Definitions of terms and units used in this document are found in Appendices B and C. The term 'shall' is used in this document to refer to essential practice, and 'should' is used to refer to desirable practice. Where '6 months' age is referred to in this document, this is 6 months corrected age.

## 3. General considerations

Acoustic reflex measurements and Eustachian tube function testing are beyond the scope of this document and will be addressed in separate documents. Also, the use of high-frequency tympanometry in subjects over six months old is outside the scope of this document.

The examiner shall adopt procedures relating to hygiene and infection control as described by relevant local policies, considering, at least, hand-cleaning prior to and after examination, the covering of breaks in the skin, the avoidance of direct contact with bodily fluids and the cleaning or disposal of tips. The same tip shall not be used for different subjects unless it has been appropriately cleaned (see previous statement). Single use disposable tips should be used if available. The same tip shall not be used for each ear of a subject where there is a risk of transferring an infection between the ears<sup>1</sup>.

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<sup>1</sup> As judged by the examiner. For example, on the basis of examination of the first ear, the subject's symptoms or medical history or advice provided by another (e.g. medical) professional. If the examiner is in doubt, he/she shall seek advice or use a separate tip for each ear.

## 4. Equipment

The tympanometer and probe tip shall be clean (i.e. free from dust and dirt and in compliance with local infection control standards). Tympanometers shall meet the performance and calibration requirements of BS EN 60645–5.

There are two main types of probe tip shapes used: umbrella and mushroom. In most cases, the mushroom shape is preferable, particularly when inserting the probe tip into the ear canal and not holding it in place because the umbrella shape may buckle in such instances. In all cases it is essential to select the correct tip size to ensure that testing is not uncomfortable for the test subject and that an adequate seal is maintained. When holding the probe tip in position, for example when performing screening tympanometry on a young child, an umbrella shape tip that covers the entrance of the ear canal may be preferable.

## 5. Calibration

The calibration of the instrument shall be checked daily with the probe fitted to an appropriate cavity such as the one supplied by the manufacturer. The performance of the instrument shall also be checked on an ear known to produce a normal, peaked tympanogram (e.g. to ensure the pump is operational and its tube is not blocked).

Test cavities must have dimensions which are small compared to the wavelength of sound at 226 Hz; metal or hard plastic cylinders with a ratio of length to diameter of between one and three and volumes in the range 0.5 to 5.0 cm<sup>3</sup> are recommended. A calibration check in the test cavity should produce a horizontal line, and the volume measured must be within the tolerance levels specified by the manufacturer.

If the line is not horizontal (i.e. it slopes upwards with decreasing pressure) this may indicate a leak in the test cavity or the probe, or the probe may not have been inserted into the test cavity correctly. Correct insertion of the probe should be verified and the calibration check repeated, using a different cavity if necessary. If it is not possible to obtain a horizontal line the equipment may be out of calibration. The exception to this is the 5.0 cm<sup>3</sup> cavity, in which it is normal to obtain an upward sloping line with decreasing pressure. This occurs because the susceptance component of admittance increases with decreasing pressure, which is more noticeable when larger volumes of air are measured.

It should be noted that many manufacturers specify a 5 % tolerance for cavity volume. Based on this, suggested acceptable<sup>2</sup> values for cavity volume are as follows:

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<sup>2</sup> Most tympanometers only measure volume to one decimal place. It therefore follows that the 0.5 cm<sup>3</sup> must give a volume of exactly 0.5 cm<sup>3</sup> because a reading of 0.4 cm<sup>3</sup> or 0.6 cm<sup>3</sup> could be out of calibration by as much as 20%. Where two decimal places are displayed, a range of 0.48–0.52 cm<sup>3</sup> is acceptable.

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<b>Cavity</b>	<b>Acceptable value</b>
0.5 cm <sup>3</sup>	0.5 cm <sup>3</sup>
2.0 cm <sup>3</sup>	1.9–2.1 cm <sup>3</sup>
5.0 cm <sup>3</sup>	4.8–5.2 cm <sup>3</sup>

These are given as guides; in all cases calibration shall be conducted according to the manufacturers' manuals and BS EN 60645–5.

Where 1000-Hz probe tones are to be used, a high-frequency test cavity provided by the manufacturer shall be used. This test cavity is not sealed, so volume is not measured. A measurement of admittance should be taken at 0 daPa and compared to the specifications of the manufacturer.

A more detailed examination and laboratory test of all functions should be made every six months, and shall be made no less than once per year in accordance with BS EN 60645–5. Equipment found to be out of calibration shall not be used to test patients.

## 6. Subject preparation

Before examination, the subject (or the person responsible for the subject) should be asked if he/she currently has any ear-related symptoms (including discomfort, pain and discharge), is currently being treated for any ear-related problems or has previously had surgery involving the ears. Any symptoms, or other relevant issues, should be explored through questioning as appropriate.

The subject should be seated comfortably and should remain as still as possible during the test. Young children may need to be held by an appropriate adult, which should be the person responsible for the child. For example, the child could be seated sideways on the adult's lap, with the child's hands secured by one hand and the child's head held against the chest with the other hand. In older children and adults, an instruction to remain still will usually suffice. Any objects that may interfere with insertion of the probe (e.g. a hearing aid) should be removed.

Tympanometry shall be preceded by otoscopic examination (see BSA, 2010) to ensure that there are no contraindications to continue. Testing shall proceed only with informed consent (e.g. verbally) from the subject or person responsible for the subject and if it is the judgement of the tester that it is safe to do so. In the context of tympanometry, otoscopy in neonates is only intended as a general inspection of the outer ear for obvious signs of disease, blockage or malformation. Care shall be taken not to insert the speculum deep into the ear canal of young babies.

## 6.1 Considerations for testing

This section is intended as a guide when considering whether it is safe and appropriate to proceed with tympanometry. It is not exhaustive, nor is it intended to be prescriptive, and allows for discretion of sufficiently competent testers.

- Patients under general anaesthetic may have a positive peak pressure above 200 daPa due to an artefact produced by the anaesthetic gasses. Testing can proceed and this should be taken into account when interpreting.
- Outer ear defects such as complete stenosis or atresia. It may be more comfortable for the patient, and more effective when testing, to hold an umbrella-type probe in position.
- Otorrhoea contraindicates tympanometry in all cases
- Acute otitis media
  - Where a red and bulging tympanic membrane is observed during otoscopy, tympanometry is contraindicated
- Tenderness/ soreness in the ear and otitis externa
  - If possible, testing should commence with the healthy ear, so that the patient is better able to judge whether they are happy for the “sore” ear to be tested
  - If it is deemed that it would be of clinical value to perform tympanometry, this shall only proceed with the express consent of the subject and the subject must know how to signal that the test should be aborted if they experience discomfort
- Presence of foreign body in the ear canal
  - It can sometimes be desirable and appropriate to conduct tympanometry in the presence of a grommet that has or may have extruded, although testing should proceed with caution. Otherwise, foreign bodies (e.g. insects, cotton bud tips or peas) shall be removed prior to tympanometry by a person qualified and competent to do so in order to ensure that no damage to the outer ear or eardrum is caused.
- Excessive wax
  - Testing is contraindicated where there is a risk that insertion of the probe tip may push against impacted wax, risking damaging the eardrum
  - Soft wax in the cartilaginous portion of the ear canal can damage the tympanometry probe
  - Wax may be removed prior to tympanometry by someone who is qualified and competent to do so

- Although it can be useful to undertake tympanometry in an ear where the view of the tympanic membrane is obscured by wax (i.e. to see if there is any tympanic membrane mobility or a possibility of a perforation), this shall only be performed when someone is sufficiently qualified, competent and experienced to make a judgement that it is safe and appropriate to proceed. In such cases it is advisable to use an over-sized umbrella-type probe tip and hold it in position
- Previous ear surgery
  - There is no agreed standard on when it is safe to conduct tympanometry post ear surgery. If in doubt with a particular subject, medical advice shall be sought before testing
  - Testing shall only be performed given medical advice that it is safe to proceed following ossicular surgery (e.g. stapedectomy, stapedotomy) or reconstruction of the eardrum (e.g. tympanoplasty, myringoplasty)
  - Tympanometry shall not be carried out within 2 months of ear surgery unless formally approved (and documented) by the subject's medical ear nose and throat (ENT) specialist

## 6.2 Subject instructions

The tester shall adopt an effective communication strategy with the subject (or his/her representative) throughout testing. This must take account of the subject's age, hearing, language skills and any other possible communication difficulties.

The examiner shall explain, and where necessary demonstrate, the procedure to the subject and/or person responsible for the subject. Where possible, the subject should be instructed to report immediately any discomfort or pain experienced during the test. Informed consent shall then be obtained (e.g. verbally) from the subject or person responsible for the subject.

The tester shall inform the subject that the test can be discontinued at any point, such as if he/she becomes uncomfortable, and how to signal any discomfort to the tester (e.g. by raising their hand or saying "stop"). The following instructions or equivalent should be used and it is helpful to show the subject the probe whilst giving the instructions:

"I will insert a probe into the opening of your ear canal. The probe has a soft tip to seal the ear. You will feel some pressure in your ear for a few seconds while I measure the function of your middle ear. This test is automatic and I do not require you to do anything, but please avoid any unnecessary movement and avoid speaking or swallowing after the probe has been inserted. Should you find the procedure painful and want me to stop, please indicate this by either saying "stop" or by raising your hand."



Although outside the scope of this Recommended Procedure, if acoustic reflex tests are to be performed automatically immediately following the tympanometry then this should be included in the instructions given to the subject to ensure that the probe remains in position until the acoustic reflex tests are completed.

## 7. Test procedure

### 7.1 Subjects with a corrected age over 6 months using a 226-Hz probe tone

Fit a clean tip of suitable size and shape<sup>3</sup> to the probe and straighten the ear canal by gently pulling the pinna<sup>4</sup>. Point the probe in the direction of the tympanic membrane to avoid the risk of occluding the probe aperture, for example against the wall of the canal.

Insertion of the probe to obtain an airtight seal is sometimes difficult, especially for an inexperienced operator. If difficulties arise, the position or size of the probe tip should be changed. Care shall be taken not to apply extra pressure or insert the tip too deep into the ear canal. It is sometimes helpful to apply a smear of white petroleum jelly to the tip (taking care not to block its aperture), particularly if the entrance to the ear canal is hairy. This may, however, lead to the probe slipping out of the ear when positive pressure is applied. Once inserted, the probe should not be held in place as this can be a source of artefacts. If correctly inserted, the probe will usually stay in position on its own. If the probe is not supported by the tester during the test, it should be ensured that the probe cable is appropriately positioned and supported so that it does not pull on the probe causing it to move during the test. When it is not possible to obtain an adequate fit, for example with young children or where the anatomy of the outer ear makes this difficult, it is acceptable to hold the probe in position, however care shall be taken that the trace is free from artefacts and repeated if necessary to obtain a clear trace.

A slow rate of change of pressure ( $50 \text{ daPa s}^{-1}$  or less) should be used but with young children it may be beneficial to use a faster sweep, sacrificing some accuracy for speed of operation. In the absence of other requirements, tracking should commence at  $+200 \text{ daPa}$  and end once the peak, if it exists, has been clearly recorded (see Appendix D for effects of speed and direction of pressure change). On automatic systems a lower limit of about  $-300 \text{ daPa}$ , depending on instrument, should normally be selected but occasionally it may be necessary to go to  $-600 \text{ daPa}$  in search of a peak. In cases of normal tympanograms, tracking should stop at  $-200 \text{ daPa}$  for adults and  $-300 \text{ daPa}$  for children to minimise discomfort.

When testing adults and children on the same equipment, all test parameters shall be checked and set appropriately prior to testing.

<sup>3</sup> See section 4

<sup>4</sup> The most effective manipulation of the pinna varies between subjects, particularly between adults (where manipulation is typically upwards and backwards) and young children (where manipulation is typically backwards and sometimes also downwards).

If an unexpected result is obtained the test shall be repeated in its entirety, that is, by removing the probe, inspecting the ear, checking the probe to ensure it is not blocked, for example with wax, and re-testing. Unexpected results shall not be accepted without verifying that they are repeatable and running a calibration check of the probe in the test cavity and performing biologic calibration.

After tympanometry has been completed the probe tip shall be removed and all contaminated tips shall be disposed of or cleaned as per local policy.

## 7.2 Subjects with a corrected age under 6 months using a 1000-Hz probe tone

Fit a clean tip of suitable size and shape to the probe and straighten the ear canal (e.g. by gently pulling the pinna downwards and outwards). Point the probe in the direction of the tympanic membrane to avoid the risk of sealing the tip against the wall of the canal. Movement of the infant and crying can result in a false peak in the tympanogram. The baby does not need to be asleep but should definitely be resting quietly during the test.

The direction of pressure change should be from positive to negative and the range should be at least from +200 daPa to -400daPa (and preferably -600daPa). A fast screening mode speed of up to 600daPa s<sup>-1</sup> should be used.

The recommended classification system is that of Baldwin (2006), adapted from Marchant et al (1986). Admittance is used in this scheme and one should check that the equipment is set to measure this.

Traces should usually be repeated, if possible, to check that the result is repeatable and not due to artefacts such as baby movement. It is especially important to retest any ear with an abnormal or difficult-to-interpret tympanogram.

After tympanometry has been completed the probe tip shall be removed and all contaminated tips shall be disposed of or cleaned as per local policy.

## 8. Results and reporting

The following is offered as a guide. Full interpretation of results is beyond the scope of this document.

Tympanometric results do not identify pathology uniquely and should be interpreted in the context of other information from the complete test battery being conducted and with particular regard to the otoscopic findings and history.

Where spurious results or artefacts are suspected, the test should be repeated and the probe tip should be inspected to ensure it is not blocked, for example by wax. These include flat traces, traces with more than one peak, changes in ear-canal volume during testing, noisy traces and ear-canal volumes that are significantly higher or lower than expected.

## 8.1 Subjects with a corrected age over 6 months using a 226-Hz probe tone

See Figure 1 below for an illustration of a normal adult tympanogram.

### 8.1.1 Tympanometric shape

The trace should have a single sharp peak, as in Figure 1. Double peaks may be seen when there is scarring on the eardrum, but should be repeated to exclude artefacts. Rounded or wide peaks should also be repeated. The tympanometric width (width at 50 % height) may be used as a descriptor, in which case a value of less than 200 daPa may be considered normal for children between 1 and 7 years of age (Nozza et al, 1994).

### 8.1.2 Tympanic peak pressure and middle ear pressure

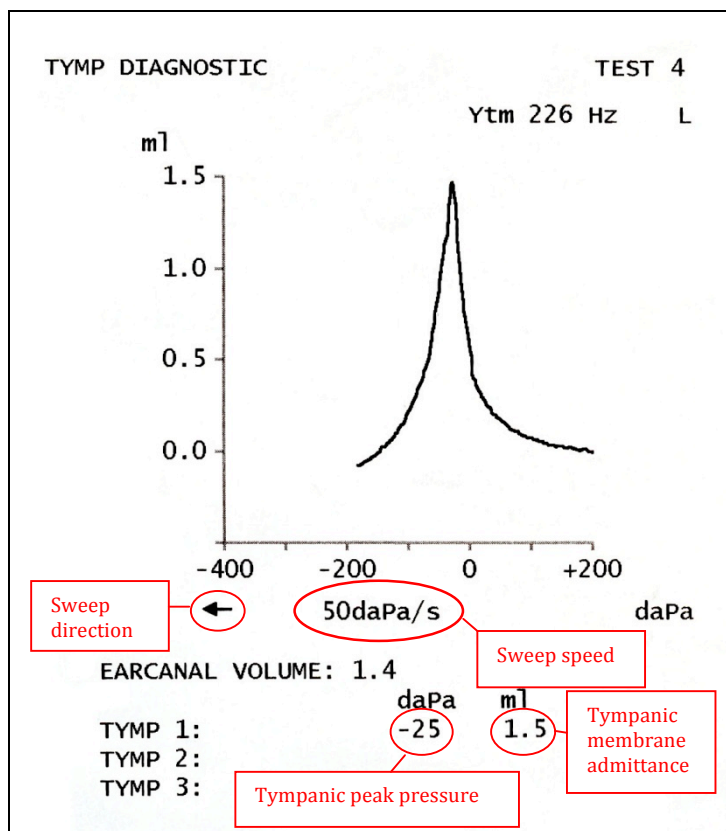
Tympanic peak pressure is the value on the horizontal axis of the tympanogram at which the peak occurs. This is used to estimate the middle-ear pressure, see Appendix D. Normal middle-ear pressure has a mean value of zero. Under carefully controlled conditions the 95 % range in normal subjects is  $-20$  to  $+20$  daPa, though pressures from  $-50$  to  $+50$  daPa can be considered normal in adults; pressures down to  $-100$  daPa may be of little clinical significance in isolation. Children often have slightly low middle-ear pressures; pressures down to  $-200$  daPa may have little clinical significance.

### 8.1.3 Admittance or compliance

Admittance or compliance is the quantity on the vertical axis. Middle-ear admittance or compliance is the peak value of admittance or compliance, assuming that the contribution of the ear canal has been removed (sometimes referred to as 'corrected' or 'compensated') as is usually the case by default. Middle-ear admittance or compliance is normally in the range  $0.3$  to  $1.6$   $\text{cm}^3$  in adults;  $0.2$   $\text{cm}^3$  is acceptable as the lower limit in children aged under 6 years but over 6 months. Note that the units ml,  $\text{cm}^3$  and mmho are interchangeable when using a 226-Hz probe tone.

### 8.1.4 Ear-canal volume

The acoustic properties of the ear canal (from probe tip to tympanic membrane) are necessarily involved in tympanometric measurements (see definition of equivalent volume, Appendix B). At 226 Hz, the canal contributes an admittance (or compliance), which for practical purposes may be added arithmetically to the admittance presented by the middle ear as seen from the tympanic membrane. The canal and middle-ear components are distinguished by applying air pressure in tympanometry. Should the tip of the probe be occluded, for example by the wall of the canal, a seemingly small canal volume will be indicated, whereas an open perforation will add the middle-ear volume to that of the canal so giving an abnormally large result. Probe occlusion and an open perforation will both be accompanied by a flat tympanogram. Typical values for ear-canal volume (ECV) are between  $0.6$ – $1.5$   $\text{cm}^3$  for adults and  $0.4$ – $1.0$   $\text{cm}^3$  for children.



**Figure 1**

*Example of a normal tympanogram from an adult left ear.*

### 8.1.5 Reporting results

The report should include the measurements obtained for middle-ear pressure, admittance or compliance, and ECV. Ear-canal volume is particularly important where a flat trace is seen in order to identify a possible open perforation and exclude blockage or incorrect placement of the probe (i.e. against the wall of the ear canal). The shape of the tympanogram should also be described and simple descriptions such as 'normal', 'rounded', 'flat', 'wide' or 'W-shaped' are acceptable (Feldman 1975). In the case of rounded or wide traces, a tympanometric width measurement may also be included for subjects aged between 1 and 7 years.

The use of classification systems (Jerger, 1970; Jerger et al, 1972) of tympanograms according to their shape is not recommended since this can lead to confusion or mistakes, and it is also possible that not all parties receiving a copy of the report will be familiar with the classification system used.

A copy of the tympanogram shall be included with the report and may form the main part of it, but it is advisable to include numerical values of middle-ear pressure and admittance or compliance, especially if the record charts are

printed with multiple scales. If the tympanogram is flat, or nearly flat, middle-ear pressure may be reported as 'indeterminate'.

Report forms should include normal values as an aid to interpretation.

For more detail and normative data references, the reader is referred to American Speech-Language-Hearing Association (1988).

## 8.2 Subjects with a corrected age under 6 months using a 1000-Hz probe tone

The value of ear canal volume should be disregarded when high-frequency probe tones are used because it will not be precise<sup>5</sup>. The exception is for use as an indicator of a possible blockage (i.e. very small volume given), although this should be verified (e.g. otoscopy or checking the probe).

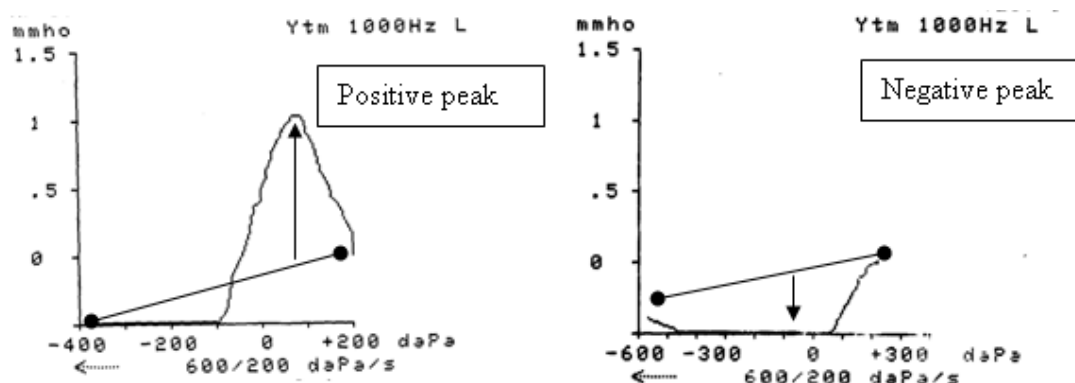
It is recommended that the traces recorded are classified as normal or abnormal using a classification system reported by Baldwin (2006; adapted from Marchant et al 1986); see Figure 2:

- Draw a baseline on the trace at pressure extremes (–400/–600 to +200 daPa); if the trace disappears below the x axis, the baseline should be drawn to the x axis, as shown in Figure 2
- Identify the main peak which can occur at any middle-ear pressure
- Draw a vertical line from the baseline to the peak of the trace
- If the peak is above the baseline it is a positive peak and normal
- If the peak is below the baseline it is a negative peak and abnormal
- If there is a positive and negative peak the trace should be classified as positive (i.e. normal)
- A positive peak at a positive or negative middle-ear pressure is classified as normal, whereas a flat or “trough-shaped” i.e. negative peak is abnormal

If the conditions are good and the outcome is clear, repetition is not always necessary to draw a conclusion. However traces should usually be repeated if possible to check for reliability. Repeated traces should be classified in the same category of positive or negative. If the outcome is not clear the trace should always be repeated.

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<sup>5</sup> Both ear canal volume and middle ear pressure should be disregarded when using a 1-kHz probe tone. At 226 Hz, mmho and cm<sup>3</sup> are interchangeable; however, this is not the case at higher frequencies where it is not possible to accurately calculate cavity volumes. Without an accurate measure of volume it is not possible to calculate pressure, since pressure = density/volume.



**Figure 2**

Examples of a positive and negative peak (adapted from a method used by Marchant et al, 1986).

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## Appendix A. Authors and acknowledgements

The document on which the current recommendations for high-frequency tympanometry were based was written by Margaret Baldwin (editor), Graham Sutton, Judy Gravel and Rob Low; it was approved by the NHS Newborn Hearing Screening Programme (NHSP) Clinical Group (2008). The ongoing review of that document was handed over to BSA in 2011 and has been incorporated into the BSA Recommended Procedure for tympanometry. The combined document was revised and processed by the Professional Practice Committee in collaboration with Margaret Baldwin between May 2011 and July 2013. The Committee thanks all involved with previous versions of this document and all who contributed to this review, including the consultation (summer 2012). An electronic copy of the anonymised comments received during this consultation, and the responses to these by the authors, is available from BSA on request.

## Appendix B. Definitions

**Acoustic admittance.** The reciprocal of acoustic impedance. The three components of admittance are conductance, positive susceptance and negative susceptance.

Note on acoustic admittance: Most existing aural acoustic impedance/admittance instruments present the result as admittance or compliance expressed as an equivalent air volume, which is acceptable at 226 Hz.

**Acoustic compliance.** The ratio of volume displacement to acoustic pressure at a surface.

Notes on acoustic compliance:

Acoustic compliance is the acoustic analogue of electrical capacitance. It is the fundamental property of an idealised acoustic element whose movement in response to sound is determined solely by its elastic (spring-like) properties.

At low frequencies the middle ear behaves for practical purposes as a pure compliance and in tympanometry (at 226 Hz) the compliance presented to the probe may be taken as the sum of the middle-ear compliance and the compliance of the air in the ear canal. The compliance of the middle ear is a measure of its 'mobility' at low frequencies. A probe frequency of 1000 Hz is used for babies because the impedance/admittance of their ears is mass-dominated.

The acoustic admittance associated with pure compliance is directly proportional to the compliance and to the frequency of the sound.

**Acoustic impedance.** The opposition to the flow of sound through a surface. Acoustic impedance has three components: resistance, negative reactance (relating to the mass of the system) and positive reactance (relating to the stiffness of the system).

**Corrected Age.** Used to describe the age of children under 2 years old who were born preterm and represents the age of the child from their expected date of birth. For example, a 36-week-old who was born at 28 weeks gestation (i.e. 12 weeks early) has a corrected age of 24 weeks.

**Equivalent volume.** The volume of an air-filled cavity having the same acoustic admittance (or impedance, compliance etc) as that of the component or system which it represents. One implication of this is that ear canal volume is not measured directly but inferred from the measurement of admittance.

**Middle-ear admittance or compliance.** (Also known as: peak compensated static acoustic admittance, 200 Y<sub>tm</sub>.) In tympanometry, the difference between peak admittance/compliance and admittance/compliance measured at a reference pressure sufficient to effectively eliminate the influence of the middle ear.



Notes on middle-ear admittance/compliance:

The reference pressure is normally a positive pressure of 200 daPa. At this pressure the indicated admittance or compliance is that of the air-filled space within the ear canal between the tip of the probe and the tympanic membrane. Tympanometry should normally commence at the reference pressure.

The measured value of middle ear admittance or compliance may depend on the rate and the direction of the pressure change during tympanometry and also on the time for which a constant pressure (the reference pressure) was applied.

**Middle-ear pressure.** Static pressure in the middle ear relative to ambient atmospheric pressure. This is estimated from the tympanic peak pressure. See Appendix D.

**Peak admittance or compliance.** In tympanometry, the maximum admittance/compliance; the height of the peak of the tympanogram.

**Probe.** A coupling device to the external ear canal connecting the tympanometer to the ear.

**Tympanogram.** A graph of acoustic impedance/ admittance (or of a related quantity such as compliance) as a function of air pressure in the external ear.

**Tympanic peak pressure.** This is the ear canal pressure at which the peak of the tympanogram occurs and is used to estimate middle ear pressure. See Appendix D.

**Tympanometric width.** Calculated by measuring the width of the tympanogram curve at 50% of its height. A value of less than 200 daPa may be considered normal for children between 1 and 7 years of age (Nozza et al, 1994). Tympanometric width is sometimes also referred to as Tympanometric Gradient although these are not necessarily the same thing and more often than not aren't. The gradient describes the steepness of the tympanogram peak close to that peak (Fowler and Shanks 2002). Different manufacturers may use different algorithms to derive this so use of the tympanometric width may be more consistent and reliable.

**Tympanometry.** The measurement of acoustic impedance/ admittance (or of related quantities such as compliance) as a function of air pressure in the external ear.

Note on tympanometry: the terms impedance/ admittance audiometry, acoustic admittance and immittance audiometry are depreciated.

## Appendix C. Units

**Table 1**

*Comparison of units and those recommended for tympanometry.*

Quantity	Absolute unit (SI)	Traditional unit	Recommended unit
Acoustic impedance	Pa s m <sup>-3</sup>	ohm (cgs)	cm <sup>3</sup> equiv. vol.
Acoustic admittance	m <sup>3</sup> Pa <sup>-1</sup> s <sup>-1</sup>	mho (cgs)	cm <sup>3</sup> equiv. vol.
Acoustic compliance	m <sup>3</sup> Pa <sup>-1</sup>	cm <sup>3</sup> equiv. vol.	cm <sup>3</sup> equiv. vol.
Relative air pressure	Pa	mm water	daPa

Notes on units:

At 226 Hz the acoustic admittance of a 1 cm<sup>3</sup> air-filled cavity is 1.0 x 10<sup>-8</sup> m<sup>3</sup> Pa<sup>-1</sup> (1.0 mmho, cgs) at standard atmospheric pressure (1.013 x 10<sup>5</sup> Pa). This is not true at 1000 Hz, so cm<sup>3</sup> equiv vol. should not be used at this frequency; rather, use mmho.

A pressure of 1 mm water is equivalent to 0.98 daPa.

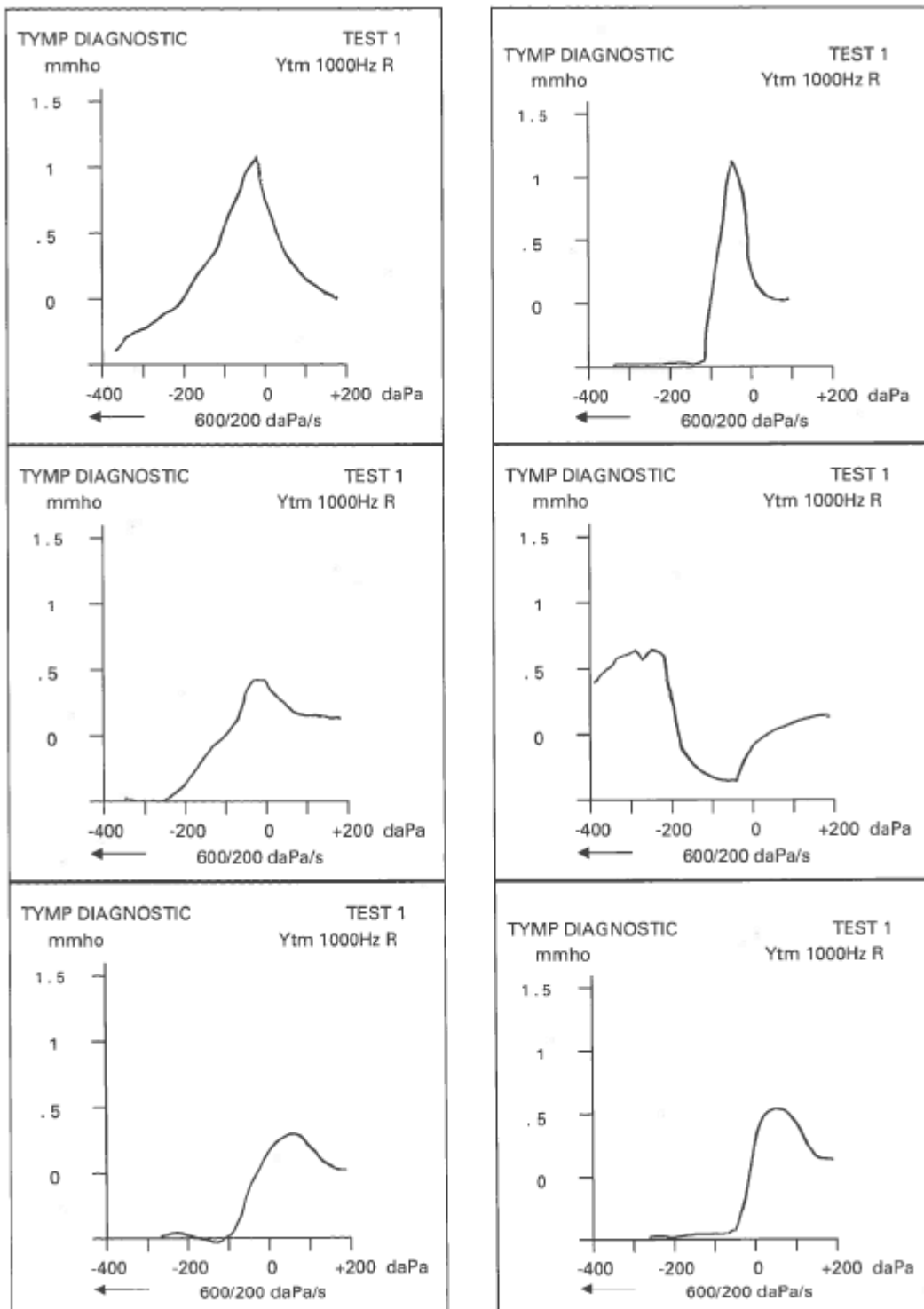
## Appendix D. Effects of sweep speed and direction

Tympanometry overestimates ear canal volume by as much as 24–39 % (Margolis and Smith, 1977; Moller, 1965; Rabinowitz, 1981; Shanks et al, 1988; Vanpeperstraete et al, 1979). Using descending sweeps and slower sweep speeds minimises this effect.

Tympanogram peak pressure can overestimate middle ear pressure by 30–70 daPa, particularly with small middle ear volumes or hypermobile tympanic membranes (Eliachar and Northern, 1974; Flisberg et al, 1963; Renvall and Holmquist, 1976), and when higher sweep speeds are used.

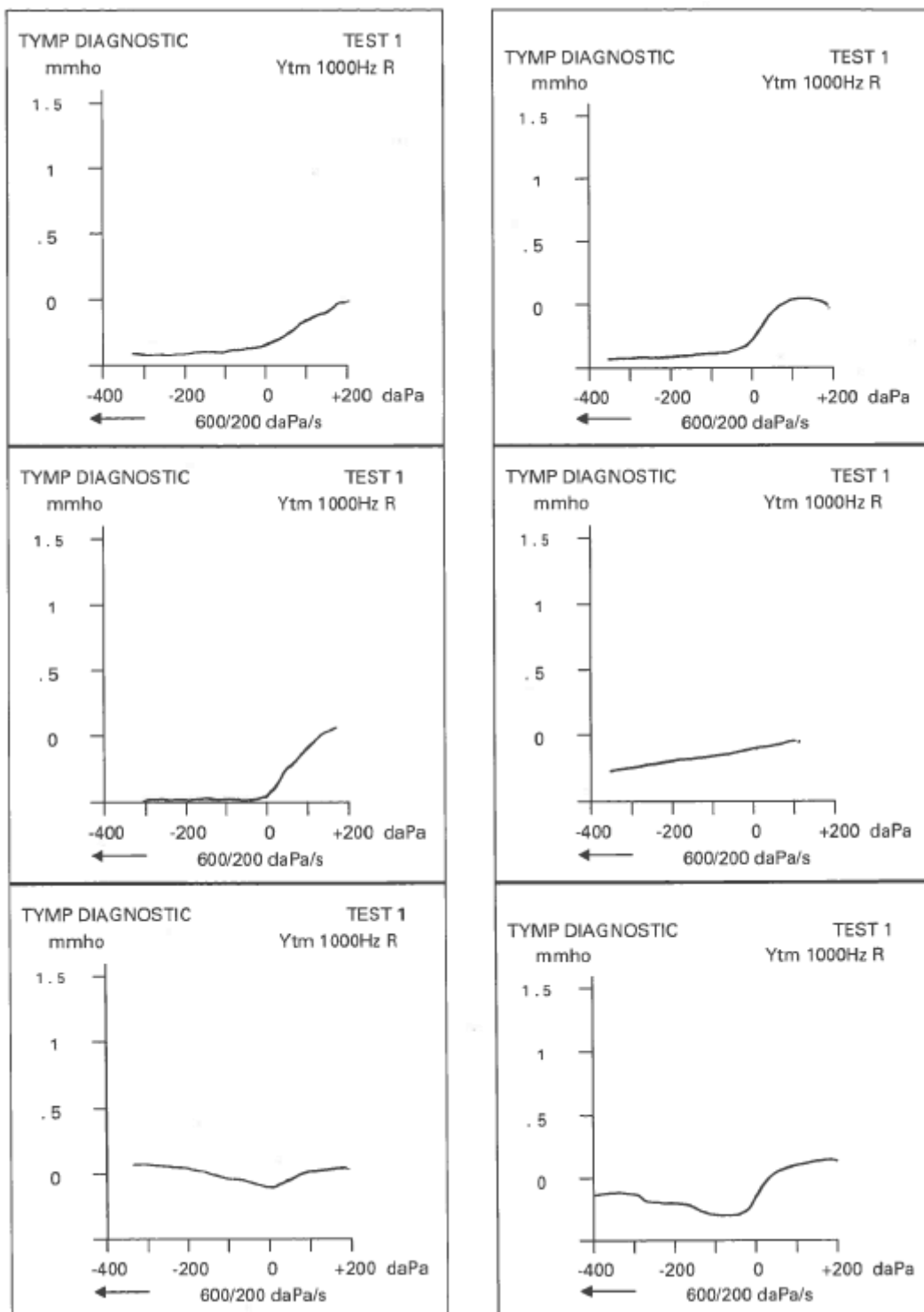
Hysteresis is the term for the displacement of the pressure peak in the direction of the sweep, and is greater at higher sweep speeds.

## Appendix E. Examples of 1000-Hz tympanometry traces



**Figure 3**

Examples of 1000-Hz tympanograms classified as 'normal'.



**Figure 4**

Examples of 1000-Hz tympanograms classified as 'abnormal'.