Impedance measurements: Some recent developments

By Joselen Ransome (London)

Impedance measurements constitute one of the most remarkable advances in audiometry in the last two decades, and new applications are constantly being developed.

I. Importance of impedance audiometry

(1) With a modern impedance bridge and X–Y recorder, it is possible to obtain a great deal of information, not only on the nature of conductive lesions, but also on the site of sensorineural lesions. It is even possible now, using a white noise stimulus, to obtain an estimate of the pure tone hearing threshold, and since this is not only an objective test, but also a very simple one, it is potentially of great value.

(2) It is possible to obtain all this information, in a matter of a few minutes, using one compact piece of equipment costing considerably less than that required for electric response audiometry.

(3) All the tests are 'objective' in so far as the patient is not required to signal perception of the stimulus. The tests thus constitute a formidable section of the battery of 'objective' tests. However, as with most other forms of clinical measurements, the clinician must interpret the results in conjunction with other data.

(4) All the tests are non-invasive.

II. Essentials of impedance audiometry

When sound energy falls on the normal tympanic membrane, most of it is absorbed causing the membrane and ossicular chain to vibrate (as indicated by the arrows to the right (Fig. 1)), but a small percentage is reflected or impeded (as indicated by the arrow to the left). In impedance audiometry it is this impeded sound which is measured, whereas in *all* other forms of audiometry, it is the sound energy absorbed by the ear and converted into nerve impulses which is measured.

The essentials of an impedance bridge are shown in Figure 2.

The percentage of sound impeded increases if the middle-ear transformer mechanism becomes stiffer: (a) by varying the ear canal pressure, which is the basis of tympanometry; (b) by stimulating the stapedius

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muscle to contract, using a sound of critical loudness, i.e. eliciting the stapedial or acoustic reflex. (Note: in this paper the terms 'stapedial reflex' and 'acoustic reflex' are used synonymously.) The increase in impedance so produced can be measured, using the now well-known 3-tube probe (see Fig. 2) connected to the impedance bridge: the probe is sealed into the ear canal, and a test tone enters the closed cavity so formed via the first tube. The sound pressure level in this cavity will be constant as long as the physical state of the cavity remains constant. But if the stapedius contracts, or the tympanic membrane is stretched by varying the pressure in the canal via the second tube, the impedance will increase

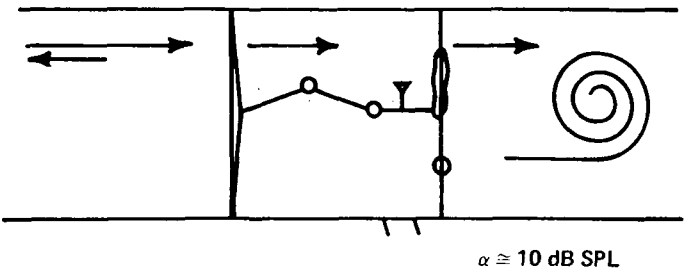


FIG. 1.
(Reproduced by permission of Madsen Electronics)

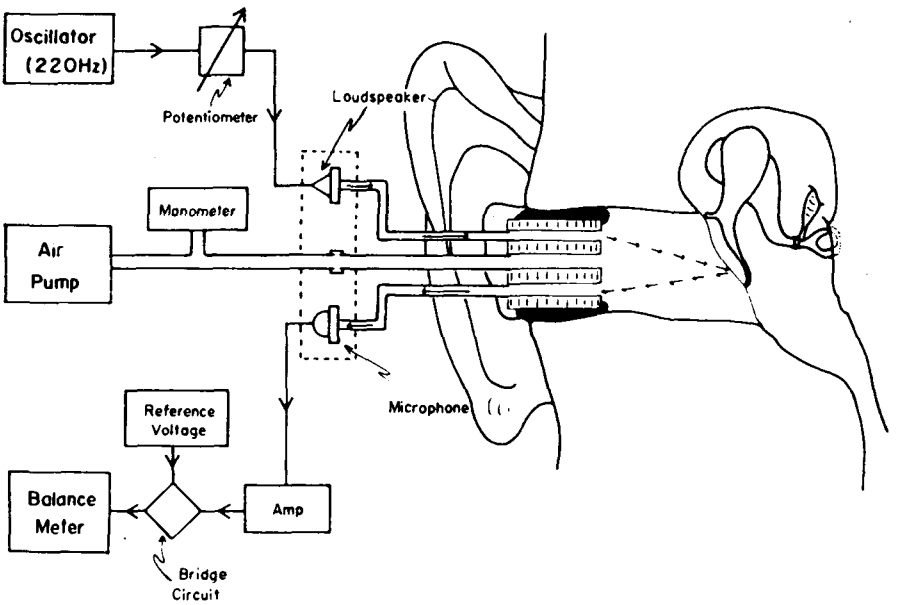


FIG. 2.
Principal components of the electro-acoustic impedance bridge.
(*From Jerger, 1970*)

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and the sound pressure level of the test tone changes: this event is monitored via the third tube and shows as a deflection of the balance meter needle. Most readers are now familiar with the equipment and test procedures for carrying out tympanometry and the contralateral pure tone acoustic reflex, and these details will not be described here.

III. The stapedial reflex arc

All the recently developed tests are based on the stapedial reflex, and it is important to consider the factors affecting it. These are summarized in Figure 3. For simplicity, only the contralateral pathway is shown.

IV. Applications of impedance audiometry

Table I summarizes the range of tests now available. Those which seem to be the most useful recent developments will now be considered.

V. The acoustic reflex to white noise [2, (i)]

Since 1963 (Fisch and von Schulthess, 1963) it has been known that the acoustic reflex threshold for wide band noise is more sensitive than that for pure tones.

The first to exploit this finding as a practical test of hearing were Niemeyer and Sesterhenn (1974) who presented their work in 1972. They studied the 2 types of acoustic reflex threshold in normal ears and in ears with sensorineural hearing loss, and found that in the latter, the gap

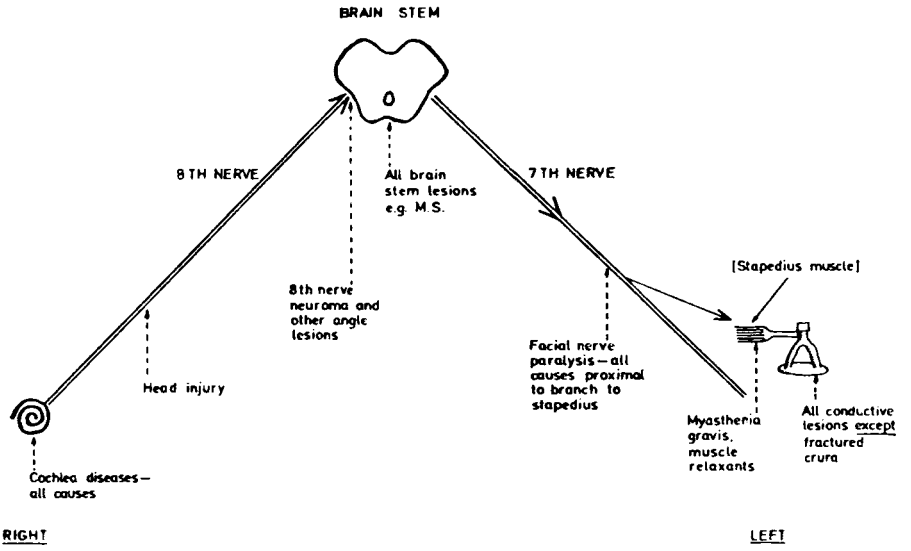


FIG. 3.
Factors affecting the stapedius reflex.
(*From Ransome, 1973*)

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TABLE I.

TESTS PERFORMED WITH THE IMPEDANCE BRIDGE

A. *Tympanometry*
   1. Differential diagnosis of middle-ear conditions.
   2. Investigation of Eustachian tube function.

B. *Acoustic reflex tests*
   1. *Using a pure tone stimulus*
      (i) Pure tone acoustic reflex threshold:
         (a) contralateral
         (b) ipsilateral.
      (ii) Acoustic reflex decay.
      (iii) Latency of acoustic reflex.
      (iv) Reflex relaxation index.
   2. *Using a noise stimulus*
      (i) Acoustic reflex threshold for white noise.
      (ii) Acoustic reflex threshold for high and low-pass filtered white noise.

between the two reflex thresholds narrows. As the hearing loss increases so the gap diminishes. From these two acoustic reflex thresholds (w.n. and p.t.) they were able to derive a formula for calculating the pure tone hearing threshold which is:

$$\text{Pure tone threshold} = \text{SRT tones} - 2{\cdot}5\ (\text{SRT tones} - \text{SRT w.n.})$$

where 'SRT tones' stands for the stapedial reflex threshold for pure tones (averaged from 500–4,000 Hz) and 'SRT w.n.' the reflex for white noise.

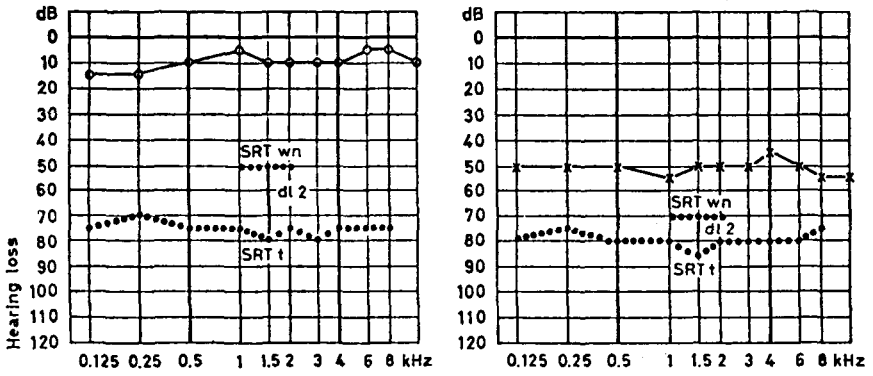
Figure 4 shows the application of this formula in one of Niemeyer and Sesterhenn's cases, the calculated thresholds in both the affected ear and in the normal ear being within 4 dB of the subjective pure tone threshold.

Here then is a test which seems to have great possibilities, because, rapidly and objectively and without vastly expensive equipment, one can arrive at an idea of the pure tone threshold, in those patients who are unable or unwilling to co-operate in a subjective P.T.A. These would include not only young children but also patients in whom non-organic hearing loss is suspected. How accurate then is it? Niemeyer and Sesterhenn found an accuracy of ± 10 dB in 73% of their 223 ears and ± 20 dB in 100% ears. The test was also studied by Jerger and his colleagues (1974) in 1,156 patients. They used a more complex formula, and placed the ears in 6 categories of hearing loss. They found serious errors (that is of more than one category) in 4%.

In Britain the test has been applied by Morrison (1975), who found it useful, and also by Miller, Davies and Gibson (1976) who studied 84 ears and found 87% of predictions were accurate within -15 to $+25$ dB limits. However, they warn that 10% of serious errors may occur.

The test is less accurate in ears with a steeply sloping pure tone audiogram, but this difficulty can be overcome to some extent by testing

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Right ear	dB	Left ear	dB
SRT tones 0.5–4 kHz (mean)	76.7	SRT tones 0.5–4 kHz (mean)	80.8
SRT white noise	50.0	SRT white noise	70.0
dl 2	26.7	dl 2	10.8
2.5 dl 2	66.8	2.5 dl 2	27.0
SRT tones	76.7	SRT tones	80.8
–2.5 dl 2	–66.8	–2.5 dl 2	–27.0
Calculated hearing threshold	9.9	Calculated hearing threshold	53.8
Measured hearing threshold	9.2	Measured hearing threshold	50.0

FIG. 4.
A case of Menière's disease.
(*From Niemeyer and Sesterhenn, 1974*)

additional reflex thresholds for both low-pass and high-pass filtered white noise [see Table I, B 2 (ii)], and from these levels subtracting one from the other, an idea of the slope of the audiogram can be derived.

All in all, the published reports are enthusiastic about this test as a quick and easy objective screening test, especially in young children.

VI. The ipsilateral pure tone acoustic reflex

Until recently, with commercially produced impedance bridges, it has only been possible to test the acoustic reflex by delivering the tone stimulus into the ear contralateral to the probe. This has limited the scope of the test, for example in patients with unilateral conductive hearing loss. Now, however, it is possible to deliver the pure tone stimulus into the ear containing the probe, and this is the ipsilateral test [see Table I, B 1 (i)(b)]. This has great diagnostic potential, as reference to Figures 5 and 6 will show.

Figure 5 indicates the probable connections within the brain stem between the afferent and efferent sides of the stapedial reflex arc. It shows how impulses travelling from the right cochlea up the VIIIth nerve and arriving at the right cochlear nucleus reach the facial nerve nucleus on

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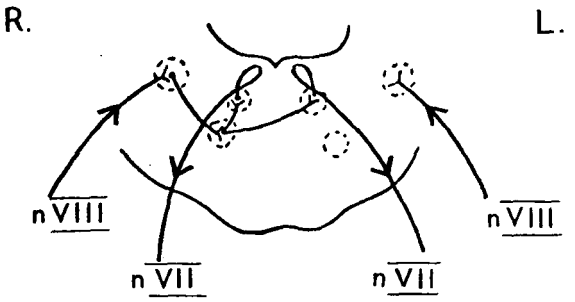


FIG. 5.
Cross section of pons, indicating probable course of stapedial reflex arc.
(*After Greisen and Rasmussen, 1970*)

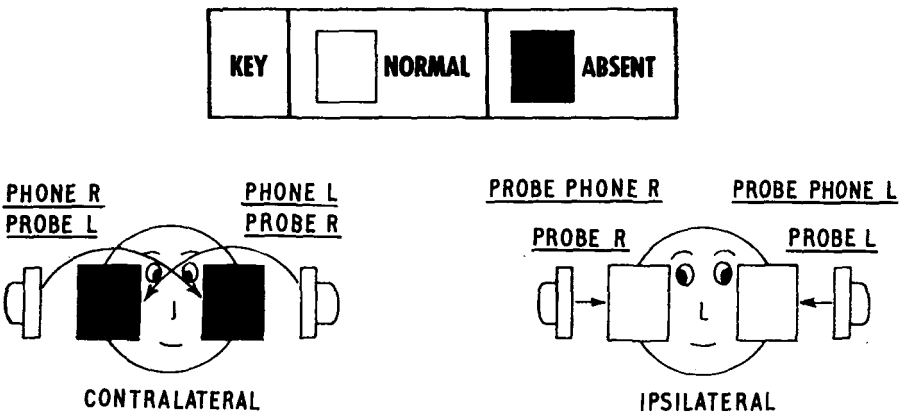


FIG. 6.
(*Reproduced by permission of Madsen Electronics*)

both sides: hence the bilateral nature of the stapedial reflex. It also shows, *ipso facto*, the ipsilateral acoustic reflex pathway. The diagram is over-simplified in that the reflex arc probably passes mainly through the superior olive as well. However, it illustrates the important concept that the contralateral reflex arc involves neurones which cross the midline, whereas the ipsilateral arc does not.

Now consider Figure 5 and postulate a lesion in the midline of the pons. If a patient with such a brain stem lesion has the contralateral test performed, the acoustic reflex will be absent with the earphone to either ear, because the neurones crossing the midline have been interrupted. But if the ipsilateral tests are performed (Fig. 6) the reflexes may both be present, and this may be valuable confirmatory evidence of a central lesion.

Jerger and his colleagues (1975) reported a case of a brain stem tumour in which the contralateral reflexes were initially absent but the ipsilaterals

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were present. During treatment with radiotherapy the contralateral reflexes returned. Greisen and Rasmussen (1970) also reported two cases of brain stem tumour in which the combination of contralateral and ipsilateral tests considerably aided the topical diagnosis.

Another situation in which a combination of contralateral and ipsilateral reflexes might be useful can be postulated by referring again to Figure 5. Suppose there were a right acoustic tumour: this might give an absent contralateral and ipsilateral reflex with the earphone to the right ear. If the VIIth nerve were also affected by the tumour both contralaterals would be absent, because with the earphone to the left ear the efferent pathway on the right would be affected, and only the left ipsilateral reflex would remain.

There are several more permutations of these results which aid in topical diagnosis, too numerous to describe, but which can readily be deduced. It should be stated that results of this test should be interpreted with caution as electrical artefacts have been said to occur because of the problem of putting the probe and test tones into the same ear. The equipment should be regarded as still not quite out of the developmental stage. However, once these technical problems are ironed out, this ipsilateral test, in combination with other tests, should greatly increase our diagnostic potential.

VII. Acoustic reflex decay [Table I, B 1 (ii)]

This will be considered in conjunction with absence of the acoustic reflex and elevation of the acoustic reflex threshold. These tests have been extensively studied in a search for early diagnosis of retrocochlear disorders.

Anderson, Barr and Wedenberg (1970) measured the persistence of the contralateral pure tone stapedial reflex on prolonged stimulation using an impedance bridge connected to an X–Y recorder. They studied 16 cases with VIIIth nerve tumours and 5 with posterior fossa tumours—a total of 21 ears. Thirteen of the ears showed *reflex decay*, i.e. the response amplitude was reduced by 50% in under 5 seconds. The stimulus used was 500 and 1,000 Hz (some decay may be seen at 2,000 Hz in normal ears), duration 10 seconds, and intensity 10 dB above the threshold of the stapedius reflex at the frequency tested. In all of these 13 ears the stapedial reflex threshold was elevated: in the remaining 8 the reflex was absent. The pure tone subjective threshold in the affected ear (the mean for 500, 1,000 and 2,000 Hz) was no greater than 60 dB, and in half the ears was better than 20 dB. A conclusion was reached that acoustic reflex decay is an extremely sensitive audiometric test of a retrocochlear disorder, even occurring in ears with a normal pure tone threshold.

The test aroused considerable interest in both Europe and the United States, but in later unselected series of proved acoustic neuromas, acoustic

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reflex decay had a much lower incidence. This may be because Anderson *et al.*, excluded cases with a mean pure tone hearing threshold greater than 60 dB, and thus tended to select less advanced tumours. Absence of the acoustic reflex is a more common finding, and affords valuable evidence for a retrocochlear disorder, when middle-ear disease can be excluded.

Thus Jerger *et al.* (1974) found *decay or absence* of the reflex in 26 of 30 surgically confirmed cases of retrocochlear disease: but of those 26, only 4 had acoustic reflex decay. Interestingly, they found that although the tests of the acoustic reflex successfully identified 87% of the tumour cases, Békésy Type 3 or 4 tracings occurred in only 47%.

Similarly Olsen *et al.* (1975) found decay or absence of the acoustic reflex in 24 of 28 ears of patients with surgically confirmed tumour involving the VIIIth nerve, and reflex testing was a better indicator of retrocochlear disease than threshold tone decay tests. But, they also found decay or absence of the acoustic reflex in 20% of patients with sensory deafness, so the incidence of false positive results is higher than previously thought.

When the acoustic reflex is present, the threshold is frequently elevated in retrocochlear disease: unilateral elevation or even a marked difference between the two ears should arouse suspicion.

It seems probable that in early cases of retrocochlear disease tests of the acoustic reflex may either be normal, or show decay or elevated threshold; whereas cases presenting late are more likely to show absence of the reflex.

The use of the acoustic reflex threshold to identify recruitment is well known and will not be described here.

VIII. Latency of the acoustic reflex [Table I B 1 (iii)]

This has been studied in normal subjects, but as yet there have been few reports on latency of the reflex in various diseases. Since the reflex arc passes through the brain stem, any increase in latency may have a role in neurological as well as otological diagnosis.

Bosatra and his colleagues (1975) studied the reflex in brain stem impairment induced by barbiturate administration, and found in one subject that his normal latency of 100 msec. was increased to 250 msec. They also found prolonged latency in brain stem disease.

IX. Reflex relaxation index [Table I B 1 (iv)]

Norris and his colleagues (1974) described this test, in which they elicited the stapedial reflex using a *pulsed* tone. They found a difference between normal ears and ears with sensorineural hearing loss. This is depicted in Figure 7. In both cases the off-time between pulses resulted in a relaxation of the reflex and the tracing tended to fall towards the base line, but this was much more marked in the normal ears. They measured

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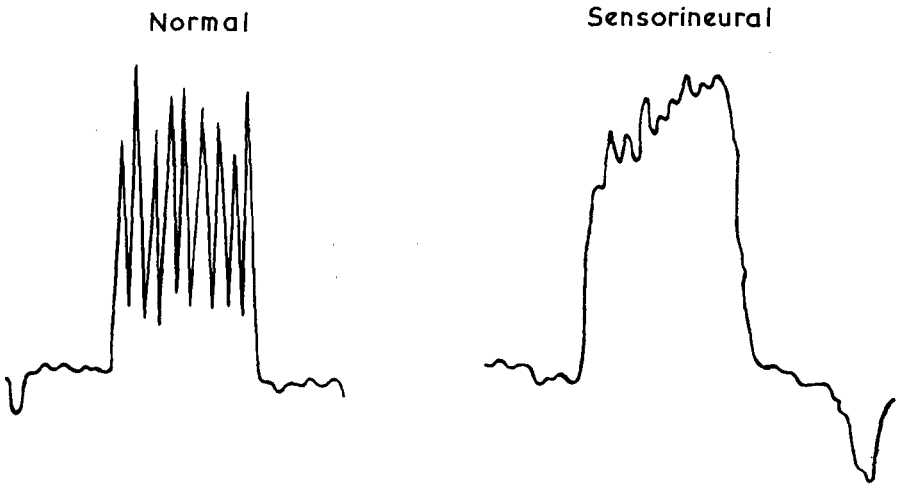


FIG. 7.
Reflex responses elicited by pulsed stimuli.
(*From Norris* et al., *1974*)

the width of the pulsed tracing and expressed it as a percentage of the distance between the base line and the highest excursion of the tracing.

Taken in conjunction with the acoustic reflex response to white noise, this test may afford a further means of distinguishing between sensorineural loss and normal ears in unresponsive children.

X. Conclusion

The role of impedance audiometry has been considered. The impedance bridge, the applications of which are still developing, is the most versatile instrument we have for examining deafness objectively. Not only can it usually distinguish conductive from sensorineural deafness and cochlear from retrocochlear disorders, but it now even gives an objective *estimate* of the hearing threshold. It also has an increasing role in neurology, since it can give evidence of angle tumours and brain stem disease even in patients with normal hearing.

Some recently developed tests based on the stapedial reflex have been briefly outlined in this article.

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