64

TITLE

DEVELOPMENT AND EVALUATION OF A FREE-FIELD VOICE TEST FOR POTENTIAL USE AS A COMMUNITY SCREENING TOOL FOR HEARING IMPAIRMENT IN CHILDREN

A DISSERTATION SUBMITTED IN PART FULFILMENT FOR THE DEGREE OF MASTER OF MEDICINE IN OTORHINOLARYNGOLOGY, UNIVERSTY OF CAPE TOWN

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DECLARATION

THIS DISSERTATION IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR A DEGREE IN ANY OTHER UNIVERSITY.

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DEDICATION

This work is dedicated to:

1. **My late parents, Mr. and Mrs C. O Omoding for showing me the way. This would have been a perfect gift as token of appreciation of your love. May god rest your Souls in peace.**
2. **My wife, Imelda and my daughter, Sarah, for their patience, understanding, encouragement and support throughout the study period.**
3. **All the children out there, living alone in a silent world. May we be inspired to do better.**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Early identification of hearing impairment in children is essential to avoid potentially disabling effects of hearing loss or deafness. This necessitates effective **screening** measures appropriate to the community in question.

Current methods used in South Africa, especially for pre-school and school going children have resulted in poor coverage as they are designed for the more developed countries. There is thus a need to devise a screening method that is appropriate to our local conditions.

In this study, a free-field live voice test was developed based on three levels: whisper, conversational and loud. This was evaluated against pure tone audiometry for sensitivity, specificity, cost and ease of application in two studies: hospital and school- based.

A total of 394 children were tested; 189 in hospital-based study and 205 in school based study. 378 of the total were eligible for analysis.

In the hospital-based study, the results of 177 children were analysed. The age range was 3 – 12 years with a mean of 5.8 years. The sensitivity (ability of the test to detect hearing impairment) was 80.0%; and the specificity (ability to identify children with normal hearing) was 95.0%.

In the school-based study, done after modification and standardisation of the test set, the sensitivity and specificity were 83.3% and 97.8% respectively. Age range was 3 – 8 years with 79% being 4 – 6 years.

In both studies, the voice test was simpler to perform, easily understood and acceptable to the children and the testers; and considerably cheaper as the only equipment required was picture/toy set.

The main limitation was non-standardisation of the test set. This was rectified in the school-based study.

The drawbacks noted were the inability of the voice test to detect unilateral hearing loss/deafness and high frequency hearing loss.

The voice test generally correlated well with pure tone audiometry and could be used as alternative for screening for hearing impairment in the community especially for pre-school and school going children.

However, it is recommended to repeat the study in actual community settings using Community Health Care Workers as the testers. This would also determine the reliability of the voice test, as this can not be reliably established at this stage.

1.0 INTRODUCTION

Hearing impairment is one of the most prevalent health disability problems and has a pervasive impact on almost every aspect of an affected individual's life. In 1985, it was estimated that there were at least 450 million disabled people worldwide, a significant proportion of these being contributed to by hearing impairment (Wilson 1985). Eighty five per cent of these people are in the developing countries. Furthermore, in 1985, the United Nations Emergency Children's Fund (UNICEF) estimated that in the developing countries, one third of the disabled are children (Wilson 1985). Until recently, even in the developed countries, relatively less attention had been given to hearing impairment and its effects, principally because the disability produced is unseen.

Hearing impairment, like blindness, is measurable. It is hence essential to briefly define parameters used to measure thresholds of hearing. These are ***frequency*** and ***decibel.***

Frequency: Number of cycles per second (relative to a sound wave). It is measured in Hertz (abbreviated as Hz) in honour of Hertz, a German physicist (Austin 1990). One cycle equals one Hz. The number of cycles i.e. the frequency of a sound wave, determines the pitch of a sound. ***Speech frequencies*** refer to frequencies covered in range of everyday conversational speech and range from 500 Hz to 2000 Hz.

Decibel (dB) one tenth of ***a bel,*** is a measurement of sound intensity. It relates the measurement (sound intensity) to a reference level and is defined as 20 times the logarithm of the ratio of sound pressure to the reference level (20 μPa[1]). The

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[1] MicroPascals

logarithmic scale is used to reduce the range of values needed to describe sound levels due to the wide ranges of sound power (10^{-9} W - 10^{6} W)[2] (Ballantyne 1990, Stevens 1997). The reference point for sound pressure level was chosen to coincide approximately with the thresholds of normal subjects at I kHz level. Hence, the sound pressure level (SPL) corresponding to reference acoustic pressure is 0 dB SPL (Goodwin 1987).

Decibel hearing level (dB. HL): This is the value in decibels which expresses the pressure of sound in relation to a reference pressure Po[3] which, conventionally, is the minimum pressure required for the perception of 1000 - 4000 Hz sine wave in the average normal hearing adult.

Decibel Sound Pressure Level (dB SPL): Is the minimum intensity at which a person can hear at a specific frequency in relation to a basic value (0 dB HL) which represents minimum hearing in normal adults. This is the unit used in conventional testing of hearing.

1.1 DEFINITION

According to the current World Health Organisation (W.H.O) criteria, hearing impairment is present when hearing thresholds are greater than 25 dB HL over 4 frequency range (500, 1000, 2000 and 4000 Hz). Significant impairment is said to be present when hearing loss exceeds 40 dB HL (Gell 1992, Nober 1998). The W.H.O prevalence figures and disability calculations are all based on the 40 dB, 4 frequency range criterion.

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[2] W = Watts
[3] Po = 0.0002 dynes/cm^2 or 20 μPa

The Deaf Federation of South Africa (DEAFSA), in a policy statement on early identification of deafness and ear care defined hearing impairment as "a condition which results from the impairment of the sense of hearing to an extent that interferes with communication and affects the social, emotional, educational and vocational aspects of the life of an individual (DEAFSA 1997). This definition is more comprehensive than that adopted by the American Speech and Hearing Association (ASHA) which defined it as " a deviation or change for the worse in either auditory structure or auditory function, usually outside the range of normal" (Barrett 1994).

These definitions include all disorders of hearing regardless of their nature, cause or severity. Two subgroups, namely, ***hearing loss*** and ***auditory processing disorder,*** constitute hearing impairment (Boothroyd 1982).

Hearing loss is an impairment of sound detection which can be measured by psychoacoustic or physiological function such as pure tone hearing thresholds, otoacoustic emissions and brainstem response to clicks, whereas ***auditory processing disorder*** is an impairment of sound interpretation (Boothroyd 1982; Davis 1998). Two other commonly used terms, ***"deaf"*** and ***"hard-of-hearing"*** reflect how an individual uses hearing (with amplification, if necessary), and have been defined by the Conference of Educational Administrators Serving the Deaf (CEASD) as follows:

"A deaf person is the one whose hearing is disabled to an extent that precludes understanding of speech through the ear alone, with or without the use of a hearing aid."

" A hard-of-hearing person" is one whose hearing is disabled to an extent that makes difficult, but does not preclude, the understanding of speech through the ear alone, with or without a hearing aid (Frisina, 1974, quoted by Jamieson 1994).

Deafness, however, is now viewed in a different perspective and has resulted in a distinction being made between the terms deaf with a small d and Deaf with a capital D; "deaf" persons being the one who can still communicate ***orally*** despite being severely to profoundly hearing impaired, and "Deaf" referring to individuals who communicate only by ***sign*** language (Penn 1993).

Various scales of hearing impairment have been produced and recommended for use. The one currently in use in most countries is that recommended by the World Health Organisation (Nober 1998):

-10 dB – 25 dB: Normal hearing level,

26 dB – 40 dB: Mild hearing loss

41 dB – 55 dB: Moderate hearing loss,

56 dB – 70 dB: Moderately severe hearing loss,

71 dB - 90 dB Severe hearing loss

91+ dB: Profound hearing loss.

1.2 PREVALENCE (Table 1)

Precise and defensible figures on the prevalence of hearing loss are difficult to obtain not only for developing countries but also for many developed nations. Many published reports on prevalence are based on very small samples of inadequately collected and vaguely described data. The variation present in published estimates is also influenced by the use of different criteria for hearing loss by different investigators since there is no universally accepted definition of the level of hearing impairment which should be used to develop prevalence figures (Davidson et al 1989; Mauk et al 1993; McCormick 1993; McPherson and Swart 1997). What stands out when reviewing literature is that there is usually only fragmentary national knowledge, especially in developing countries, of prevalence rates of hearing loss and various ear diseases (Davidson et al 1989; Alberti 1996; Cameron 1997).

Although, in general global prevalence of hearing loss is not well known, some reputable figures have been published. In 1995, the World Health assembly (W.H.A) estimated that there were at least 120 million people worldwide with hearing loss exceeding 40 dB HL over 4 frequencies (500 - 4000 Hz) (Hinchcliffe 1995). Using 25 - 35 dB HL criterion for hearing loss over the same frequency range, Kapur (1993) and Alberti (1996) gave independent but similar estimates of 300 million people worldwide. Taking into account the different criteria and the trading relationships for prevalence, mentioned later on page 10, the 2 estimates would appear compatible. A recent W.H.O report estimated 121 million people worldwide with ***disabling*** hearing impairment (Hiroshi Nakajima 1997).

In developed countries, prevalence figures range from 1.0 – 2.0/1000 for children with bilateral sensorineural hearing loss exceeding a 50 dB threshold (Davidson et al 1989;

Pabla Singh 1991). In the United States of America, severe to profound sensorineural hearing losses are present in 1/1000 live births, and moderate sensorineural or unilateral hearing losses are present in 6/1000 live births (Mauk et al 1993). In 1988, a study in the United Kingdom found that 1.7/1000 children aged over 5 years had moderate hearing loss in the better ear (Sancho et al 1988). Recent studies further show that about 20% of the total adult population of the United Kingdom has a hearing impairment of 25 dB HL or greater with an annual incidence for new cases of 1-1.5%. The same studies found a prevalence of 1.33/1000 for permanent childhood hearing impairment equal to or more than 40 dB HL (Davis A 1998). In Denmark, the overall prevalence rate in the population of a hearing loss defined as equal to or greater than 35 dB for the better ear was 14/1000 (Parving A 1983). A recent French study found prevalence of 0.54/1000 in children under 9 years old with a severe to profound hearing loss equal or greater than 70 dB. (Baille et al 1996).

From the Middle East a recent survey in Saudi Arabia involving 6421 urban children found 7.7% of the children to be hearing impaired (Bafaqeeh et al 1994). An earlier study by the same researchers in rural children found the prevalence to be as high as 30%. Comparisons between these two results or between these and others in literature cannot be made as the authors did not define their criteria for hearing loss.

In sub-Saharan Africa, a region with about 10% of the world's population, over 1.2 million children aged between 5-14 years have been estimated to have moderate to severe bilateral hearing loss (McPherson and Swart 1997).

From West Africa, a 1983 study in the Gambia found 2.7/1000 children to have severe to profound hearing loss (average threshold at 0.5, 1.0, and 2.0 kHz was equal or greater than 70 dB eq. H.L ISO for the better ear) (McPherson and Holborow 1985). A recent population-based study of 2015 children undertaken in Sierra Leone aged 5 – 15 years found a prevalence of bilateral hearing loss of 4.0/1000 (Seely et al 1995). Nine percent of the sample was found to have hearing loss exceeding 25 dB in one or both ears.

From Southern Africa, a 1987 study in Swaziland involving 4000 children aged 5-14 years found a prevalence of 10/1000 for hearing loss equal to or greater than 40 dB in the better ear (Hatcher et al 1994). In Botswana, the population prevalence of hearing loss in children aged 3-14 years was 18/1000 (Corocan et al, cited by Hatcher et al 1994). Bastos (cited by McPherson and Swart 1997) in Angola found overall prevalence of 20/1000.

In South Africa, as in other parts of Sub- Saharan Africa, of the studies that have so far been published, the majority have involved assessments of school children. Van Rooy et al (1995) in an assessment of 2036 elementary school children 5-10 years of age found a prevalence of 7.5/1000 with mild to moderate hearing loss. Swart (cited by McPherson and Swart 1997) in a community based survey found the prevalence to be 2.1/1000. In 1990, the South African National Council for the Deaf (SANCD), now the Deaf Federation of South Africa (DEAFSA), estimated about two million people in South Africa to be hearing impaired.

From East Africa, a school-based survey of 5368 children in Kenya using the handheld Liverpool Field Audiometer found 3.4/1000 children with a unilateral hearing loss, 2.2/1000 with bilateral hearing loss. The overall prevalence rate of for profound bilateral hearing loss equal or exceeding 80 dB HL was 2.4/1000 (Hatcher et al 1992).

What is evident from the above is that prevalence surveys in Sub-Saharan Africa (2.4/1000 – 20/1000) show consistently higher rates of severe and profound bilateral hearing loss than typically observed in developed countries (1.1/1000 –1.33/1000) (Table 1). However, there is still a paucity of prevalence information for the majority of countries in Sub-Saharan Africa, making future hearing service planning and provision difficult to implement in many of these countries.

Table 1 below is a summary of some published prevalence rates. Comparisons between them is difficult though possible because of the variations in the criteria adopted for definition of hearing loss. It has been suggested that one way to compare them would be against an expected trading relationship in which the prevalence of hearing loss is halved for every 10 dB increase in the hearing loss thresholds adopted for definition of hearing loss.

TABLE 1: Prevalence of hearing loss in childhood

SOURCE	DATE	COUNTRY	dB HL (better ear)	SAMPLE SIZE	PREVALENCE
Mcpherson	1985	Gambia	70 dB	2,015	2.7/1000
Seely et al	1995	Sierra Leone	-	2,011	4.0/1000
Bastos et al	1993	Angola	>30 dB	1,030	20/1000
Hatcher et al	1992	Kenya	>80 dB	5,365	2.4/1000
Van Rooy et al	1995	South Africa	-	2,036	7.5%
Hatcher et al	1987	Swaziland	>40 dB	4,000	10/1000
Baille et al	1996	France	>70 dB	-	0.54/1000
Bafaqeeh et al	1994	Saudi Arabia	-	6421	7.7%
Davis	1998	United Kingdom	>40 dB	-	1.33/1000
Sancho et al	1988	United Kingdom	-	-	1.07/1000
Marki-Torkki et al	1998	Finland	>40 dB	-	1.2/1000
Mauk et al	1993	United States of America	>20 dB	38,559	12.1/1000

1.3 IMPACT OF HEARING IMPAIRMENT

The "principal catalyst" in the effort to identify hearing loss as early as possible in children is the benefit gained from maximum intervention at critical times and the consequences of ignoring or delaying identification (Mauk et al 1993). In general, the earlier in life the hearing loss occurs, the more debilitating the effects on the person's speech and language, creating a situation in which hearing loss becomes a disability, a situation particularly prevalent in developing countries (Jamieson 1994; Hinchcliffe 1997). The cumulative wealth of society and the economic opportunities for an individual derive in a large measure from an individual's ability to communicate and, "attainment of optimal communication skills requires synergy between the quality of the linguistic input to the child and his or her hearing capacity"(Ruben 1997). In school-age children, even mild and /or fluctuating losses may impede learning and deny the child the opportunity to develop his/her academic potential (Douek 1991).

The effects of hearing loss occurring in childhood can therefore be considered in terms of language, educational and psychosocial development.

1.3.1 Language development

Language is the main bridge between the external world and the world of thought and perception within. Without adequate language development, life is stunted (Tweedie 1987). Several researchers have demonstrated a relationship between poor language development and hearing impairment (Jamieson 1994; Mauk et al 1993; Adams 1997; Feagans 1992). It has also been shown that children who are rehabilitated early in life had superior speech expression and receptive language skills compared to those who were rehabilitated later (Quigley 1978; Ruben et al 1982).

In general, hearing impairment, in children, creates major problems for both the child and its parents. Words form the basis of much of our cognitive function. We learn words by hearing them and giving them meaning. Hearing impairment therefore can lead to failure to develop cognitive vocabulary with resultant impaired intellectual development (Chase 1992). Linked to this is the effect of hearing impairment on speech development, as speech is developed by mimicking words heard, the extreme being a child who is "deaf and dumb" because words have never been heard and therefore speech never developed (Tweedie 1987; Thornton 1992).

1.3.2 Educational development

"Hearing impaired" children lag behind their normal hearing counterparts in term of academic achievements; and "hard-of-hearing" perform better than "deaf" children. On average, academic achievements of "hard-of-hearing" children are delayed by approximately two years. (Jamieson 1994;Tweedie 1987).

1.3.3 Psycho-social developments

The inability of auditory input to keep pace with emotional development puts the child under great strain, especially in cases with less severe but fluctuating hearing losses. The child is bewildered by responses that cannot be related to experience and by unpredictable attitudes on the part of their close peers/adults (Tweedie 1987). This may set up a vicious cycle with subsequent social maladjustment.

The impact in socio-economic and human terms is significant. The disability, affecting all ages, may not be immediately apparent, but these people can suffer in many ways: normal education and job opportunities may be denied to them, as they may require special education, special placement, and vocational training in order to develop their potential and this may not be available to them.

Severe hearing impairment (deafness) whether congenital or acquired, is usually recognised by the parents (Simmons 1978; Parving 1984; Watkin et al 1990). Parents, usually but not always, seek out confirmation and assistance from available medical services. Primary care workers and physicians for one reason or the other, may fail to initiate referral and/or institute necessary treatment though they may be aware of such a need. Such children may then go unrecognised or be treated ineffectively and, as a result, be very much at risk in terms of linguistic, educational and psychosocial attainments.

Less severe degrees of hearing impairment often go unrecognised, slow development of speech and retarded intellectual development often being attributed to other things.

Even the older children who acquire hearing loss later need timely intervention in order to prevent any deterioration in their communication skills and to develop the appropriate communication strategies which are required to maintain their position in society (Tweedie 1987).

Early identification with the potential for intervention is thus essential to avoid disabling effects of hearing loss (Haggard 1990). This can be achieved by preventive means, principally ***secondary prevention*** which encompasses early detection by ***screening*** and prompt treatment (primary medical care). The other two forms of prevention: ***primary*** (prevention of injury or disease through health education, immunisation, environmental modification/s etc) and ***tertiary*** (limitation of disability and rehabilitation from disease) (Sharrar 1992) are beyond the scope of this study.

Screening should be followed by provision of appropriate correction and/or amplification and carefully planned and supervised parental guidance. If well done, this can, in most cases produce an emotionally stable and socially well adjusted individual (Markides 1986).

There is hence a need to develop methods of screening to detect hearing impairment and deafness appropriate for use in the community situation in developing countries. Such methods need to be simple in design and should require the minimum of equipment and skill so that they can reasonably be made available at all primary care facilities; and be incorporated as a routine part of health improvement programmes.

1.4 SCREENING FOR HEARING IMPAIRMENT

Screening is " a proactive centrally administered system to ensure testing of a high percentage of the members of a population or a specified population stratum to detect a specified condition" (McCormick 1997). It is not diagnostic in nature but if well conducted, should highlight a subgroup of the population which is likely to exhibit the condition who can then be further assessed to either confirm or exclude its presence. Aptly summarised, screening is "a brief assessment procedure designed to identify those who should receive more intensive diagnosis or assessment" (DEAFSA 1997).

The rationale behind screening for hearing impairment is the supposition that there are many children with hearing impairment not obvious to parents or caregivers (who would otherwise seek assistance for the problem) and that early identification will improve their eventual outcome through medical treatment and/or placement in rehabilitation programmes (Watkin et al 1990, Haggard 1992; Ramakalawan et al 1992). The scientific evidence for this may be scanty in the context of the developed countries but given the sparse coverage of existing screening programmes in the developing countries, many would accept that there is sufficient evidence to justify identification as early as possible (Watkin et al 1990; Haggard 1992).

Unfortunately, in comparison to other disabilities such as blindness, deafness and hearing impairment had been a neglected area until recently when the World Health Organisation (W.H.O.) initiated a programme for prevention of deafness and hearing impairment (PDH) (Smith 1997). The reasons for this neglect are multiple. Principally, this is because deafness and hearing impairment produce unseen disability. In developing countries, more so than developed countries, there is lack of awareness of possibilities for prevention as well as uncertainties about most appropriate methods of detection, treatment and rehabilitation. This is coupled with ignorance of the true size and nature of the problems and conspicuous lack of resources to tackle the problems (Hinchcliffe 1997).

At the moment, in Africa, only Kenya, Botswana, Malawi, Ghana, Egypt and South Africa appear to have made any organised attempts to provide primary Ear Care (Rupani 1997; van Hassalt, personal communication). Even in these countries, there is more of tertiary than secondary prevention. Existing programmes for detection of hearing impairment and deafness are still designed and modelled on those designed and tested in the developed countries, again emphasising the need do develop methods appropriate to our setting.

At present, world wide, hearing impairment is detected in one of the following ways:

1. The child is known to be ***"at risk"*** of having hearing loss and is referred for hearing testing.
2. The person (child) fails a hearing ***screening*** test.
3. Parental or professional suspicion.
4. A child fails to develop speech and language in the normal way.

1. "At risk" register.

The "at risk" registers for hearing impairment and deafness giving lists of pathological processes likely to affect hearing is available in most Health Centres in the developed countries. The situation in the developing countries is very variable. In general, conditions included in such a register include:

- family history of deafness
- congenital perinatal infections (rubella, syphilis, herpes, cytomegalovirus, toxoplasmosis)
- congenital abnormalities of head and neck
- low birth weight (<1500 grams)
- neonatal jaundice
- anoxia
- meningitis
- septicaemia.

In 1990, the SANCD recommended screening for all "at risk" babies either before discharge from the maternity unit or before the infant reaches 3 months of age. However, this method has been shown to be relatively ineffective as up to 50% of babies with congenital hearing losses do not present with any risk factor at birth, and are therefore not screened (Mauk and Behrens 1993). This highlights the dangers of "restrictive" screening procedures.

2. Screening tests:

There are a number of screening tests recommended for infants/children of different ages. Some of these such as the auditory response cradle (ARC) are now outdated but are included here for completeness:

a) Neonates: (Usually done for the "at risk" as above")

i) Auditory Brain Stem response tests (ABR)

ii) Otoacoustic emissions (OAE)

iii) Auditory Response cradle (ARC)

iv) Startle response

b) Eight months to one year:

i) Distraction test

ii) The Behavioural screening test (BeST), a semi-automated distraction test.

iii) Structured surveillance (questionnaire)

c) 1-4 years:

Toy discrimination test – McCormick Toy Test

- E2L Toy Test (Bellman et al 1996)

d) School Entry:

i) Sweep Audiometry.

ii) Tympanometry- mainly to supplement audiometry if conductive hearing loss is suspected.

3. Parental suspicion:

Experience at the Red Cross Children's Hospital has shown that almost always, a parent is right when he/she suspects an infant/child to be "hard-of-hearing". This has also been the experience of others in America, Europe and the United Kingdom (Lilholdt et al 1980; Hitchings and Haggard 1983; Parving 1984; Simmons 1978; Robertson et al 1995; Kankkunen 1982)

Absence of suspicion, however, does not necessarily indicate normal hearing. Recent data indicate that only 20-25% of parents with hearing impaired children were responsible for initiating a referral for diagnostic testing (Watkin et al 1990; McCormick 1997). The Current recommendation is therefore to combine parental vigilance and ***sensitive hearing screening*** programmes (McCormick 1997).

4. Failure to develop speech:

Some of these children have hearing loss in addition to other problems such as emotional or mental retardation. The trend world-wide is to screen or perform full diagnostic tests on children with delayed speech development.

The above is a general outline of screening procedures. Each centre/country, however has a different health care policy, and hence a different approach in terms of timing, instrumentation and the personnel involved. The American Joint committee on Infant Hearing recommends that every child be screened and rehabilitated, if necessary, by 6 months of age (Barret 1994). In Finland, the recommendation is to screen every child free of charge before leaving the maternity centre, and again at 8 months, 2-3 years and 5 years of age (Maki-Torkki 1998). In the United Kingdom, the trend is to screen only the "at risk" babies at birth with later screens by Health Visitors (McCormick 1997). In South Africa the recommendation is to screen all "at risk" infants before leaving the maternity unit or at no more than 3 months of age (SANCD 1990).

It is clearly evident that there is no universal policy acceptable to all countries and that each country has to formulate their recommendation in accordance with existing resources. There has been a tendency by some developing nations to implement recommendations developed elsewhere without due regard to the prevailing circumstances with deleterious consequences.

It has been realised, world-wide, that hearing-impaired children are still detected later than ideal despite improvements in techniques (Newton 1985; Parving 1993a; Robertson et al 1995). This is true also for communities with well administered health care systems in which the age at which significant childhood hearing loss is detected is still too high (Marttila and Karikoski 1995). It has also been found that the age of identification is statistically highly correlated to the severity of the hearing loss; less severe being detected later than more severe (Marttila T.I; Karikoski J.O 1995).

Current programmes in South Africa attempt to address all aspects of prevention of hearing impairment after models developed in and for other countries. Issues that arise in South Africa include lack of awareness of hearing impairment as a disability, insufficient epidemiologic data and lack of facilities and infrastructure with which to implement intervention programmes (SANCD 1990). These problems, together with a limited number of trained technicians, make implementation of screening programmes, especially in underdeveloped and poorer areas, very difficult. This highlights the need to design "appropriate" programmes which utilise available community manpower.

At present, there appears to be no national strategy for prevention of hearing impairment (SANCD 1990; DEAFSA 1996). Screening for hearing impairment, when done, is by distraction testing using the Ewing Foundation high frequency rattle (HFR). This together with the Swart's Parent Questionnaire, is geared to neonates and infants. Pre-school and school age groups are not well catered for. In a few areas where it is done, a screening audiometry is used. Research is clearly needed in this area to design and validate an alternative procedure that is cost effective, easily applicable and yet reliable in terms of sensitivity and specificity for this age group.

The rationale for this study stems from the need to develop an alternative screening procedure appropriate to South African context. This is born out of the fact that current recommended procedures are available to a minority of the population due to;

1. Lack of the facilities and infrastructure with which to implement the programmes.
2. High cost of the equipment, including maintenance and salaries of personnel.
3. Availability of few trained personnel majority of whom are in tertiary institutions

In this study, based on work by Hinchcliffe (1981) and Browning et al (1989), a simple voice test (see below) based on three levels, whisper, conversational and loud, was developed as a possible screening tool for hearing loss in the community setting.

1.5 FREE-FIELD VOICE TESTS

Free-field voice tests were introduced by Wolf in 1871 (Hinchcliffe 1981). Lucae, in 1907, put forward concrete recommendations regarding their quantification following earlier attempts by Bezold in 1897 and Reuter in 1904 (Hinchcliffe 1981). Since then, a number of reports have evaluated the potential role of clinical (free-field) voice testing in an adult population. Fowler and Trowbridge in 1947 independently reported poor correlation between audiometric thresholds and free-field voice tests (Browning et al 1989). King (1953) criticised the test on the basis of unpredictability and variability of loudness used. These reports, coupled with introduction of pure tone audiometry into clinical practice in the 1940's led to gradual decline of the use of free-field voice test.

Despite their reported imprecisions, many clinicians found them useful as clinical ***screening*** tests (Hinchcliffe 1981). For example, Sohoel (1956) found that voice tests detected 75% of audiometrically demonstrable hearing losses. Recently, a study by Browning et al (1989), using a method suggested by Hinchcliffe in 1981, showed that the clinical voice tests could be used as a quick screening method for hearing impairment in an adult population.

There is paucity of data regarding the role of voice tests in children. The few studies reported give conflicting results. Groen 1975 (cited by Dempster et al 1992) in an evaluation of 197 normal 5-year old children concluded that the test was as suitable method of screening as it was likely to detect all those with a significant hearing impairment and was easier to perform than pure tone audiometry. A later study by Dempster and Mackenzie (1992) showed that the test was satisfactorily sensitive in detecting hearing impairment of equal or more than 30 dB but missed about 20% of children with impairment of equal or less than 25 dB. The overall sensitivity was considered not sufficiently accurate to merit its use in specialist situations where facilities for pure tone audiometry are available.

However, in screening for a disorder, simplicity is essential. In developing countries, such specialist situations are hard to come by. Taking into account the enormity of the problems facing the developing nations, and the realisation that developing countries cannot achieve the ideal as recommended in literature, free-field voice testing may be a sufficient alternative. This would be of value in screening patients with hearing loss where audiometry is not available, as is a case in most developing countries.

This study, hence, attempts to develop and validate a Free-Field live Voice testing as a possible screening tool especially for pre-school and school age groups.

To test the reliability and validity of the test, a hospital-based study was undertaken and, based on the results of this study, school based study was undertaken after modifications and refinements of the test procedure.

2.0 METHODOLOGY

2.1 AIMS

2.1.1 Primary: These were:

1. To ***develop*** a simple, rapid, easily applicable, cost effective and yet, reliable method for screening for hearing loss appropriate to the developing countries.

2. To ***validate*** such a procedure against standard pure tone audiometric screening and/or diagnostic procedures.

2.1.2 Specifically:

To ***devise a simple voice test*** that can be used as a screening tool for detection of hearing impairment in the community setting.

2.2 RESEARCH DESIGN

This was a qualitative study seeking to establish the correlation between the voice test and pure tone audiometry.

It was divided into three parts as follows

1. Development of the voice test.
2. Hospital based validation study.
3. School based study.

2.2.1 DEVELOPMENT OF THE VOICE TEST

In the context of developing a simple method for screening to detect hearing impairment and deafness, it would be reasonable to assume that, for the majority, hearing is most valuable for verbal/aural communication. In such a situation, a person with ***"normal"*** hearing should be able to hear and understand a ***"whispered voice"*** spoken at a distance of about one metre from the receptive (test) ear. If there is mild hearing loss, then a whispered voice would not be heard or understood but a "***conversational voice***" would be heard and understood. If there is significant (severe) hearing loss, then conversational voice would not be heard or understood but a ***"loud voice"*** may be heard and understood. If there is **"profound hearing loss"** even a "loud voice" would not be heard or understood.

Using a sound level meter (calibrated in dB A), at one metre from the ear, it was ascertained that a whispered voice corresponded to a sound level of 30-45 dB; conversational to 46-60 dB; and loud to 60-80 dB.

In general, to understand words spoken, they have to be heard at 30 dB or greater above hearing threshold. (Although in speech audiometry, words can be heard at 5 dB above threshold, for 100% score, words need to heard at about 30 dB above threshold). Therefore, understanding the whispered voice equates with normal hearing (-10 – 25 dB threshold), conversational voice to mild hearing loss (26 – 40 dB threshold) and loud voice to moderate (41 –55 dB threshold) or severe (56 – 90 dB threshold) hearing loss and "no response" to profound hearing loss (90 dB+).

With the confirmations of the accuracy of the assumptions made, a test procedure was developed and refined in the hospital-based study. The results obtained appeared to confirm the feasibility of the test. However, further refinements and standardisation of the test material and response set was felt necessary so as to increase the reliability and validity of the second phase of the study i.e school based study.

The test material for the community study was hence refined and standardised using word lists incorporating both the full range of frequency related sounds and competing words such as house/horse, doll/ball with matching picture cards to which children could point at or touch as a measurable response. These words were derived, with permission, from the E2L[4] study carried out by Bellman et al in England in 1996. This was felt appropriate as it dealt with children from various racial and ethnic backgrounds who spoke English as their second language, a situation quite similar to South Africa. However modifications were made to suit the local settings, for example, toys which were used in the original study were replaced with picture cards and words not likely to be known by our children were replaced with commonly used ones in our set up. Replacing toys with the pictures also reduced the cost of the test as this is one of the goals to be achieved. Words used were appropriate for the age group tested and within their vocabulary.

For both the hospital based and community based studies, the voice test was developed based on the following:

- accurate response to "whispered voice" to infer normal hearing,

[4] E2L = English as second language. Words were designed to test children who spoke English as second language.

- inaccurate or no response to whispered voice but accurate response to "conversational voice" infers mild to moderated hearing loss,
- inaccurate response or no response to conversational voice but accurate response to "loud voice" infers severe hearing loss, and,
- no response to "loud voice" infers total (profound) deafness.

In general hearing impairment, regardless of the degree, was present if the subject did not accurately respond to a whispered voice.

2.2.2 HOSPITAL BASED STUDY

2.2.2.1 SETTING

Departments of Audiology and Ear, Nose and Throat at the Red Cross Children's Hospital, Cape Town.

2.2.2.2 SUBJECTS

Children attending Ear, Nose and Throat out patients' department at the Red Cross Children's hospital.

SAMPLE SIZE 189 Children

SUBJECT SELECTION CRITERIA

a) **Age:** The children were required to be between the ages of 3 and 12 years.

b) **Language:** Children were required to use English as either first or second language. Sufficient fluency was determined in a pre-test interview.

c) **Exclusion:** Children with known neurological, cognitive and/or mental delay were excluded, as were children with previously confirmed permanent hearing loss.

2.2.2.3 TEST MATERIAL

VOICE TEST

A Quest sound level meter (ANSI SI 4, type S2A) was used to calibrate the voice level before the live voice test.

Test material consisted of Toys familiar to the children - ***house, horse, car, duck, dog, boat, pen, spoon, doll, and ball.*** The test was delivered by a means of informal conversation as mentioned above with the toys randomly selected for presentation. Six to eight of these were used at a time. Based on pass/fail criteria used in previous studies (Bellman et al 1996; Browning et al 1989; Hinchcliffe 1981; Dempster et al 1992), a child passed the level tested if he/she got at least 50% of the items correct.

For the older child (6 or more years), ***spondee words*** randomly selected appropriately from the spondaic word list as per CID (Central Institute for the Deaf) auditory test list were used. The words selected were appropriate for age and culture of the population studied.

PURE TONE AUDIOMETRY

- Peter's free field audiometer for children aged 3 years and below.
- Maico MA 41 diagnostic audiometer (with headphones) for children aged 3-8 years.
- Madsen OB 822 clinical audiometer for children aged over 9 years.

2.2.2.4 PROCEDURE

a) TESTERS:

The tests were performed in conjunction with the audiologists at the Red Cross Children's Hospital. The tester was unaware of the subject's hearing status prior to the voice test. Where possible, a different tester administered the audiometric test.

TEST ENVIRONMET

Sound proof rooms in the Department of Audiology, Red Cross Children's Hospital

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b) TEST PROCEDURE

The tester, using a sound level meter, first calibrated his/her voice to the following approximate levels:

(a) "whisper" : 30-45 dB

(b) "Conversational" : 46-60 dB

(c) "Loud" : 60 dB+

The tester ascertained that the child was familiar with the test material. This was to ensure that the hearing level was being tested and not the subject's knowledge of the test material.

The procedure was explained to the subject regarding what the tester would be doing and what the subject should do such as " I want you to show me or point at.... when I ask you to do this". A trial run of the test procedure was then performed using a normal voice to ascertain that the subject understood the test procedure.

The tester standing behind the subject at an arm's length away proceeded to deliver the test, first in a whispered voice with gradation, if necessary, to conversational and loud voice levels.

Appropriate response was recorded for that set of toys. The voice level at which the subject passed at least 50% of the test was noted and recorded.

If a subject was found to have asymmetrical hearing loss, when subsequently tested with standard audiometric tests, the voice test was repeated after masking the better ear by pressing on the tragal cartilage. The threshold response for the worse ear was then recorded. This was carried out to see if there is any correlation between the voice test and degree of hearing loss on the worse hearing ear.

PURE TONE AUDIOMETRY AND IMMITTANCE STUDIES

These were always performed ***after*** the voice test. Standard diagnostic audiometry in a sound proof room was performed together with immittance studies.

Audiometric assessment was done for the frequencies: 500, 1000, 2000 and 4000 Hz. Pure tone average was calculated for each ear and recorded on the data sheet (appendix 1)

2.2.2.5 DATA ANALYSIS See 2.3 below.

2.2.3 SCHOOL BASED STUDY

This was undertaken using the test set and procedure ***refined*** and ***standardised*** after preliminary analysis of the results of the hospital based study.

2.2.3.1 SETTING

Pre-primary schools (crèches) in the area of Observatory, Cape Town.

2.2.3.2 SUBJECTS

Children aged 3-7 years attending these schools.

SAMPLE SIZE 205 Children.

SUBJECT SELECTION CRITERIA

a) **Age:** Children were required to be aged 3-7 years.

b) **Language** Children were required to speak English as either first or second language.

c) Children were required to be familiar with the test material.

2.2.3.3 TEST MATERIAL

a) Sound level meter, Cirrus CRL 4.12, calibrated in dB A scale for voice calibration as in the institution-based study.

b) Maico MA 41 audiometer for pure tone audiometry.

c) A set of 14 picture cards designed for use by subjects who spoke English as a second language. The pictures replaced the toys as originally described by Bellman et al 1996. The objects depicted in the pictures were phonetically balanced and culturally appropriate for the test population. These were: ***Bus/Brush; Sweet/Key; Car/Bath; Bed/Plate; Cup/Duck; Plane/Egg; Hen/Pen.***

c) Portable screening audiometer for pure tone testing. This was always performed after the voice test.

d) Portable tympanometer for immittance studies.

2.2.3.4 TEST PROCEDURE

a) **TESTERS** Tests were performed in conjunction with staff from the Department of Logopaedics, University of Cape Town and Groote Schuur Hospital involved in screening for hearing loss in the community.

b) **TEST ENVIRONMENT** School classrooms with ambient noise ranging from 30 dB - 40 dB.

c) **TEST PROCEDURE**

i) The tester, using a sound level meter, first calibrated his or her voice to approximate levels as in the institution based study above.

ii) He/she ascertained that the subject was familiar with the test material. For example: "Today, we are going to play a little picture game. I want you to show me a picture as quickly as possible when I ask you to. Can you do that for me? Show me the bus ... etc"

iii) The subject is asked to show/identify the required object depicted in the picture, first with "whispered" voice, with appropriate gradation to "conversational" and "loud" as necessary. For example: "Now we are going to do the same thing again, but this time I am going to sit behind you. Can you do that for me? Show me....."

iv) All tests were delivered with tester standing behind the subject at arm's length.

v) The voice level at which the subject correctly identified at least 50% of the test material was noted.

vi) Pure tone audiometry was then performed, where possible, by a different tester, using a sweep screening audiometer.

vii) Subjects with asymmetrical hearing losses as shown by pure tone audiometry underwent repeat voice test with the better ear masked by tragal pressure and appropriate response threshold noted.

2.3 TREATMENT OF RESULTS

Statistical analysis was carried out to test the hypothesis that voice test **correlates** well with pure tone audiometry and that it can be used as a alternative method for screening for hearing impairment. Simple comparison of figures would be inaccurate, as the two variables measured were not statistically similar, the voice test thresholds being a qualitative variable and pure tone thresholds quantitative. Hence meaningful comparisons could only be obtained by calculating the specificity and sensitivity of the voice compared with pure tone audiometry.

In both studies, the results were entered onto the data sheet (appendix 1) and subjected to statistical analysis using the SAS Output Statistical Analysis package (for hospital based study) and SYSTAT 8.0 statistical package (for school based study) having been fed to the computer, in each case, using excel 5/95 spread sheet. The choice of the statistical package was at the discretion of the stastitian, each package capable of giving similar results. Analysis was performed by two independent statitians, one for the hospital based and the other, school based results.

In addition, different audiometric patterns, depicting different types of hearing losses were noted. These were subsequently analysed and results compared statistically with voice test results.

3.0 RESULTS

A total of 394 children were tested across both studies. Out of these, 378 were eligible for analysis, 16 were excluded from analysis for reasons mentioned under individual studies. A detailed breakdown of these results and subsequent analysis for each study is outlined below.

3.1 HOSPITAL BASED STUDY

A total of 189 children were tested. Ten were excluded from analysis because of insufficient information on the data sheet and two, because of non co-operation during the testing. The data from 177 children were analysed using SAS statistical output package.

Age: The mean age was 5.8 years with a range of 3 – 12 years.

Voice Thresholds (Table 2)

When free-field voice test was performed, 128 children responded, as indicated in Table 2 below, appropriately to whisper, 34 to conversational and 15 to loud voice level. The children were then subjected to pure tone audiometry (see table 3 below).

Table 2: VOICE TEST THRESHOLDS.

VOICE TEST THRESHOLD	NUMBER
WHISPER	128
CONVERSATIONAL	34
LOUD	15
TOTAL	**177**

Audiometric assessment (Table 3)

Audiometric assessment (undertaken after voice test and in a sound proof room) found 122 children with normal hearing thresholds (<25 dB over frequencies 500 Hz to 4000 Hz), and 55 with hearing impairment. These results are shown in table 3 below.

Table 3: PURE TONE THRESHOLDS. N = 177

Pure Tone Thresholds (dB)	Number
<25 (Normal)	122
>25(Hearing impaired)	55
Total	**177**

Audiometric assessment Vs Voice Test Thresholds (Table 4)

A total of 128 children out of 177 were identified by the voice test as having normal hearing (responses corresponding to whispered voice level). Out of these, 117 corresponded to the pure tone audiometry thresholds. The number of children with normal hearing identified by pure tone audiometry was 122. The **specificity** of the voice test, defined as "the proportion of the children with normal hearing who were correctly identified by the voice test" was 117/122 or 95.9% (95% confidence intervals based on the normal approximation of the binomial distribution of 92% - 99%). (Table 5 below).

Table 4: Audiometric assessment Vs Voice Test Thresholds

Pure Tone	**Voice Test Thresholds**			
(dB)	Whisper	Conversation	Loud	**Total**
<25	117	5	0	**122**
>25	11	29	15	**55**
Total	**128**	**34**	**15**	**177**

Table 5: Sensitivity and Specificity of the Voice Test (Better ear)

VOICE TEST	**PURE TONE THRESHOLDS**		
	<25 dB	**>25 dB**	**TOTAL**
C + L	5 (4.1%)	44 **(80.0)**	**49**
WHISPER	117 **(95.9%)**	11(20.0%)	**128**
TOTAL	**122**	**55**	**177**

C+L: Conversational and loud voice thresholds combined.

From the above, the voice test incorrectly identified 5 children as hearing impaired when actually they were normal. These constituted the **false positives** expressed as 5/122 or 4.1%.

Out of 177 children, 55 were detected by pure tone audiometry as hearing impaired. The voice test only detected 44 of these. Eleven children were incorrectly labelled by the voice test as normal hearing when they were actually hearing impaired. The **sensitivity** (ability to detect hearing impairment) of the voice test in this study was therefore 44/55 or 80%. (Table 5). The 11 children incorrectly labelled by the voice test as having normal hearing constituted the **false negatives** (11/55 or 20%). The majority of these children had mild hearing losses between 26 dB and 30 dB (Table 6).

This may indicate the fact that the voice test may not identify some children with mild hearing losses. Table 6 below is a detailed breakdown of the children who constituted the false negatives.

Table 6: Pure Tone Thresholds for false Negative Children

VOICE THRESHOLD	BETTER EAR (dB) (PTA)	WORSE EAR (dB) (PTA)
W	27	33
W	26.5	30
W	36	36
W	27	32
W	37	40
W	26.7	32
W	26.7	32.5
W	30	32.5
W	26.7	45
W	35	45
W	28	33

PTA = Pure tone Average over frequencies 500 Hz to 4000 Hz.

W = Whispered voice level

Following pure tone testing, 18 children were found to present with a unilateral hearing loss. Two of these had profound unilateral hearing loss in the worse hearing ear, one severe hearing loss and two with a mild hearing loss in the worse hearing ear.

When the better hearing ear was masked, and the voice test repeated, appropriate responses to either conversational or loud voice levels were obtained. This highlights one of the deficiencies of the voice test in that it will not normally detect unilateral hearing loss if the hearing in the better hearing ear is normal.

Based on the above results which revealed specificity and sensitivity of 95.9% and 80% respectively, the test was judged viable (Browning et al 1989, Dempster et al 1992). It was hence refined and standardised and applied in the community testing as outlined above. The results obtained are shown and analysis thereof presented below.

3.2 SCHOOL BASED STUDY

A total of 205 children were tested. Of these, four were excluded because of inadequate information in the data sheet, 201 were analysed using the Systat 8.0 statistical package and the Pearson Chi-square for test statistics.

Ages ranged from 3 – 8 years. 79 % were aged 4 – 6 years (Table 7 below)

Table 7: Age in years.

AGE	NUMBER	PERCENTAGE
3	8	4
4	33	16.4
5	62	30.9
6	64	31.8
7	30	14.9
8	4	2
TOTAL	**201**	**100**

<u>Voice test thresholds</u> (Table 8: Figures 1 and 2)

Children's responses were recorded as appropriate to whisper, conversational or loud voice levels. No child was categorised as "no response". 182 children were categorised as giving appropriate response to "whispered", 17 to "conversational", and 2 to "loud" voice thresholds.

Table 8: Voice thresholds. n = 201

Voice threshold (level)	**Number**
Whisper	182
Conversational	17
Loud	2
Total	**201**

Figures 1 and 2 below show graphical presentation of voice thresholds against pure tone audiometry thresholds.

Figure 1 depicts proportionate distribution of the children according to the various voice test levels. Figure 2 is a graphical representation of the voice test against pure tone audiometric results. As shown, in the majority of the children, the voice test correlated with respective pure tone audiometric thresholds.

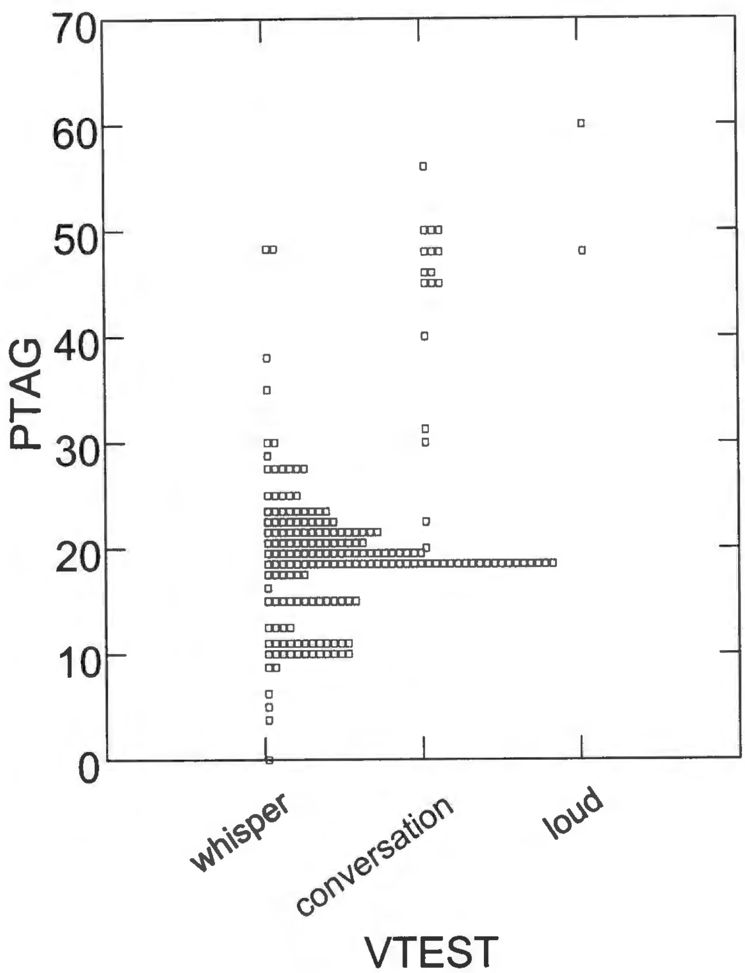

Figure 1: Voice Test Thresholds: Proportionate distribution

VTEST = Voice Test Thresholds

PTAG = Pure Tone Average

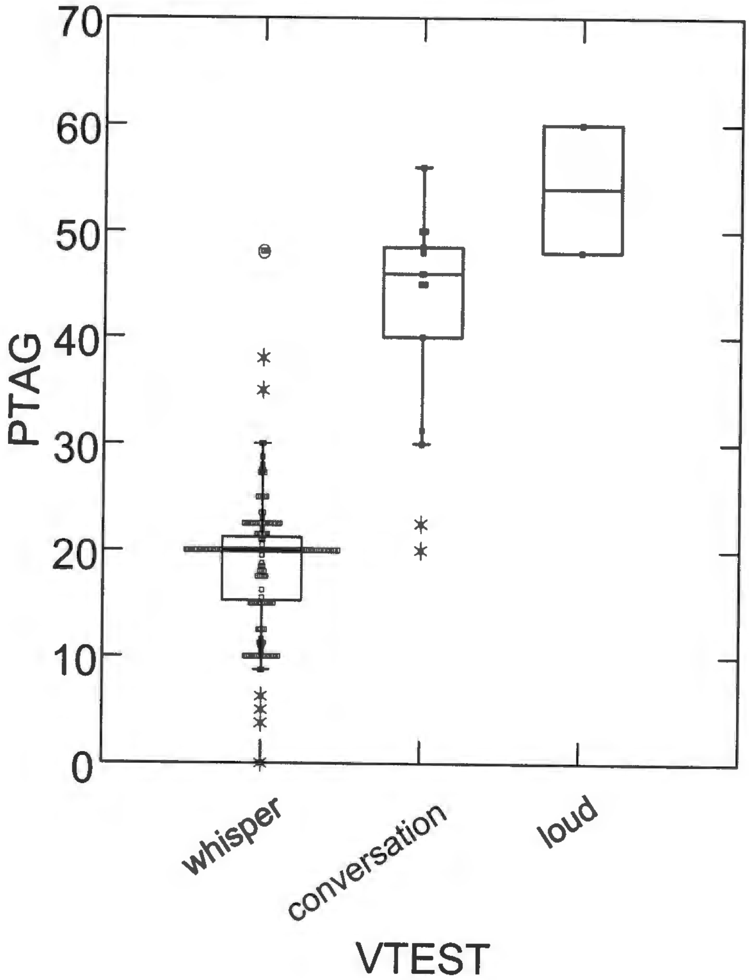

Figure 2: Voice Test VS Pure Tone Audiometry

VTEST = Voice Test Thresholds

PTGA = Pure Tone Average

<u>Audiometric assessment</u> (Table 9, figure 3)

Pure Tone audiometry was undertaken in all children following completion of voice test. They were then categorised into two groups: < 35 dB HL as normal and >35 dB HL as hearing impaired. The 35 dB HL cut off was chosen instead of 25 dB HL because the test was performed in a classroom with ambient noise averaging 30-40 dB.

Following this classification, 183 children were categorised as normal (<35 dB), and 18 as hearing impaired (>35 dB), giving a prevalence for hearing impairment of 18/201 or 8.9%.

Table 9: Pure Tone Thresholds. n = 201

Pure tone thresholds (dB)	**Number**
<35	183
>35	18
Total	**201**

Figure 3 below is a graphical presentation of pure tone thresholds showing detailed proportionate distribution. Majority of the children had 20 – 25 dB thresholds.

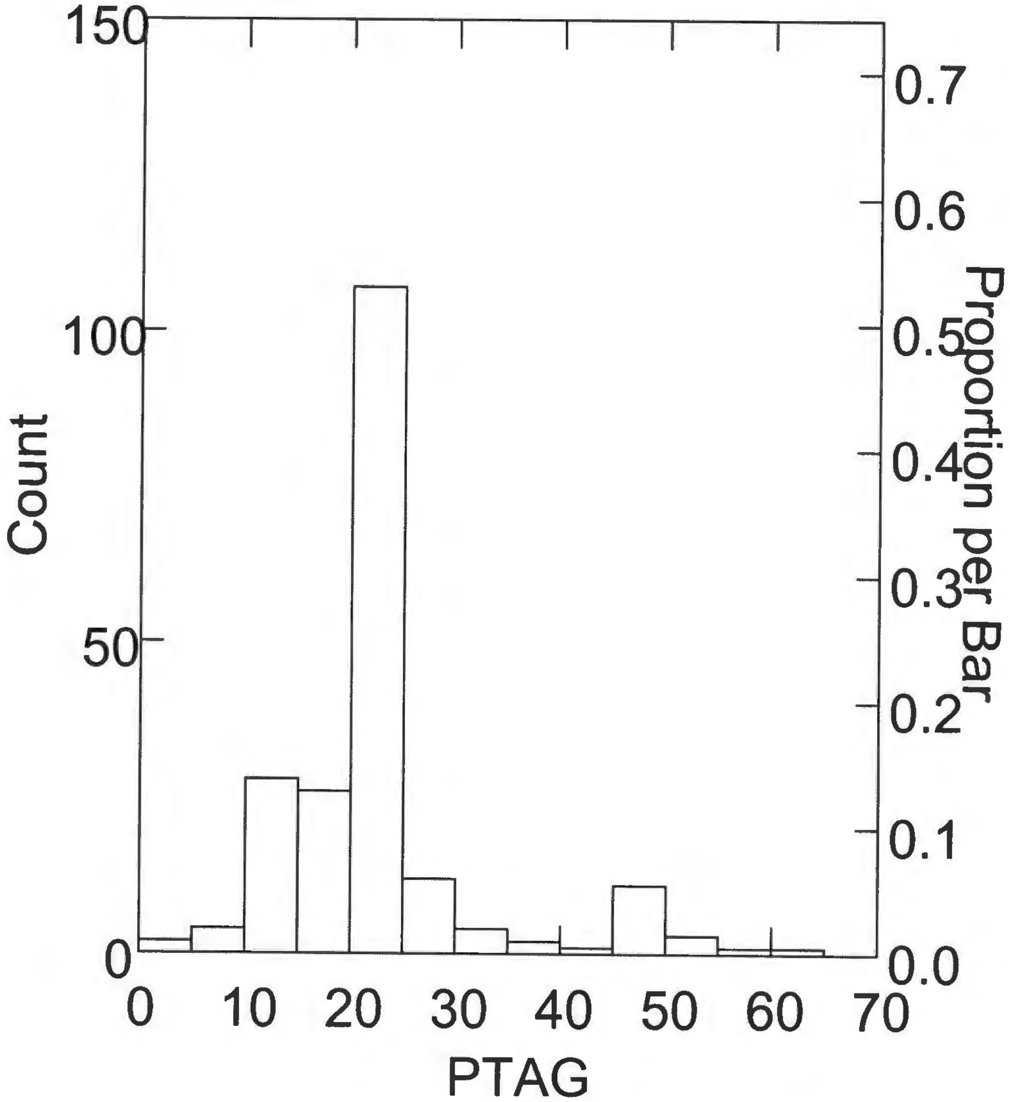

Figure 3: Pure Tone Thresholds Proportionate Distribution

PTGA = Pure Tone Average.

Comparison of Voice Test thresholds with Pure tone Audiometry

1. Audiometric assessment Vs Voice test thresholds (Table 10)

In this study, the voice test categorised 182 children as normal (responses correlating to whispered voice level). Out of these, 179 correlated with the audiometric assessment. The total number with normal hearing as identified by pure tone audiometry was 183. The voice test incorrectly identified 4 children with normal pure tone audiograms as hearing impaired. These were the **false positives**, defined as "the number of children who were incorrectly identified by the voice test as hearing impaired" and their ratio is 4/183 or 2.2%.

Audiometric assessment identified 18 children with hearing impairment as opposed to 15 by the voice test. The voice test hence identified 3 children as normal when they actually had hearing impaired. These constituted the **false negatives** defined as " proportion of the children with hearing impairment who were not detected by the voice test". The numerical ratio of the false negatives was thus 3/18 or 16.7%.

Table 10: Pure tone audiometric assessment Vs Voice test: n = 201

PTA	Voice Threshold							
	Whisper		Conversational		Loud		Total	%
<35 dB	179	97.8%	4	*2.2%*	0	0.0%	**183**	**91.1%**
>35 dB	3	*16.7%*	13	72.2%	2	11.1%	**18**	**8.9%**
Total	**182**	**90.5%**	**17**	**8.5%**	**2**	**1.0%**	**201**	**100%**

The **specificity** of the voice test, (the proportion of the children with normal hearing who were correctly identified by the voice test) was 179/183 or 97.8% (95% confidence intervals of 95.7% - 99.9%).

The **sensitivity** of the voice test, defined as "the ability of the voice test to detect children with hearing impairment" is the ratio of the children with hearing impairment identified by the voice test to that identified by the pure tone audiogram. This was numerically 15/18 or 83.3% (95% confidence intervals of 66% - 100%). This wide range of confidence intervals is due to the small number of the children involved.
Overall audiometric assessment identified 183 out of 201 as having normal hearing thresholds. Out of the same total, the voice test appropriately identified 179.

1. <u>Analysis according to the type of audiogram</u> (Tables 11 and 12)

After the pure tone audiometry the children were categorised according to type of audiogram. The following definitions were applied:

"Normal" referred to pure tone average of <35 dB HL over the following frequencies: 500 Hz to 4000 Hz.

"Hearing impairment" referred to pure tone averages exceeding 35 dB HL (35 dB HL to 60 dB HL).

The 35 dB cut off was decided upon taking into account the masking effect of ambient noise (Swart et al 1995). The tests were performed in a sound field in classrooms with noise levels averaging 30 dB to 40 dB.

Audiograms were classified as follows:

- ❖ Type I: "flat" symmetrical (both ears) audiogram with normal hearing.
- ❖ Type II: "flat" symmetrical (both ears) audiogram with hearing impairment.
- ❖ Type III: "flat" symmetrical (both ears) audiogram with deafness.
- ❖ Type IV: "hearing impairment" but not "flat" audiogram. The audiogram in this case indicated either low frequency (ascending audiogram) or high frequency (descending audiogram) hearing impairment.
- ❖ Type V: "deafness" but not "flat" audiogram. The audiogram was either ascending or descending type.
- ❖ Type VI: Unilateral "hearing impairment".
- ❖ Type VII: Unilateral "deafness".

Using the above definitions, 158 children had type **I,** 15 type **II**, 19 type **IV** and 9 type **VI** audiograms (Tables 6 and 7 below). No children were categorised in **III**, V, or **VII**.

Table 11: Age (years) by type of audiogram.

	Type of audiogram					
Age	**I**	**II**	**IV**	**VI**	**Total**	**Percent**
3	7	1	0	0	**8**	**4.0**
4	28	1	3	1	**33**	**16.4**
5	46	7	6	3	**62**	**30.9**
6	47	4	8	5	**64**	**31.8**
7	26	2	2	0	**30**	**14.9**
8	4	0	0	0	**4**	**2.0**
Total	**158**	**15**	**19**	**9**	**201**	
Percent	**78.5**	**7.5**	**9.5**	**4.5**		**100**

Table 12: Type of audiogram Vs Voice Test thresholds: n = 201

	Voice Threshold							
Audio	**Whisper**		**Conversational**		**Loud**		**Total**	**%**
I	153	96.8%	5	3.2%	0	0.0%	**158**	**78.5%**
II	6	40.0%	8	53.3%	1	6.7%	**15**	**7.5%**
IV	16	84.2%	2	10.5%	1	5.3%	**19**	**9.5%**
VI	7	77.8%	2	22.2%	0	0.0%	**9**	**4.5%**
Total	**182**		**17**		**2**		**201**	
%	**90.6%**		**8.4%**		**1.0%**			**100%**

Analysis according to the type of audiogram revealed the following: 158 of the children had type **I** audiogram with 153 (96.8%) giving responses correlating with the whispered voice level and only 5 (3.2%) to conversational voice levels. None of the children with this type of audiogram were categorised in "loud" or "no response" voice threshold levels. The finding that the majority of children with type I audiograms correlate to "whispered" voice levels confirms the assumption that responses to "whispered" voice level is indicative of normal hearing.

Type **II** audiograms (flat symmetrical hearing impairment) were found in 15 (7.5%) children. Tympanometry results were available in 13 of these children and 10 had evidence suggestive of otitis media with effusion. Out of the 15 children, 9 (60%) were appropriately identified by the voice test as hearing impaired and 6 (40%) as normal. Unfortunately, because of practical constraints, voice tests and pure tone audiometry were done on different days (within 24 hours) in 5 of these children and this may have contributed to the above 40% as fluctuating hearing loss is a known feature of otitis media with effusion.

There were 19 (9.5%) children who had type **IV** audiograms (hearing impairment but not flat audiogram) and 15 (78.9%) of these had high tone hearing losses mainly at 3000 HZ to 8000 HZ with normal hearing over speech frequencies (500 HZ to 2000 HZ). The remainder, 4 (21.1%), had ascending audiograms with some element of conductive hearing losses. It is not therefore surprising that 16 (84%) were classified by the voice test as normal as the majority had normal hearing over speech frequencies suggesting possibility of the voice not being able to identify children with high frequency hearing losses.

Audiograms depicting unilateral hearing impairment (type **VI**) were seen in 9 (4.5%) children. All had normal hearing on the opposite ear. The voice test classified 7 (77.8%) of these as normal and 2 (22.2%) as hearing impaired. However, when the voice test was repeated with masking of the better ear, all children gave responses appropriate to either conversational or loud voice thresholds. This demonstrates the inability of the voice test to detect unilateral hearing losses as it is " a free-field" test.

The above results and subsequent analysis thereof are discussed below.

4.0 <u>DISCUSSION</u>

The principal of hearing screening would make it an acceptable procedure for inclusion among health detection programmes as it meets most of the criteria for a successful screening programme. Since their inception, there has continued a search for an ideal technique/method, resulting in continued modification and/or abandonment of the existing methods. The challenge for the developing countries lies in designing methods for hearing screening appropriate for their situations where technology and skills are often lacking.

Paradise and Smith (1978), cited by Bess and McConnell (1981) suggest that a good screening tool should be valid, reliable, acceptable and cost effective. The outcome of this study will hence be discussed using these criteria.

4.1 Validity

As noted in several reports (Bess and McConell 1981; Cochrane and Holland 1971; McCormick 1997), validity of a screening programme is comprised of ***sensitivity*** and ***specificity.***

The school-based component of this study found that the **sensitivity**, defined as ability to accurately identify children with hearing impairment, was 83.3%. The **specificity**, defined as ability of the test to identify children with normal hearing, was 97.8%. The figures for the hospital based (pilot) study were 80% and 95% respectively. The improvement in the results of the school based study compared with the hospital based study is thought to be due to the refinement of the test procedure and in particular, standardisation of the test material.

The above results compare well with previous studies by others. Browning et al (1989) in a well-controlled study on adults found sensitivity of 86% and specificity of 90%, and concluded that in a non-specialist situation, the test would be useful as a quick screening method for hearing impairment. Dempster et al (1991) in a similar study on children found sensitivity of 80% and specificity of 95% using 25 dB HL as cut off point. Their conclusion was that the test would not be of value in situations where specialist services are available as it missed 25% of the children with mild hearing losses. In situations where there are no specialist services at all, and access to more proven methods is almost non-existent, it would probably be acceptable to miss 25% of the mild hearing impaired by using a less sensitive screening test rather than to miss all the hearing impaired regardless of the degree of hearing impairment if it is felt inappropriate to use a less than ideal screening procedure and hence not undertake screening for hearing impairment at all.

4.2 Reliability (Precision/Repeatability)

The practical constraints of the situation in which testing was undertaken on school children during normal school hours were such that repeat testing, either of a single child by different examiners on the same day or of a single child by the same examiner on the a different days, was not feasible. This is an obvious constraint on the interpretation of data and is something that needs to be addressed in future studies.

However, the good correlation between voice test responses and pure tone audiometry (sensitivity and specificity) in both hospital based and school based studies suggests that the voice test would be a reliable method for hearing screening in ambient noise situations.

4.3 Acceptability

Since the voice test involved identification of pictures at graded voice levels, it was considered by many children as a form of a game. There was a lot of enthusiasm by the majority to take part, with resultant high degree of co-operation. The children quickly mastered the required tasks and in general the voice test took about one half of the time required to perform pure tone audiometry.

The audiologists and trainee audiologists administering the test were already familiar with hearing testing. Once the test procedure was explained to them and they were given the test materials, no training in administration of the test was required apart from voice calibration using a sound level meter. It was hence simple, fast to perform and acceptable to the subjects.

4.4 Cost

Cooper et al 1974 (cited by Bess and McConell 1981) have suggested a simple formula to estimate the cost of a screening programme thus:

$$\text{Cost per child} = \frac{S}{R} + \frac{C + (M \times L)}{N \times L}$$

Where: C = Cost of equipment (in dollars),

S = Salary of the screening personnel in dollars per hour,

L = Life time of the equipment in years,

M = Annual maintenance cost in dollars,

R = Screening rate: children per hour,

N = Number screened per year.

Equipment

In comparison to audiometric tests, the only equipment required for the voice test is the picture cards set. It hence is considerably cheaper in this aspect, a portable audiometer costing about R 20,000.00 and a picture card set about R 10.00.

Salary

The voice test, when perfected, will not require highly trained personnel demanding high wages. It is anticipated that community personnel will be trained in the administration of the voice test as part of routine in-service training and will use the test as part of their normal health screening services.

Life time of equipment

Picture cards, when laminated, should last for at least one year. In any case, production is relatively cheap and once produced they require very little in the way of maintenance.

Screening rate

The screening rate in this study was on average 5 minutes per child compared with audiometric test which was on average 8 - 10 minutes per child. Consequently, the number of children who can be screened per hour using the voice test is far greater than the number who could be screened using pure tone audiometry.

Overall, the cost per child of the voice test is considerably less than of that for pure tone audiometry.

Some of the children, as shown in figures 1 and 2 were classified by the voice test as normal (whisper) but as "hearing impaired" by pure tone audiometry. Some children who were classified by the voice test as "conversational" level were actually "normal" by pure tone audiometry. There are two possible explanations for these responses:

1. The child may not have understood the test procedure well enough to accurately perform the test.
2. There may be a central auditory processing defect such that pure tones can be accurately perceived but complex sounds such as words are not well perceived. If further assessment of these children indeed confirms auditory processing defect it would mean that the voice test, unlike pure tone audiometry, is able to detect all forms of hearing impairment including auditory processing disorder. This would mean an added advantage of using voice test instead pure tone audiometry as a screening tool

Generally, it would appear from the above that free-field voice test is valid, cost effective, simple and would be a reliable screening method for hearing loss in situations where pure tone audiometry is not available as it compares well with pure tone audiometry. This is shown by the fact that, 83.3% of the children identified as having hearing loss exceeding 35 dB were determined by the voice test. This value is likely to improve with further refinement of the test procedure and test material.

Such refinement includes testing the children using the language spoken by the child as his/her first language and development of words appropriate to these languages that cover the desired frequencies to be tested. The numbers involved were small. 15 out of 18 children were correctly identified. It is possible that the sensitivity may be improved in a larger study.

Previous studies by Meyerson (Bess and McConnel 1981) confirmed good correlation between speech reception thresholds and pure tone intensities. This proven relationship further lends support to the validity of the voice test.

Some of the problems noted include:

1. Unilateral hearing loss. This is likely to be missed especially if the better ear is normal. There were 9 (4.5%) children with unilateral hearing loss and 7 (77.8%) of these were missed by the voice test. This may be overcome by testing one ear at a time while masking the none test ear though this has the danger of complicating the test procedure and requires more time.
2. High tone hearing loss especially those outside the range of speech frequencies. In this study, there were 19 (9.5%) children with either ascending of descending audiograms. 15 (78.9%) of these had high tone hearing loss (descending audiograms) with normal hearing over speech frequencies and all of these children

were classified as normal by the voice test. This problem could potentially be overcome by selecting words covering these frequencies in addition to speech frequencies, and incorporating subsets of competing words. These could be incorporated into the test battery as an isolated additional test. However, administration and interpretation of these would require the services of trained audiologist to stand any chance of being able to detect the presence of high tone losses.

3. Language: In some instances, the tester and the child did not speak the same first language. However, this was minimised by use of a word set derived from the set designed for the subjects who use English as their second language. In the context of South Africa where bi-lingualism and multilingualism is common, the use the set derived from English was considered appropriate as in most families, English is spoken either as first or second language.

5.0 CONCLUSION AND IMPLICATIONS

In this study, the voice test compared well with pure tone audiometry and proved to be valid as shown by its sensitivity and specificity. From the above results, it would also appear to be reliable though further research is needed to confirm this.

The test is cheap, simple to perform, fast and acceptable to the children. The simplicity of the test is such that, although not addressed by this study, it should be possible for it to be administered by primary health care workers and schoolteachers following basic instructions with particular reference to the voice levels to be employed.

It is able to detect all degrees of hearing impairment. It cannot, however, provide the exact degree of hearing loss in decibels but can gauge the severity of hearing impairment. This is not a limitation as the primary aim is to determine presence or absence of hearing impairment and further action, if necessary, would determined at the next referral level.

The voice test is primarily aimed at pre-school and kindergarten school children and in this country the age range for this would be 4 - 10 years. The Swart's parent questionnaire and the Ewing High Frequency Rattle are used for the younger children.

The main limitation to the study was noted in hospital based study in which the test material and the test response set were not standardised. These were however rectified in the school-based study which forms the main basis of the above conclusions.

Clinical Implication

The voice test can be used in community level to screen for hearing loss in South African context as it is cheap, simple to perform, valid and reliable. Furthermore, the target age group (pre-school/school children) is currently least catered for, the current methods being mainly geared for the younger age groups.

Future Research

Before embarking on the above, there is need to repeat this study in various communities using material and language appropriate to that community. All testers should be from within the community (Community Health Workers, teachers etc) and should speak same language as the community members.

The main constraint is likely to be a variation in the normal levels of a whispered and conversational voices between examiners and from test to test in the one examiner. Either would lead to inaccurate assessments. This was avoided in the study by having the examiners practice the technique prior to testing using a sound level meter and monitoring their voice levels whilst performing the test. It could be a problem in routine administration of the test by Community Health Workers and another method of periodic checking and calibration of the voice thresholds may have to be introduced to counteract any tendency to abnormally raise voice test levels over time in the community setting.

"We can say with some assurance that although children may be victims of fate, they will not be victims of our neglect" J.F Kennedy Oct. 24. 1963.

To fulfil the above, we have to start somewhere depending on our resources.

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APPENDIX 1

DATA SHEET

1. PATIENT'S PARTICULARS

NAME…………………………………..AGE…………..SEX………..

2. METHOD USED

a) "Repeat after me" **b)** "answer my question" **c)** "point to/touch something"

1. VOICE THRESHOLD

a) "Whisper" b) "Conversational" c) "Loud Voice" d) "No response"

1. TYPE OF AUDIOGRAM

I: "Flat" symmetrical with normal hearing.

II: "Flat" symmetrical with "hearing impairment".

III: "Flat" symmetrical with "deafness".

IV: "Hearing impairment" but not "flat" audiogram.

V: "Deafness" but not "flat" audiogram.

VI: Unilateral "hearing impairment".

VII: Unilateral "deafness".

2. **PURE TONE AVERAGE.** Staple a copy of audiogram and tympanogram. For the school-based study, measure and note the noise level of the test environment.

Any significant comments that may have affected the accuracy of the test such as:

a) Patient's general condition: retarded/confused/language problems etc.

b) Patient not fully co-operative and reason/s why.

c) Other problems.

APPENDIX 2

INSTRUCTIONS FOR THE VOICE TEST

MATERIALS;

1. Sound level meters.
2. Portable audiometers
3. A set of picture cards

PROCEDURE:

Calibrate your voice using a sound level meter to the following approximations:

Whisper: 30 - 45 dB;

Conversational: 46 - 60 dB;

Loud: 60 dB+

1. Make a random run to assess the child's knowledge of the test material. It may be necessary for you to explain to the child what the item is.
2. Note the child's knowledge of the test material.
3. Explain to the child what you are going to do e.g: I want you to show me (your teacher/ mother) or point at the pictures as I mention them; give.... To the teacher etc.
4. Stand behind the child at an arm's length (cover your mouth and face the child) and perform the test by delivering the speech stimulus in a *whispered* voice. Note the response. If negative, proceed to *conversational* voice and if necessary, to *loud* voice level.
5. Note the appropriate response level in the accompanying data sheet.