AUDIOMETRY ENVIRONMENT REMOTE CONTROL SYSTEM TO ASSIST IN PAEDO-AUDIOMETRY

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PUBLICATIONS

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ABSTRACT

The early detection and treatment of hearing disabilities in young children (6 months to 2 years) is vital if the natural development of concepts which culminate in normal speech and language is to occur. Audiologists employ many techniques to establish and measure the hearing abilities of a child. The techniques applicable to adults can usually be applied to children, however, there are many instances when, because of the developmental level of a child, special diagnostic procedures must be adopted.

Audiometers have developed through the years, taking advantage of modern technology, and many types of equipment are available today to measure the hearing levels of a patient. The equipment is often used in ingenious ways or supplemented with devices to suit local needs. A problem remains with the control of the child in the test setup : an assistant is usually required in addition to the parent. A remote control system which allows the audiologist to conduct the test single-handed is described. The system has been in regular clinical use for 12 months and was subjected to a methodical assessment by analysing the task of the audiologist with and without the system. The results of the task analysis and subjective comments on the use of the system are presented and discussed.

The use of the system is shown to facilitate audiometric testing of children by eliminating the need for an assistant and enabling the audiologist to complete a successful test in less time than was previously possible.

DECLARATION

I, Brian Clement Goemans, hereby declare that the work on which this thesis is based is original (except where acknowledgements indicate otherwise), and that neither the whole or any part of it has been, or is to be submitted for another degree in this or any other University.

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LIST OF ABBREVIATIONS AND SYMBOLS

The following abbreviations and symbols appear in this document

ABR	Auditory Brain stem Response
AERC	Audiometry Environment Remote Control
BOA	Behaviour Observation Audiometry
bone	bone conductor vibrator (placed on mastoid process)
DOS	Disk Operating System
F.F.	Free field loudspeakers
IBM XT	International Business Machines - model XT (computer)
Mask NB	Masking, narrow band noise
PT	pure tone
VRA	Visual Reinforcement Audiometry
WIPI	Word Identification Picture Recognition

1. INTRODUCTION

Audiometry is the measurement of the hearing ability of a person. Since a hearing disability can retard or prevent the development of speech in the first years of life, communication through life can be severly affected. As techniques of management of children with hearing loss have improved, so the need to detect a hearing loss as early in life as possible has increased. This thesis describes the techniques used in testing the hearing of children, the problems encountered at one of the leading centres in South Africa, and the design and evaluation of a remote control system to assist audiologists in their work with the children.

In chapter 2 the development and use of the techniques are described. An overview of visual reinforcement audiometry and speech audiometry describes the historical development of these techniques. The remote control system is discussed in chapter 3, and its evaluation is described in the next chapter. Chapter 5 contains the conclusions and suggestions for further research work that could be undertaken using the remote control system.

2. CLINICAL AUDIOMETRY FOR CHILDREN - A LITERATURE REVIEW

2.1. Introduction

Speech and language are imitative processes, acquired primarily through the auditory sense. A hearing defect, either congenital or acquired early in life can interfere with the development of concepts that culminate in normal speech and language. Thus the earliest possible identification of a hearing deficit is crucial. The earlier in life aural habilitative measures can be applied, the greater are the chances for the successful development of speech communication (Martin 1991).

Most of the audiometric procedures applicable to adults can be applied to children. However, there are many instances when, because of the level at which a particular child functions, special diagnostic procedures must be adopted. A further challenge, as great as that of the diagnosis, is the management of the child and family during the emotional times that follow diagnosis, but that subject is beyond the scope of this thesis.

Modern technology has greatly increased the number of options available to test the hearing of infants and children. However, regardless of how sophisticated testing techniques become, there will always be a need for the insightful audiologist who can determine how to test each child, since it is not cost- or time-effective to administer all tests to every child. No test is "better" than any other, - a broad test battery approach with children is advisable, and audiologists who deal with paediatric patients must be skilled in a wide variety of testing techniques (Northern and Downs 1984).

The tests available for children include (Jerger 1984) :

1. Behavioural Audiometry - observation of overt responses to controlled auditory signals.
    a. Behaviour Observation Audiometry (BOA) - a passive approach where the examiner observes change in behaviour elicited by auditory stimuli. No reinforcement is used. The technique has limitations because responses are not brought under stimulus control.
    b. Visual Reinforcement Audiometry (VRA) - a head turn toward a sound source is reinforced by an attractive visual stimulus (eg an animated toy). Among conditioning procedures for infants, visual reinforcement audiometry has emerged as a successful assessment tool for infants from 6 months to 2 years of age because the response and reinforcement are well geared to the developmental level of infants.

2. Immittance Audiometry is useful in identification of middle ear disease and sensorineural hearing loss through acoustic reflex measures.
    a. Tympanometry - measurement of relative change in compliance of the middle ear system as air pressure is varied in the external ear canal.

b. Static compliance - measurement of the compliance of the middle ear system in its resting state.
c. Acoustic reflex threshold - minimum intensity that will result in a detectable reflexive contraction of the stapedius muscle.

3. Speech Audiometry - measurement of speech reception threshold and recognition of speech for repetition or picture / object identification.

4. Electrophysiological Audiometry
   a. Auditory Brainstem Response (ABR) - electrophysiological activity of neural pathways in response to a click stimulus at the ear.
   b. Evoked Otoacoustic Emissions (EOAE) - the "cochlear echo" waveform received from the ear canal in response to a click stimulus at the ear (Kemp, Ryan and Bray 1990).

2.2. The development of hearing

In the human embryological stage, the commencement of the development of the auditory system is distinguishable at 3 weeks. The development continues through gestation and birth and is only fully complete in the ninth year of life. An extensive review of the responsiveness of the human foetus to acoustic events was published by Tanaka and Arayama in 1969. They investigated the change of foetal heart rate as a response to intense acoustic stimulation and showed that only 50% of the 134 foetuses studied responded up to the "10th month of pregnancy". An earlier study of 12 foetuses by Johansson, Wedenberg and Westin (1964) identified reliable heart rate changes as responses to acoustic stimulation at an average gestational age of 26 weeks. Note that alterations of foetal heart rate have been shown to be independent of maternal heart rate.

The readiness to listen is easily observable in very young children. Gerber (1969) described cessation of motor activity in children as young as 2 months of age - the baby stops moving or crying to listen.

Localisation is a term that has been used to describe a variety of motor behaviours which arise in response to sound. Frisina (1963) reported eye turning at ages as young as 2-4 months. Northern and Downs (1974) claim that an infant will localise to speech by the age of 6 months. Vertical localisation (locating a sound source above the field of vision) which is a rather difficult task , appears toward the end of the first year of life.

Infants start babbling at around 3 to 6 months, initially independent of the amount of human speech in the infant's environment (Lenneberg, Rebelsky and Nichols 1965). Within 2 or 3 months, the infant will start or stop babbling in response to a familiar voice. From 8 months, an infant will start to imitate some sounds (Northern and Downs 1974). The hearing child's ability to control speech passes from the rudimentary babbling stage to recognisable utterances in 24 months.

2.3. Clinical Testing Using Behavioural and Speech Audiometry

Of the tests mentioned above in section 2.1, behavioral and speech audiometry are the subjects of discussion in this thesis, while immittance and electrophysiological audiometry will not be covered.

The first component of any test is to question the parents on the auditory and oral behaviour of the child and ascertain the reason for the request for the test. The parents can give insight into the effect of a certain degree of hearing loss on the child's behaviour and how the history of auditory development relates to the onset and degree of the loss. An experienced audiologist will also spend some time casually observing the child - how he relates to the adults accompanying him, physical activity as an indication of general motor development, and methods of communication.

2.3.1. BIRTH TO 6 MONTHS OF AGE

For the responses expected of this age group, toy noise-makers are the most useful signals, largely because of their sudden, rapid onset. They also produce sounds more complex than pure tones and include high frequency components that have the best arousal value. Examples of such noise-makers are a small bell, a plastic block or rattle with sand inside, a rubber squeeze toy, crinkling tissue paper. The sounds produced by each of these must be measured prior to the test to determine the levels produced by these noise-makers - they obviously cannot be calibrated.

The infant is held on the mother's lap, in a seated or semi-reclining position and the attention of the child is held straight ahead by a toy. The noisemaker is held 10 cm from one ear and behind the ear so that it is out of the child's peripheral vision (two audiologists may be necessary, one to hold the infant's attention, the other to hold and activate the noise maker). After holding the noisemaker still for 10 seconds to ensure that the child is unaware of its presence, it is sounded for no more than 2 seconds. There should be an immediate response : eye widening, quieting, a rapid eye blink, a rudimentary head turn, a slight shudder of the whole body, a marked movement of the arms, legs or body, or any combination of these.

This procedure is repeated with the other sound makers and the other ear. The test is concluded with a low frequency speech signal as the stimulus. This can be presented directly by the audiologist, or via loudspeakers positioned on either side of the child. A "buh-buh-buh" sound is repeated, at a slowly ascending level of presentation from zero. When a response is seen, the test is terminated, and after a pause of 30 seconds or more, a sudden, loud (65 dB) speech signal is presented - a typical Moro's response should be seen. The mother must be warned so as not to jump, giving the infant a cue to react.

If indicated, the speech test can be repeated using a bone conductor pressed firmly by the mother to the top of the head in the midline. A child who responds better to bone conduction signals than air conduction signals should be suspected of having a bone-air gap.

2.3.2. 7 TO 24 MONTHS

From the age of 6 months, a child should be able to turn his head towards a sound, but the number of responses depend on the interest value of the sound to the child. The hearing thresholds drop in this period of life, partly due to development and partly due to a learning process of the meaning of sounds. As the child develops, it is possible to introduce more testing techniques, notably visual reinforcement audiometry and speech discrimination tests. A typical configuration for testing is shown in figure 1.

Northern and Downs (1984) advocate the use of the noise-makers in the behavioral observation audiometry test as described in section 2.3.1 for children up to the age of 2 years - their motivation being that should the child not cooperate in visual reinforcement audiometry, the audiologist will have at least some indication of the hearing abilities of the child. Other audiologists use the narrow band noise feature on audiometers, allowing more accurate measures of the hearing thresholds. Martin (1991) cautions audiologists to ascertain the band width of the narrow band noise - some audiometers have poor filters which pass sufficient energy around the centre frequency to enable the child to hear a stimulus when the child has not heard the centre frequency of that stimulus.

Other aspects of the development of the child in this period may require different techniques from the audiologist. Around the age of 9 months the child passes through a stage of being afraid of strangers who approach too close - thus it may be easier to conduct the test from the darkened observation room. As the understanding of the child develops, the child will respond to commands and be able to identify well known objects. This ability can be used in play and speech audiometry. In play audiometry, the child is instructed to perform a task, such as put a peg in a hole, or a ball on a stick, when a sound is heard. In speech audiometry at this level, the child can be asked to identify objects. It should also be possible to introduce the use of earphones, allowing better measurement of individual ears than with loudspeakers.

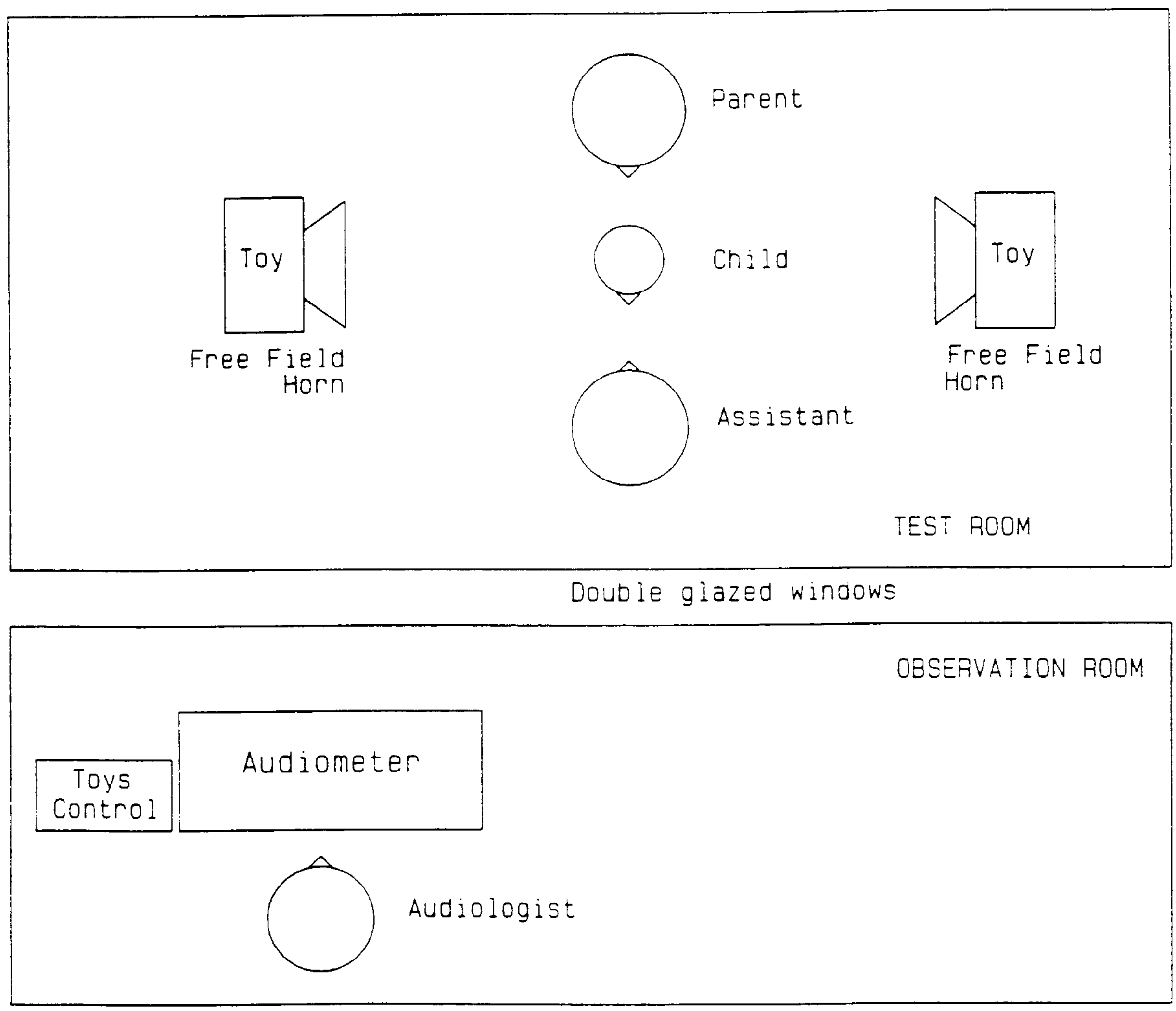


Figure 1. The testing situation for children from 6 months of age.

2.3.3. 2 TO 5 YEARS

As the child is better able to understand what is required of him, pure tones can be used in testing, allowing a more accurate characterisation of a hearing loss. A normal child will have developed the rudiments of speech by this age - a delay could be an indication of a problem. Word discrimination tests can be introduced to assess the nature of a language disability. As the child develops, testing becomes easier, however, as mentioned before, if a problem is present and has not yet been detected by this age, effective treatment will be all the more difficult.

2.4. A Perspective on Visual Reinforcement Audiometry

A standard technique today, visual reinforcement audiometry has been applied and evaluated by many researchers. The first reported use of visual stimuli was reported by Dix and Hallpike (1947) who were successful with the "peep show" where the child was shown pictures in response to an auditory stimulus. Suzuki and Ogiba (1961) described a technique where toys behind a one way glass panel, which are only visible when illuminated, are shown to the child in reward for a correct response. This technique was termed "conditioned orientation reflex" (COR). Liden and Kankunen (1961) expanded on this concept, using a slide projector to show interesting pictures to reinforce a response, and coined the term "visual reinforcement audiometry" (VRA). Visual reinforcement audiometry is currently implemented as follows : one audiologist presents auditory stimuli and controls the provision of reinforcement, and another audiologist or assistant, acting as the distractor, maintains the child's interest straight ahead between stimuli. The child is either held by its mother, or seated on its own if old enough.

A "Puppet in the Window Illuminated Test" (PIWI) which was successful in obtaining thresholds in children under 3 years of age was described by Haug et al. (1967). In 1977, Moore confirmed the success of reinforcement in eliciting responses in infants as young as 5 months using an animated toy.

Northern and Downs (1984) recommend that visual reinforcement audiometry be considered a routine part of any clinical assessment of a child over 5-6 months of age. For the difficult-to-test child and the mentally retarded, Lloyd, Spradlin and Reid (1968) devised a technique they named "Tangible Reinforcement Operant Conditioning Audiometry" (TROCA). In response to an auditory signal, the child presses a bar and is rewarded with a trinket or edible treat. This test is more elaborate than visual reinforcement audiometry, but successful with this group of children. Moore et al (1975) ranked the effectiveness of signals in producing visual reinforcement audiometry localisation responses as follows :

1. animated toy
2. flashing light
3. social reinforcement
4. no reinforcement

Visual reinforcement audiometry has one primary limitation as a screening technique - used in the traditional manner, with one examiner maintaining the child's attention at midline while another, an audiologist, manipulates the equipment from the control room, visual reinforcement audiometry is personnel intensive and expensive. Widen (1990) described a system which automates visual reinforcement audiometry and allows the test to be conducted by one audiologist from within the test room. Their system was used in a pilot project to investigate the optimal screening system for at-risk infants. Widen and co-workers proposed that visual reinforcement audiometry be used to screen infants at 6 months, while other centres investigated ABR and Crib-o-Gram in the newborn period.

The automated system was based on a computer which controlled the selection of stimulus (4000 Hz narrow band noise or speech noise), the level of presentation, the provision of rewards, and recorded and printed results. Although the system was successful, the method was not chosen as the standard procedure mainly due to the universal problem of getting families to return to the centre for screening after they had been discharged. ABR during the newborn period was chosen as the standard procedure.

Their original automated VRA system has been improved, and a more interesting outcome is the ongoing development of a screening algorithm which could lead to a test simpler than the time consuming staircase method of threshold testing. This algorithm was developed by a modification of the Bayesian probability formula and has been tested, along with more traditional threshold testing algorithms, using Monte Carlo simulations that take into account infant auditory response behaviour.

Widen has also reported on attempts of other researchers to automate the visual reinforcement audiometry procedure. Weber (1987) devised a portable VRA unit which included a tape player, to present a wide range of calibrated signals, along with suitable reinforcement stimuli. Popejoy et al (1988) placed a computer in the test room, which, via a menu driven program, controls an audiometer and tape deck in the control room. The reinforcement system is controlled manually in the test room. This system allows one audiologist to execute the test.

2.5. A Perspective on Speech Audiometry

Speech audiometry plays a different, but important role to pure tone (or narrow band noise for children) audiometry. Speech thresholds confirm pure tone results and give a direct measure of hearing for speech. Speech recognition tests determine the degree of clarity with which a child hears speech.

2.5.1. SPEECH THRESHOLD TESTING

Speech is used as a stimulus right from the first tests, where a repeated "buh-buh-buh" sound is presented. This tests the infant's response to low frequency speech. The only information gleaned from this test is the speech reception threshold of the infant. As the child develops a vocabulary, more meaningful speech can be presented, however, the essential measurement of the threshold at which speech is heard remains the same.

2.5.2. SPEECH RECOGNITION TESTING

It is only once the child has developed a rudimentary vocabulary that testing for speech recognition can commence. An important point is that speech tests of hearing should investigate the listener's hearing function, not their speech production or their mental, physical, linguistic or educational abilities (Martin 1987).

One of the first workers to develop a speech recognition test for children was Hudgins (1944) - his test consisted of four monosyllabic word lists based on familiar words called the Phonetically Balanced Familiar (PBF) lists. Haskins (1949) developed a similiar test, consisting of four lists of fifty words each, called the Phonetically Balanced Kindergarten 50s (PBK-50s) test. These two tests were based on an open response design and as such were difficult for children below 6 years. This led to the development of speech recognition tests based on the closed set or multiple choice format (Sortini and Flake, 1953; Pronovost and Dumbleton, 1954; Myatt and Landes, 1963).

Kendall (1953, 1954), designed a speech recognition test for children of age 3 to 5 years using toys. The Kendall Toy test consists of 3 lists, each of 10 monosyllabic words which are represented by small toy replicas. First the child is shown the ten toys to establish if the toys are within the known vocabulary of the child, then the 10 toys together with 5 extra toys (to lessen the possibility of a chance response) are laid out on a table and the child is asked to "show me the ...".

The test devised by Myatt and Landes (1963) was later revised and improved by Ross and Lerman (1970) and became known as the Word Identification by Picture Identification (WIPI) test. It is suitable for 3 to 6 year olds and consists of 4 lists of monosyllabic words arranged into 25 plates with each plate having a 6 picture matrix. A similiar test was developed by Katz and Elliott in 1978 for young (3 year old) inner-city children. Their test is called the NU-CHIPS test (Northwestern University - Children's Perception of Speech). Other tests have been devised along the lines of these mentioned above. These include the Manchester Junior, Picture Vocabulary and Sentence tests (Watson 1957), the AB Isophonemic Word Lists (Boothroyd 1968), the BKB sentence lists (Bench, Koval and Bamford 1979), the Auditory Numbers Test (Erber 1980).

An unusual test is the Sound Effects Recognition Test (SERT) developed by Finitzo-Hieber (1980). This is a non-linguistic test for children around 3 years of age, and is based on 30 environmental sounds, divided into three lists of ten words each, represented on 4 picture matrix plates.

According to Watson (1957), the major criteria for valid speech recognition test for children are the following :

1. they should be constructed of monosyllables
2. the words should be within the vocabulary range of the child
3. the lists should be phonetically balanced
4. the lists should be equal in difficulty
5. the responses required must not involve a skill which will cause the subject any difficulty or the tester any uncertainty.

The WIPI test (Ross and Lerman 1970) which is used at Tygerberg Hospital meets these requirments and is used with much success.

2.6. Objectives of this Study

One of the difficulties encountered in testing the hearing of children which is common to visual reinforcement audiometry and to speech audiometry is that of manpower - additional members of staff to assist in the test are often unavailable, or the parents are more of a hindrance than a help as they do not understand or co-operate as required.

The objectives of this study were :

- to design a remote control system to allow one audiologist to conduct the hearing tests without assistance, with as little additional effort as possible, and in a shorter period than has previously been possible (i.e. to increase cost effectiveness of testing and make better use of available manpower),
- to evaluate the system by analysing the task of the audiologist with and without the remote control system.

3. THE REMOTE CONTROL SYSTEM

3.1. Introduction

The Paedo Audiology section of the Ear, Nose and Throat department at Tygerberg hospital is well established and the staff treat many patients from all around the country. The clinical department works hand-in-hand with the Carel du Toit centre which provides habilitative therapy for hearing impaired children and their parents.

The audiologists often experience difficulties in testing the children, primarily in controlling the child in the test setup, and through poor co-operation from the parents. An extra member of staff is often called in to assist in the test, but as the department is short staffed, this option is often not possible. The audiologists requested some means of controlling the audiometer and tape deck from within the test room, and a picture presentation system. Control from the test room would allow the audiologist to control the child, and the picture presentation system would be used for testing older children who are rapidly bored by the toys used in VRA.

3.2. Overview

A remote control system was required making use of the existing audiometer and tape deck and having minimal impact on the existing arrangement of equipment and the techniques used to conduct the tests.

The audiologists first drew up a user requirements specification - shown as the left column in table 1. As the first step in the design process, a detailed user requirements analysis was conducted to investigate options for implementation of the system, and to draw up a system specification.

This analysis included the following :

- three interviews with the user,
- an analysis of the task of the audiologist (depicted as a flow chart in figure 2, with the requirements for each task tabulated in table 2),
- an investigation of the remote control capabilities of the existing equipment,
- costing of various options and consultation with the Carel Du Toit Trust Fund trustees on project costs,
- acceptance by the user of the system specification,

and many consultations with the user as the system was developed.

Original user requirement	Final system specification
	GENERAL Based on IBM computer Implementation of functionality in software Interface to user via custom built panel with buttons and alphanumeric displays
AUDIOMETER FUNCTIONS Input : masking, tape, pure tone Output : Free field, phone, bone conductor Tone present Frequency (full range) Attenuation (full range) Attenuation range extend (on/off)	AUDIOMETER FUNCTIONS Input : masking, tape, pure tone, warble tone Output : Free field, phone, bone conductor Tone present Frequency (full range) Attenuation (full range) Attenuation range extend (on/off) Reverse (on/off)
TAPE DECK FUNCTIONS Play, stop, pause, rewind, fast forward	TAPE DECK FUNCTIONS Play, stop, pause, rewind, fast forward
VISUAL REINFORCEMENT SYSTEM Serial nature Under operator control Dummy button for testee Adjustable display period (2-15 seconds)	VISUAL REINFORCEMENT SYSTEM Slide projector with lamp dim facility Under user control, forward and reverse Testee has response button Display period adjustable (2-15 seconds)
	OTHER Record data during test facility View data on remote control panel or computer screen Word list display for word discrimination tests

Note : items supplemental to the original user requirement are underlined

Table 1. The user requirement and system specification.

With the information obtained from the detailed user requirements analysis, a system specification was drawn up. As the project progressed, minor changes were made to the system specification. The original user requirement and the final system specification are compared in table 1 (items supplemental to the original user requirement are underlined).

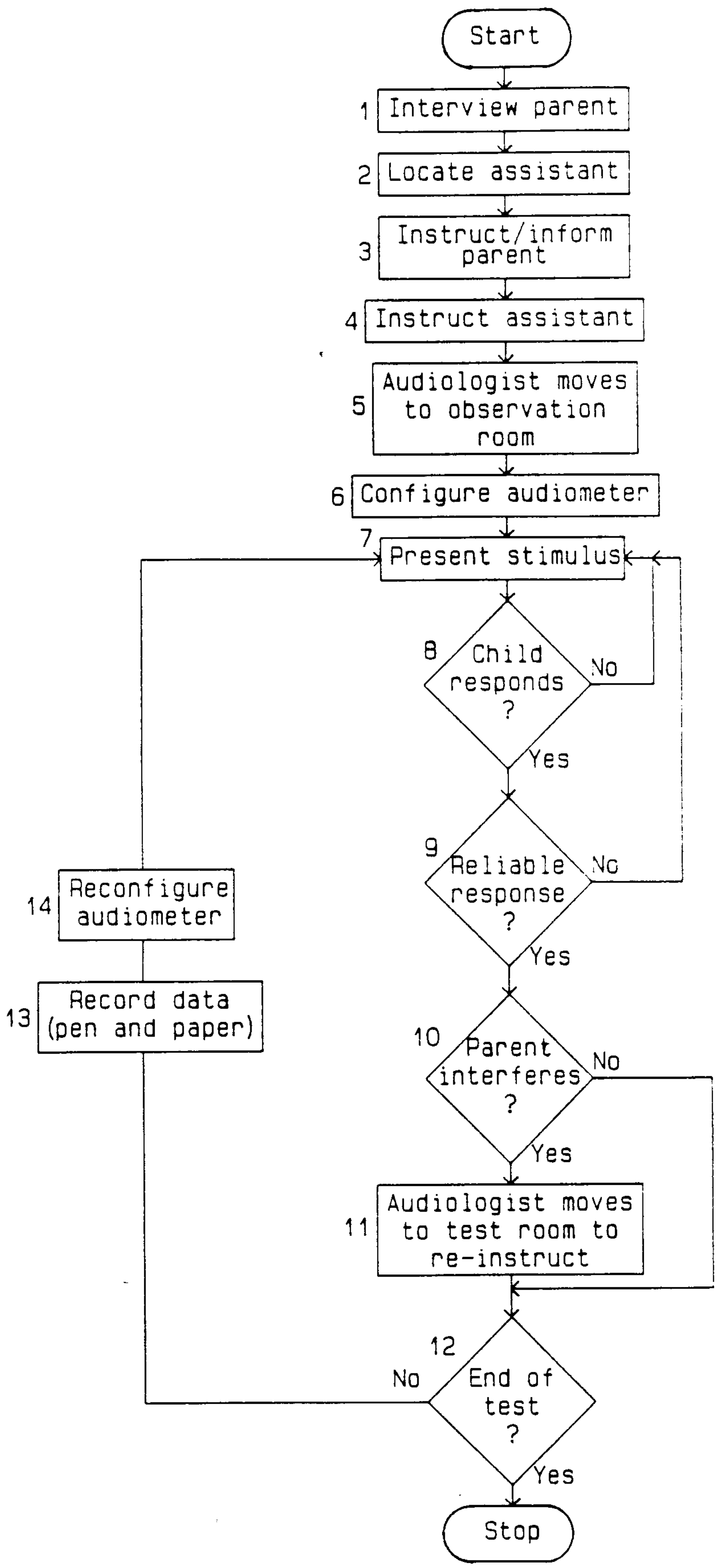


Figure 2. A flow chart of the task of the audiologist performing a basic hearing test.

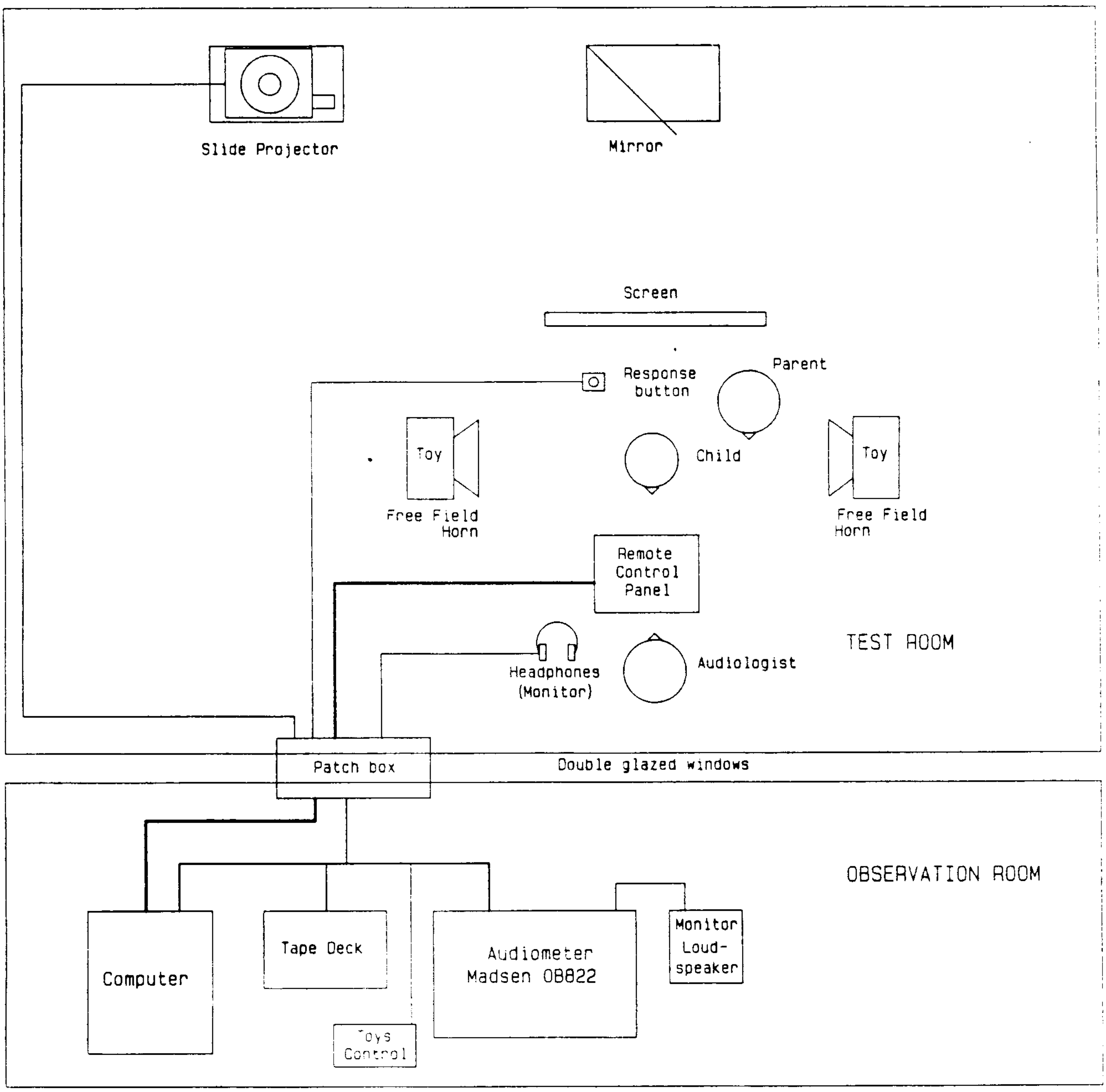
Task	Description	Requirements
1	Question parent about health and history of child	Face to face conversation
2	Locate assistant	Available trained personnel
3	Describe test about to conducted	Face to face conversation
4	Instruct assistant	Face to face conversation
5	Audiologist moves to observation room	Time
6	Configure audiometer	Familiarity with audiometer, hands on access to audiometer
7	Present stimulus	Child in view, and ready and quiet (can be difficult to judge from observation room)
8	Child responds ?	Child in view
9	Reliable response ?	Clear indication of response (may have to rely on assistant's judgement)
10	Action of parent or assistant interferes with test	Clear view of parent and assistant
11	Audiologist returns to test room to correct problem	Time
12	End of test	Sufficient results obtained
13	Record result on paper	Paper, pen / pencil
14	Reconfigure audiometer for next stimulus	Hands on access to audiometer

Table 2. Task requirements of a hearing test.

One major consideration was flexibility - allowing for future development and enhancement of the system. This was achieved through the implementation of the functionality of the system in software running on the computer.

Physical arrangement of the equipment is shown in figure 3. The computer controls the audiometer via a serial communication link, controls the tape deck, reinforcement toys and slide projector via switched signal lines, and interfaces to the user via a custom built remote control panel which accepts commands and informs the user of the status of the equipment under control. The screen is small (600mm square) and free standing and is placed in the position shown only when needed. The remote control panel, user headphones and patient response button can be used anywhere in the room. Other equipment is fixed in the locations shown.

The system is called the Audiometry Environment Remote Control (AERC).



Note :

1. Screen and toys not usually used simultaneously
2. Screen placed in position shown only when needed
3. Child and parent would face screen when used
4. Audiologist can position himself / herself anywhere to have a clear view of the child

Figure 3. The system layout.

Figure 4. A view of the system - using reinforcement toys.

Figure 5. A view of the system - using slides.

The operation of the system is described in the User's Manual and in Goemans (1992) (see appendicies A and B).

3.3. Ergonomic Aspects

3.3.1. PANEL LAYOUT

The remote control panel was designed for this project and consists of :

1. Two alphanumeric displays (to present information to the user).
2. Thirty-three buttons (28 on front panel, 4 on back panel, one recessed in base of panel).
3. A viewing angle adjustment for the displays.

Functional grouping with demarcation, and colour coding enable the user to find the required button quickly and with a high degree of accuracy (Hanes, O'Brien and DiSalvo 1982). The audiometer controls form the largest group on the control panel (see figure 6), and the lines demarcating the left and right group of controls include the displays, left and right. Colour coding identifies the increase / decrease buttons, the option select buttons and the action buttons. The tape deck controls are grouped on the left, the visual controls on the right, and the two monitor controls in the centre (tape deck used to play list of pre-recorded words). Colour coding is used to enhance the

Figure 6. A view of the remote control panel.

demarcation of these groups. The less frequently used buttons, for data recording and for system reset are not mounted on the panel face. The two data recording and data view buttons are mounted on the back, and the system reset button is mounted in a recess on the underside of the panel to prevent inadvertent activation of this button.

The front plate of the panel is sloped toward the user to aid reading of the labels for each button (above the button), and the displays. On / off functions are indicated by a lamp which is integral with its button. The viewing angle adjustment is mounted on the back of the panel.

3.3.2. INFORMATION PRESENTATION

The audiologist using the remote control system receives most of the information on operation of the system on the two displays on the remote control panel. Information presented on the computer screen is viewed only by observers or by the audiologist when viewing recorded data or re-configuring the system.

The displays on the remote control panel are each 4 lines of 16 characters. Data presented on these displays is configured to suit this format, and the location of information within the display is consistent e.g. the current status of the audiometer (input, output, attenuation level and frequency) are shown on the top two lines of the displays, error messages are shown on lines 3 and 4 of both displays, recorded messages are shown on line 3 and tone sequence messages are shown on line 4. As mentioned earlier, on / off functions of the audiometer and other devices are indicated by a lamp which is integral with the button that activates that function.

While the remote control system is active, the computer screen is used to present information on the use of the system - the two displays on the remote control panel are duplicated on the computer screen, and each button pressed is reported on the computer screen. See figure 7. Thus an observer can follow the test conducted by the user - this feature is useful in training student audiologists.

When the remote control system is disabled, a menu is presented on the computer screen. See figure 8.

All menus on the computer screen are bar menus, i.e. the user requests action by moving a cursor bar with the arrow keys (up, down, left, right) and then pressing the enter key. The main menu has context sensitive help which may be switched off, but always comes on by default. Use is made of boxes drawn with different line characters to reduce the chances of "cognitive tunnel vision" (Moray 1981) - the user's attention is locked on a subset of the data to the exclusion of the rest of the data. This decrease in the size of the field of attention can lead to monitoring failures especially when something unexpected occurs.

```
                Date 11/12/1991  Time 14:42:39

Left user display                                Right user display
+------------------+       Audiometry           +------------------+
| PT  1500 Hz      |       Environment          | Mask NB  1500 Hz |
|  30 dB to F.F.   |                            |  45 dB to bone   |
|                  |         Remote             |                  |
|                 *|         Control            |                  |
+------------------+   Version 2.3 16/10/91     +------------------+

                   press any key to disable ...

Buttons pressed by user
Frequency Up
Frequency Up
Frequency Up
Left tone present
Left tone present
Show toy left
Left attenuation up
Left tone present
```

Figure 7. Computer screen display in active mode.

```
                Date 3/12/1991  Time 15:32:52

Left user display                                Right user display
+------------------+       Audiometry           +------------------+
|   Audiometry     |       Environment          |                  |
|   Environment    |                            |  disabled ...    |
|     Remote       |         Remote             |                  |
|     Control  +-------------------+            |                  |
+--------------|     User Menu     | 0/91       +------------------+
               +-------------------+
               |  Enable system    | disable ...
               |  User Parameters  | isabled
Buttons presse |  View results     |
Right range ex |  Load list        |
               |  Control Tape     | [ Help : Enable System ]
               |  Setup projector  |
               |  Build dB table   | Enables remote control system
               |  Edit dB table    | to allow user to control
               |  Test panel       | equipment from the test room
               |  Exit to DOS      | using the remote control
               +-------------------+ panel.  The audiometer panel
               |       = select    | is disabled except for the
               |    ┘  = confirm   | talk over button.
               | F1 = help on/off  |
               +-------------------+
```

Figure 8. The computer screen display in the system inactive mode.

3.3.3. USER CONFIDENCE

Using the remote control panel, the user is physically removed from the equipment under his control, particularly the audiometer. Robson and Crellin (1989) asserted that it is possible to apply "locus of control theory" to interface issues (does the user perceive himself to be in control of a system, or does the system have control over him?). In the case of the remote control, it is important to provide the user with feedback to indicate that he is in control of the system, and that his commands are being executed. This feedback takes the form of a short response time (0.1 second or less) in response to a command to update the displays, and an activity indicator to show that the system is active and ready to accept commands. The activity indicator is implemented as a character in the lower right corner of the left display that changes from "*" to "-" at one second intervals.

3.3.4. DOCUMENT DESIGN

The written instructions on the use of the system are vital to continued utilisation of the system as staff leave and are replaced in the department. We are constantly bombarded with instructions, and ignore many of them. Conrad (1962) reported that when faced with a large mass of printed instructions, the reader takes in very little as it seems too much to understand. The purpose of document design is to provide instructions which people understand and use (Bailey 1982). These instructions must conform to ergonomic guidelines for style, clarity, legibility, organisation and information content. Many writers have produced such guidelines - Bailey (1982) provides a useful selection.

Although the remote control system was intended to function as the equipment which it controls, the system introduces additional features, and in some cases does not function as the equipment under control. Furthermore, the users of the system have little or no experience of using a computer and are very likely to have some resistance to using the system. These and other negative factors can be overcome by effective training on the use of the system, and by helpful and informative user documentation. It is anticipated that the user manual will not be consulted until the user has a working knowledge of the operation of the system, and only needs to clarify minor issues. To this end, the information presented in the user manual must be easy to find, and thorough in describing the operation of the system. Information on configuration of the system which is used less frequently is placed in the System Manager's Manual. Detailed design and maintenance information is found in the design report and maintenance manual, and is intended for readers with a good technical understanding.

With the assistance of the user, a user manual was compiled. This manual went through several revisions, as shortcomings in the system were corrected and as ambiguities and errors in the manual were found. Two users reviewed the manual, worked with the system and either asked questions or made suggestions leading to improvements in the manual. As suggested by Atlas (1981), this user edit proved invaluable in making the user manual easier to use (see appendix B for the manual). The operation of the system is described in detail in the manual, and is referred to in section 3.5 which describes the software of the remote control system.

3.4. Hardware

Existing components of the system before the commencement of this project were the audiometer, tape deck and reinforcement toys. Additional hardware purchased for the project was the computer and slide projector. Items constructed were the remote control panel, an interface circuit inside the computer and a lamp dim circuit inside the slide projector. A block diagram is shown in figure 9. Circuit diagrams are provided in the maintenance manual.

Connection of the audiometer to the computer is via the serial port of the computer. All other devices in the system are controlled via the parallel port of the computer. The interface circuit comprises address decoding and latches to convert data from the parallel port to dedicated signal lines which control the tape deck, slide projector and toys via relays. Thirty two of the buttons on the remote control panel are encoded by a keyboard encoder which presents a code indicating which button has been pressed to the parallel port. The thirty-third button is directly wired to the computer's reset circuitry. The two alphanumeric displays on the remote control panel are addressed by an 8 bit bus derived from the parallel port by the interface circuit.

The lamp dim circuit in the slide projector is a phase control on the main (220V AC) supply. It has only two modes, full power or dimmed and is under control of the computer via one of the dedicated control lines from the interface circuit.

3.5. Software

Software engineering standards for the design, coding and documentation were adhered to in this project (Yourdon and Constantine 1979, DeMarco 1979). The software program is written in the C language and comprises approximately 7000 lines of code broken down into 12 modules. This program represents approximately a one man-year effort.

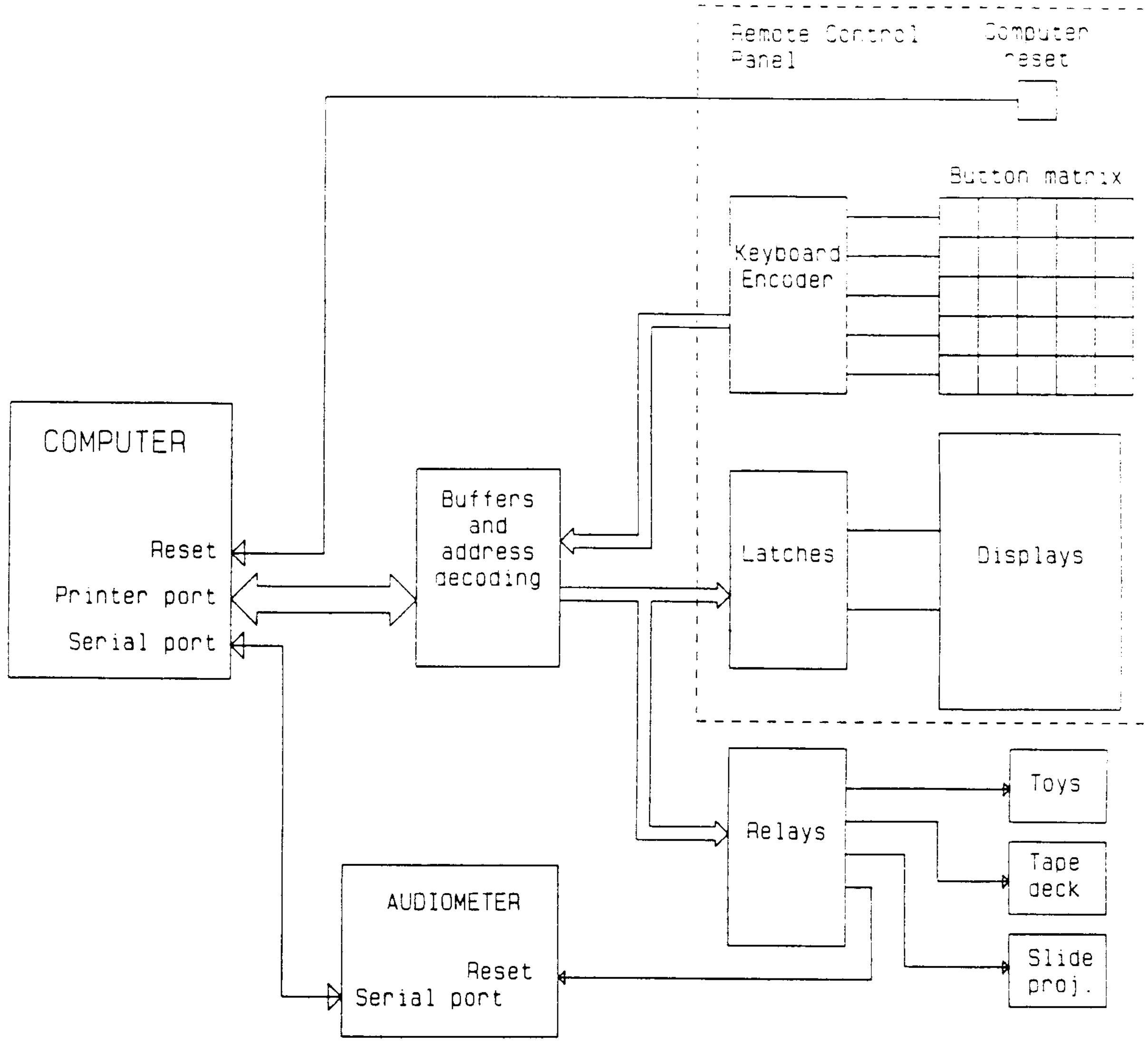


Figure 9. A Block diagram of the AERC system hardware.

The emphasis of the remote control system is to provide the audiologist with an instrument, the remote control panel, to control the equipment in the test setup, where the presence of the computer is transparent. The audiologist need only interact with the computer to re-configure the system, which should not occur often.

There are two modes of operation of the system, active mode where the system responds to commands from the remote control panel, and inactive mode where the audiologist can set up the system using the computer keyboard. For a more detailed discussion of the operation of the system, refer to the User's Manual and Goemans (1992) (appendicies A and B).

Features offered from the remote control panel are as follows :

1. Control of audiometer, left and right channels :
   a. Input select - Tone, Tape, Masking (narrow band, speech noise, white noise).
   b. Output select - Bone, Phone, Free Field.
   c. Attenuation up / down
   d. Tone Present
   e. Range Extend on / off
   f. Reverse on / off
   g. Frequency up / down (applies to both left and right).

2. Control of tape deck (stop, play, pause, rewind and fast forward).

3. Control of reinforcement toys (left and right, show and move).

4. Control of slide projector.

5. Recording of results, hearing threshold and word discrimination tests by computer.

6. Load a word list for display and recording purposes.

7. Display of results on remote control panel.

8. Erase results.

9. Enter age of patient (only used for purposes of study).

In the inactive mode the audiologist interfaces to the computer via menus which require the audiologist to use only the arrow keys and the enter key on the computer keyboard. Features offered to the user from the computer keyboard and display :

1. Activate / deactivate remote control system.

2. Modify user parameters.

3. View recorded results - a more comprehensive viewing facility than that offered from the remote control panel.

4. Load a word list - essentially the same as that offered from the remote control panel.

5. Control tape deck (stop, play, pause, rewind and fast forward) - offered because tape deck stands in test room.

6. Setup projector - keep projector switched on for 15 minutes to allow loading of slide tray, focussing and positioning of screen.

7. Build and edit dB table - a table of maximum level settings of the audiometer required by the remote control program. Can be manually edited under password control or can be built automatically by computer after interrogation of audiometer.

8. Test remote control panel - to test functionality of remote control panel which is a slave device.

9. Quit remote control program to return to DOS.

While the menu offering these choices is active, context sensitive help is provided in a window to the right of the menu. See figure 8. This help window may be disabled or enabled by pressing the F1 key. Refer to the user's manual in the appendix for a detailed description of each of the options in the menu.

The software is capable of detecting errors in normal operation of the system, and takes appropriate action to rectify the fault and continue with the test. Data is stored to disk to enable recovery when the system fails, and to configure the system as last used when powered up. In the event of system failure, the audiologist presses the computer reset button either on the computer itself or in the recess on the underside of the remote control panel.

3.6. Documentation

Documents generated as part of the project are as follows :

1. Design report and maintenance manual (detailed description of design (both hardware and software), software listing, manuals for slide projector and audiometer interface, project correspondence, information for fault finding).

2. User manual (details of user operation of system).

3. System manager's manual (less used information that is hidden from daily users).

The design report is not included in this thesis due to its bulk, but is available at Tygerberg hospital.

4. CLINICAL EVALUATION

4.1. Introduction

The remote control system was commisioned in December 1990. In the first 12 months of use the system was revised and upgraded extensively to add features not planned in the original design. The main reasons for these changes were the unexpected benefits of the system, and the preconceived limits which the audiologists had placed on the system due to their lack of appreciation of the abilities of such a system. These new features were incorporated with relative ease owing to the nature of the original design (i.e. software based system with a minimum of fixed hardware).

The audiologists have reported subjective benefits in using the system. Due to the nature of the system and the nature of the patients tested using the system, it is very difficult to objectively assess the system to prove its merit. A limited study, which is as representative as possible, has been carried out as described in the following sections.

4.2. Assessment method

The basic tenet of this study is task analysis, using techniques developed in the field of ergonomics. A flow diagram of the audiologist conducting a basic hearing test was shown in figure 2. The revised task of the audiologist using the remote control system is shown in figure 10, and the task requirements are tabulated in table 3.

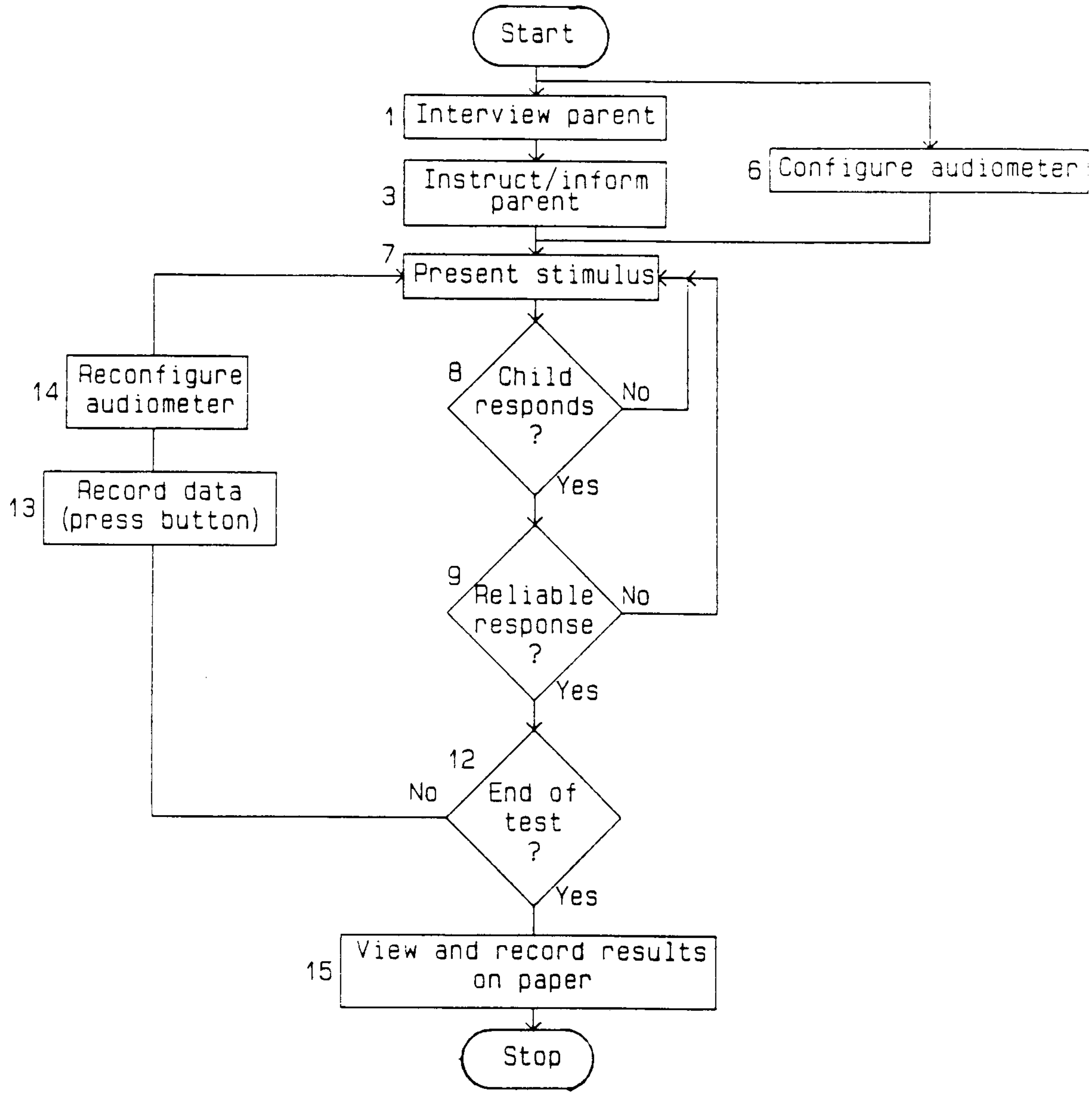


Figure 10. A flow chart of the task of an audiologist using the remote control system.

Notable differences between the task without and with the remote control as shown in figures 2 and 10, and their associated tables (table 2 and table 3) are listed below :

1. Tasks 2,4,5,10,11 are not present in table 3.
2. Task 6 is performed in parallel with tasks 1 and 2.
3. Task 13 is quicker as it requires only the press of a button to record a result as opposed to writing the result on paper.

4. Task 15 being performed at the end of the test allows the test to proceed smoothly, but requires time to record the results on paper (the logical development of providing a printout from a printer will be implemented when a printer becomes available).

Task	Description	Requirements
1	Question parent about health and history of child	Face to face conversation
3	Describe test about to be conducted	Face to face conversation
6	Configure audiometer (done in parallel with tasks 1 and 3)	Familiarity with audiometer, hands on access to control panel
7	Present stimulus	Child in view, and ready and quiet (easily judged from test room)
8	Child responds ?	Child in view
9	Reliable response ?	Clear indication of response
12	End of test	Sufficient results obtained
13	Record result	Press a button
14	Reconfigure audiometer for next stimulus	Hands on access to control panel
15	Record results on paper	Paper, pen/pencil

Table 3. Task requirements of a hearing test using the remote control system.

In the first part of the study, six audiologists were set tasks to complete, both with and without the remote control system. Three of the audiologists had not been exposed to the system prior to the test and could be considered to be novice users, while the other three had been exposed to the system, but had not used it extensively and could be considered familiar users. Before performing the tasks with the remote control system, the users were trained by the system manager. The system manager could be considered an experienced user (having used the system extensively) and did not participate in the first part of the study. As children are so variable in their behaviour and understanding of what is required of them, and would be unlikely to co-operate for the duration of the test procedure, adult volunteers were used as the subjects in these tests. Thus one important element of the real-life test is missing : control of the child.

A video recording of each audiologist executing the tasks was made. After completion of the test procedure, the audiologists viewed the video recording and were asked to comment on their actions. The adult subject was also interviewed and asked to reply to a set of questions. The test procedure and interview questions appear in appendix C.

For the second part of the study, in order to assess the system in the real-life scenario, several tests of randomly selected children by two audiologists who were experienced in use of the remote control were discreetly recorded on video, and later viewed and analysed. The audiologists were asked to alternate their testing technique (with and without remote control) wherever possible. In these cases, the nature and duration of the test was not controlled, and depended solely on the clinical requirements for each child. At the end of the study, these two audiologists were interviewed while viewing the video recordings of the tests.

4.3. Results and Discussion

For the first part of study where adults were used as the test subjects in a controlled task, the results are presented as a table of the times taken to complete the tasks by each audiologist, and as a table of comments made by the audiologists. The novice users are labelled a, b, and c, the familiar users are labelled 1, 2, and 3.

User	Time to complete task Without remote control	With remote control
a	18 man minutes	15 man minutes
b	14	10
c	16	12
1	11:45	11:45
2	17	12:30
3	22	8:30

Table 4. Time to complete tasks, novice and familiar users.

DISCUSSION - TABLE 4.

Data in this table is expressed in man-minutes so as to take account of the number of personnel involved in the test (two without remote control, one with remote control). The times taken by each audiologist to complete the set tasks vary considerably - particularly the times for the task without the remote control which involved no learning or adaptation. The factors leading to these differences include differing levels of experience in audiology, different techniques, and different subjects.

Use of the remote control system in performing the test did not result in substantial time savings (man minutes) as might have been expected. This is a useful result in that it indicates that the training and practise necessary to use the remote control should not be underestimated.

In the real-life situation, where the subjects are children, the time taken to instruct the mother what to do in the test, and to correct when the mother does not co-operate, lengthen the test considerably, and this is where the main time saving with the remote control occurs.

	User Comments	Occurrence (maximum 6)
1.	Remote control allows better control of patient	5
2.	Remote control relieves tester of inconvenience of finding an assistant	2
3.	Remote control saves time spent explaining to mother what to do during test	2
4.	Remote control not suitable for adults	1
5.	Good to have similar functions to audiometer	1
6.	Closed set of audiometer buttons on remote control easier to operate than audiometer	1
7.	Response to button press is slow	3
8.	The buttons make too much noise when pressed	2
9.	Tone present duration control poor	1
10.	Toy and slide buttons should be adjacent to tone present	1
11.	Slide reverse needed	1
12.	Inconsistency of press or hold buttons confusing	1
13.	Practice will improve performance	6

Table 5. Comments made by users on Remote control system.

DISCUSSION - TABLE 5.

Comments made by the users were unsolicited, and since it was considered likely that some aspects had not occurred to the other users, the list of comments was drawn up as a list of statements, and 5 of the 6 users (one was not available) were asked to respond True or False to each statement. These results are shown in table 6.

As the true/false results show, most of the users agreed with the comments made by the other users. Where practicable, the system was improved in response to the comments, and where not possible, users were advised so as to be able to avoid the problems encountered. A few minor faults and shortcomings in the system were identified and corrected through the assessment exercise. These are listed below :

1. Two buttons added (view results and slide reverse) - to remove ambiguity in a dual function of a button and to improve slide control (the view records button had a second function when held for 5 seconds, and slide reverse was not provided).

2. Response time to button press improved by a change in the communication sequence with the audiometer.

3. Other minor procedural faults which had not previously been found.

Response to user comments		True	False
1.	Remote control allows better control of patient	100%	0%
2.	Remote control relieves tester of inconvenience of finding an assistant	100%	0%
3.	Remote control saves time spent explaining to mother what to do during test	100%	0%
4.	Good to have similar functions to audiometer	100%	0%
5.	Remote control not suitable for adults	80%	20%
6.	Slide reverse needed	80%	20%
7.	Tone present duration control poor	60%	40%
8.	The buttons make too much noise when pressed	40%	60%
9.	Response to button press is slow	40%	60%
10.	Closed set of audiometer buttons on remote control easier to operate than audiometer	20%	80%
11.	Toy and slide buttons should be adjacent to tone present	20%	80%
12.	Practice will improve performance	100%	0%

Table 6. Response to user comments.

As the same subject was used for the test with and without the remote control, the subjects were able to comment on the differences between the two scenarios. These comments are shown in the following table.

Subject Comments		Occurrence (maximum 6)
1.	I prefer having tester in test room - I don't know what is going on when tester is in observation room	4
2.	Tester in test room distracts me from test	4
3.	The word discrimination picture recognition slides are better than the book	1

Table 7. Comments made by test subjects.

DISCUSSION - TABLE 7.

The first two comments made by the test subjects are contradictory (prefer to have tester in room, but tester is a distraction), and comment 3 would not apply to children. In the second part of the study (children subjects, real-life tests), the children were noted to be oblivious of the tester's actions (pressing buttons on the remote control), and usually concentrated on the game they were given to occupy them. The children were noted to enjoy the slide show, possibly because of the difference in format to that of a book.

DISCUSSION - PART TWO OF STUDY

Comments made by the experienced users of the system :

Disadvantages of the system

1. The more introvert patient may react to the presence of the audiologist and the remote control panel in the test room by inhibiting responses to test sounds - more so than would be the case had only the patient been present. In this case the audiologist would perform the test from the control room. A classic example of this situation was recorded on video during the study - the child (aged 28 months, and not yet talking) appeared to have a considerable hearing loss when tested with the audiologist in the test room using the remote control, but was shown to have normal hearing when tested from the control room without the remote control. The speech development problem was ascribed to the overbearing attitude of the father.

Advantages of the system

1. The test can be performed by one audiologist without an assistant - a saving in manpower.

2. The optimum moment for sound presentation in terms of
   a) the child's readiness to respond
   b) level of ambient noise generated by the child
   can be judged better by the audiologist from within the test room.

3. The presence of the audiologist in the test room often helps to keep restless or distractable children in check long enough for a successful test to be carried out; a goal which is sometimes not achieved with a familiar person acting as distractor.

4. The added appeal of the slide show facilitates an extension of the period of time a child in the "conditioning" category would co-operate.

5. Remote control makes it possible to perform speech discrimination tests by means of a tape recording on much younger children than would be the case had the tape deck and audiometer been operated from the control room.

5. CONCLUSION, RECOMMENDATIONS AND FURTHER DEVELOPMENTS

The system in its final form surpassed the original concept and the original user requirement specification to a considerable degree. Although the system performs many functions and is thus complex, it has been well received by the clinical staff. During a recent breakdown where the system was unusable for 2 weeks due to a software fault, the users realised that they were hard pressed to work without the remote control system.

The literature survey in the well researched field of paedo-audiology describes the efforts of many researchers to improve the testing accuracy and reliability of audiometric testing. Computer technology has facilitated low cost systems which are capable of substantial data processing and relieve the audiologists in audiometry of the laborious personnel intensive tasks which make it difficult to test all children accurately.

The audiometry environment remote control system described here brings several of the tried and tested techniques of testing the hearing of children together in a format which allows one audiologist to conduct the tests. Although limited, the evaluation highlighted some of the benefits of the system, and identified areas where additional training was required.

Remote control of the audiometric equipment has been the major goal of this project, however, the power of the computer could be harnessed to improve the reliability of the test results. Allowing the computer to introduce random controls, where the user only provides start, stop and response / no response information, would remove user bias. Inclusion of the work of Popejoy (1988) could yield a powerful test system which would enable the clinical staff at Tygerberg Hospital and similar centres to test children accurately and quickly, referring those who have a hearing loss to centres for assistance. This would be a logical extension to this work, but falls out of its scope.

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APPENDIX A. PUBLICATIONS

The first paper : "Audiometry environment remote control system" appears in the September issue of Medical and Biological Engineering and Computing. A copy of the galley proof is shown in this appendix.

The paper entitled "Ergonomic aspects of a remote control system for use in paedo-audiometry" has been submitted to the Applied Ergonomics journal.

Communication

Audiometry environment remote control system

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1 Introduction

AUDIOMETRIC TESTS of children up to the age of 30 months has always been difficult and requires skill and experience on the part of the audiologist to yield reliable results. To facilitate testing, techniques of reinforcing the response to an auditory stimulus with another stimulus (usually visual) have been devised. An early example of reinforcement was the 'peep show' reported by DIX and HALLPIKE (1974) where the child was shown pictures on response to an auditory stimulus. HAUG *et al.* (1967) described a 'puppet in the window illuminated test' (PIWI), which was successful in obtaining thresholds in children under 3 years of age. MOORE *et al.* (1977) used an animated toy and confirmed the success of reinforcement in elicititing responses in infants as young as 5 months. Children of 30 months and older can be conditioned to do something, e.g. to put a ball on a stick every time they hear a sound. Both reinforcement and conditioning have been developed and used by many audiologists (KATZ, 1985), but in the techniques reported, the audiologist conducts the test from a control room and is isolated from the patient, which can be disadvantageous.

Usually, the hearing of children (7–30 months) is tested in a free-field setup between loudspeakers. Babies under 12 months are seated on their mother's lap while a third person in front of the child acts as a distractor. The role of the distractor is to draw the child's attention away from the visual stimulus after a reward has been given. Ideally, children 12–30 months should sit on their own at a small table between the loudspeakers in which case the mother/parent can act as distractor. The audiologist sits behind a one-way window at the audiometer console and conducts the test from the control room. When a noise is presented to an ear, the child turns to look towards the source of the sound. If the child does not perceive the source to be interesting, subsequent sounds may be ignored. As a reward for the response, the child is shown a toy which is mounted in a box below the free-field speaker. This toy is only visible when a lamp in the box is lit by the audiologist. The toy may also be energised to move, adding another dimension of interest. To introduce variety, a slide projector has been used to present a wide range of interesting pictures (LIDEN and KANKKUNEN, 1969).

Conditioning is used when testing the hearing of older children (30 months and older). The test sounds are now presented per earphone and a smaller audiometer in the test room. The audiologist sits next to the child in the test room.

In the procedures described above, the tests are often disrupted if the parent of the child is used as a distractor. The parents either prompt the child to respond before the child has really heard the sound, or fail in drawing the child's attention away from the toy box after a reward has been given. Furthermore, parents often have difficulty in confining the child to the test setup and keeping him/her quiet enough for low-volume sounds to be presented, whereas the mere presence of a stranger in the test room, e.g. the audiologist, can often facilitate this. NORTHERN and DOWNS (1984) proposed the use of an assistant tester with a high level of cooperation between audiologist and tester. However, in this hospital, it is often not possible to have the assistance of another member of staff to act as distractor.

With these difficulties in mind, the users of the existing equipment asked if it would be possible to control the equipment in the control room from inside the test room, while sitting next to or opposite the child. This would solve the problems associated with the control of the child in a free-field test setup. In addition, a visual presentation system for use with tests with earphones (conditioning tests) was requested.

Existing equipment in the audiology room was as follows: a Madsen OB822 audiometer which is computer controlled, and has facilities for a communication link; a tape deck used with the audiometer; and toys controlled by a hand-held radio transmitter which is kept alongside the audiometer. A slide projetor was purchased for the project.

2 Remote control system

The controls for all the equipment used: audiometer, slide projector, tape player and reinforcement toys, are integrated into a small portable panel (300 mm square). The layout of the system *in situ* is shown in Fig. 1. The screen is small (600 mm square) and free standing and is placed in the position shown only when needed. The remote-control panel, user headphones and patient response button can be used anywhere in the room. The other equipment is fixed in the locations shown. Note that the toys and slides are not usually used simultaneously.

2.1 *Hardware*

As the audiometer can only be controlled by an intelligent device, a computer-based solution was indicated and the system is based on an IBM-compatible computer. The software program written for this project controls the other devices to execute all the necessary functions. A block diagram of the circuitry designed for the system is shown in Fig. 2. The remote-control panel and interface circuits are slave devices; thus faults in the circuitry will not be detected by the computer. A test procedure is provided in the software program to verify the functionality of the hardware if a fault is suspected.

The visual system was to be flexible and low cost—thus a slide projector and slides were used (LIDEN and KANKKUNEN, 1969). Owing to the physical space constraints in the test room, a mirror is used to extend the projection length. The slide projector is enclosed in an acoustically damped box to reduce the noise generated by the fan.

The user requirement of the display of the images was that each image be presented for a fixed period of between 1 and 15 s, and then be blanked. The slide projector was modified internally to provide a lamp dim function which could be controlled by the computer. At the end of a display period, the lamp is dimmed and the slide projector instructed to advance to the next slide. The image is not visible on the screen while the lamp is dimmed, and when the audiologist next presses the Slide Advance button, full power is applied to the lamp and the image is seen on the screen.

The remote control panel with which the user controls all the equipment is a keyboard with two displays (Fig. 3).

The status of the audiometer, errors and other information is shown on the dislays. The functions are grouped: audiometer, tape, visual. The audiometer functions provided are a subset of the functions available on the audiometer console: input select, output select, frequency up and down, attenuation up and down, range extend, reverse and

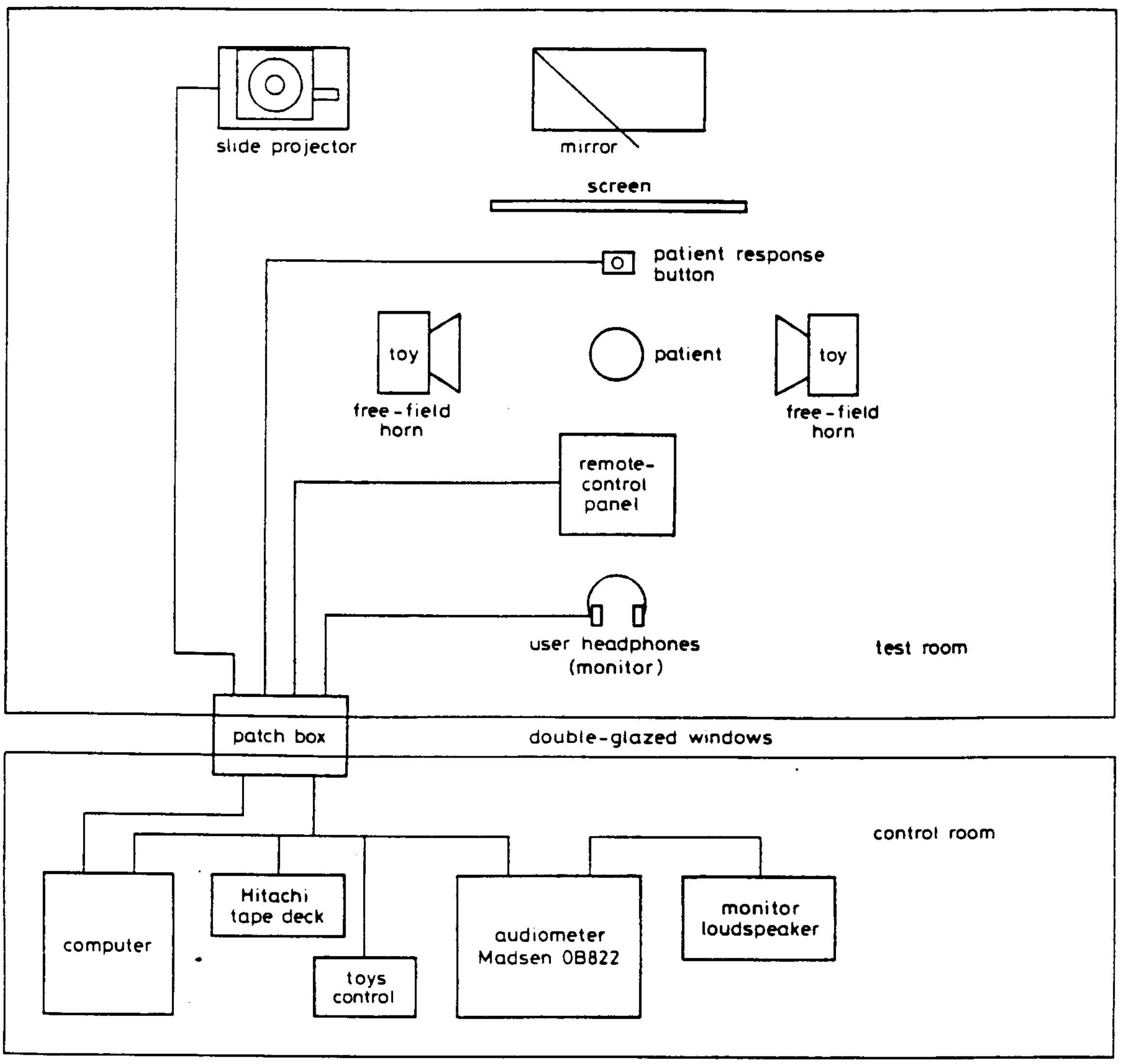

Fig. 1 *System layout*

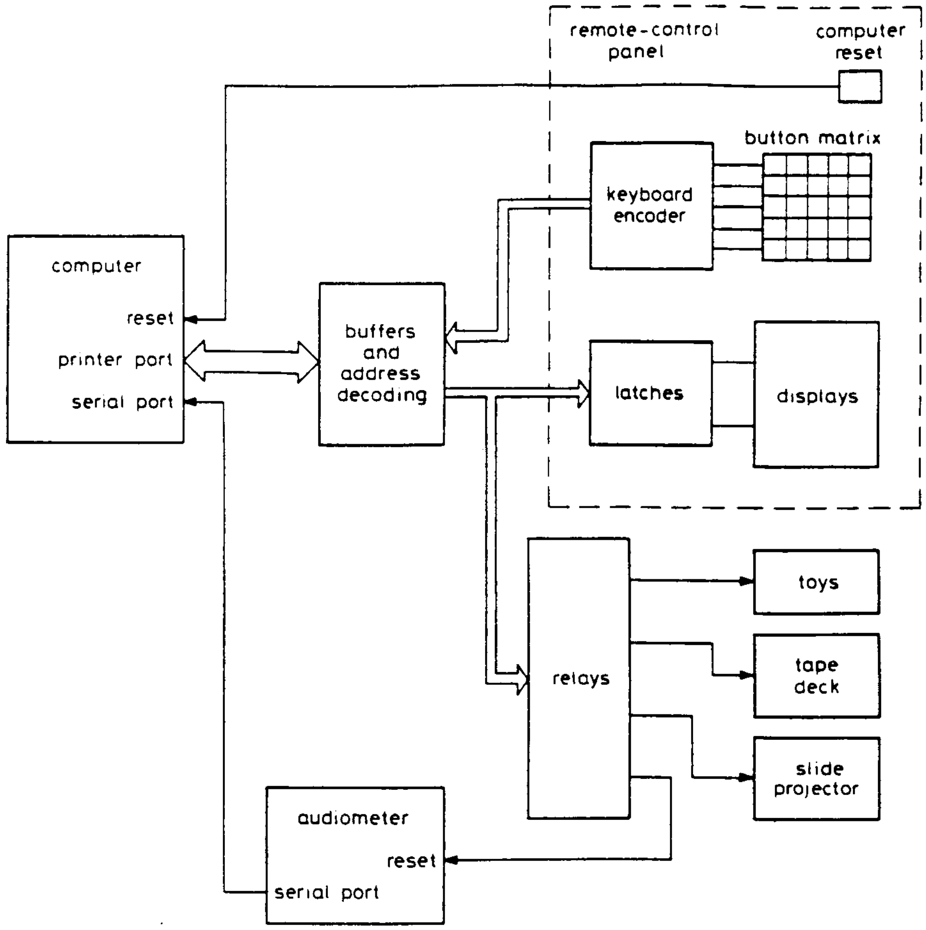

Fig. 2 *Block diagram of the hardware*

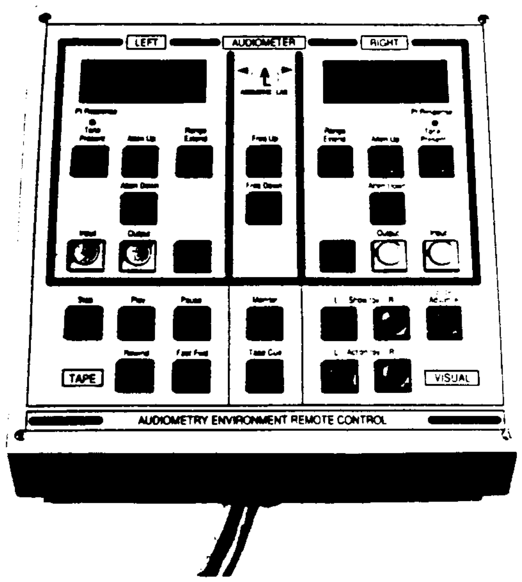

Fig. 3 *Remote-control panel*

tone present. The tape and visual control functions are as on the existing equipment; the monitor on/off controls the user's headphones and the tape cue function is to allow only the user and not the patient to hear the tape while cueing. The two buttons on the back panel of the remote control are the left and right Record buttons—when one of these is pressed, the attenuation level, input, output, frequency and contra-lateral masking of the respective channel is recorded by the computer. This feature allows the user to continue with the test procedure without having to take notes of the results. On completion of the test, the user may view the recorded data on the computer screen.

The Tone Present function on the remote control operates in a different mode from the function on the audiometer control panel. On the audiometer, the tone present button is held as long as desired; however, due to the communication protocol of the audiometer, the computer must instruct the audiometer to present a tone for a given length of time. The computer program allows the user to present multiple tones in a tone sequence, where the length and number of the tones is variable. The number of tones in the sequence and the progress of the sequence are displayed on the relevant user dislay (left or right) as 'tone 1 of 3', 'tone 2 of 3' etc. If the option is used, the computer will vary the number of tones in a sequence, and the length of each tone in a sequence on a random manner. The user provides the limits of random variation.

2.2 *Software*

The software was written in C, using the Turbo C development package from Borland. A shareware package was also used: Litecomm—a complete serial communications support library.

The formatting overhead of recordings passed to and from the audiometer is considerable, and the serial communications are the weak link in the response time of the system. The operating modes of the audiometer are complex, and in view of the limitations of the serial communications, it was decided to mimic the operating modes of the audiometer in software rather than have the audiometer report its setup status after each command. If the dB table is incorrrect, it is possible that the computer could get out of step with the audiometer; thus after every 20 key presses, the status of the audiometer is requested and compared with the software status. If a discrepancy exists, the audiometer is reset and reconfigurèd to agree with the software setup.

The audiometer also provides information on the timing of the patient resonse to a tone. This information imposes a further communication overhead, and the communication protocol is not followed when this information is transmitted. Unfortunately this feature cannot be disabled.

A flowchart depicting the program sequence is shown in Fig. 4.

2.3 *System operation*

When the computer is switched on, the remote-control program commences execution. The program has two modes of operation: active mode and inactive mode.

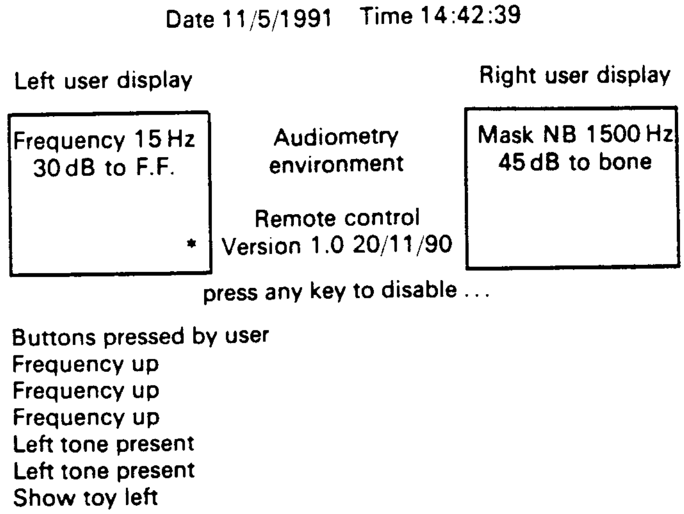

Fig. 5 *Active mode screen display*

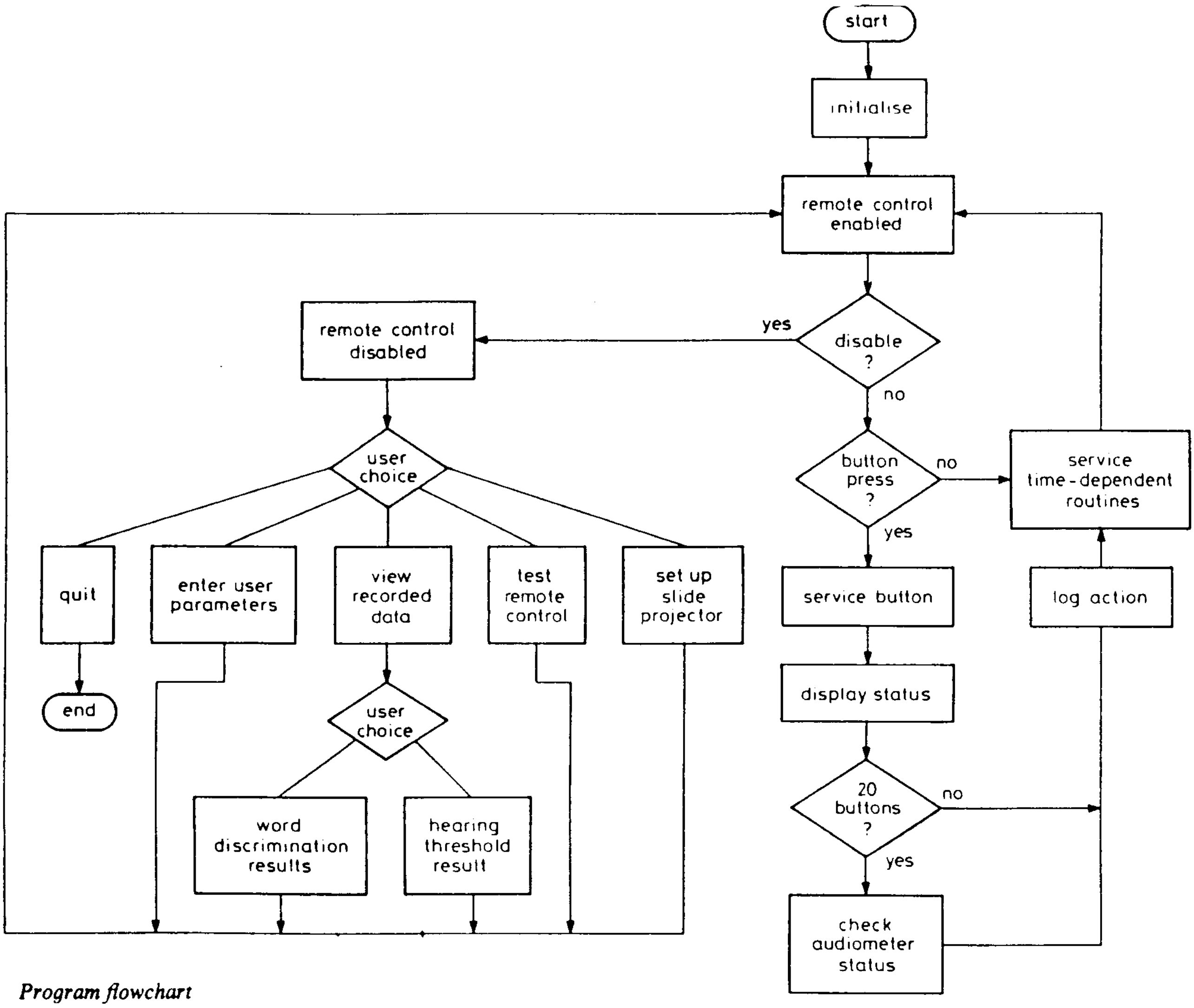

Fig. 4 *Program flowchart*

2.3.1 *Active mode.* The program immediately goes into active mode, with the start-up computer display as shown in Fig. 5. The last used setup of the audiometer, and the user parameters are retrieved from disk and the system comes up in the model last used.

The two user displays on the remote control panel are duplicated on the computer screen. The date and time are displayed on the top line of the screen. The remote control is now active, and will remain active until any key is pressed on the computer keyboard. An activity indicator is provided in the bottom right corner of the left display in the form of a character which changes from '*' to '–' at 1 s intervals.

As the user presses buttons on the remote-control panel, the actions are reported on the computer screen. These actions are also recorded in a log file.

The user has the facility to record the measured hearing level for an ear at a particular frequency. The system has been enhanced since its original installation by the addition of a feature to record the results of word discrimination tests. When 'tape' is selected as an input, and if a word list name has been supplied, that word list is loaded from disk, and the words are then shown on the unused channel display (left or right). The user advances the word list as the words are presented from the tape deck, and the word and the attenuation level are recorded when the record button is pressed.

2.3.2 *Inactive mode.* When a key is pressed on the computer keyboard, the remote control is disabled. The computer now presents the user with several options (Fig. 6). On completion of each option, the program returns to the remote control active mode.

The slide projector setup mode keeps the slide projector on for a period of 15 min to allow positioning of the screen, loading of slide trays and focusing. The test remote control facility is to test the functionality of the remote control panel and interface, which is a slave unit. The edit and build table utilities maintain the table used in the program to mimic the functions of the audiometer. The edit utility is for manual entry or editing of the table; the build utility is an automated process where the computer interrogates the audiometer to build the table (this process takes about 10 min and is executed automatically once a month or manually when the audiometer is calibrated).

2.3.3 *User parameter entry.* The user may modify parameters which control the period of the presentation of a slide on the screen, the length and number of tones in a sequence, the left/right transposition of the audiometer and

Date 11/5/1991 Time 14:43:55

left user display		Right user display
Audiometry environment remote control	Audiometry environment Remote control Verson 1.0 20/11/90	disabled ...

remote control disabled

press spacebar〉	to enable remote control
〈ENTER〉	to modify user parameters
〈v〉	to view recorded patient data
〈l〉	to load word list
〈e〉	to edit maximum dB table
〈b〉	to build dB table
〈s〉	to setup projector
〈t〉	to test remote control
〈q〉	to quit to DOS

Fig. 6 *Inactive mode screen display*

toy controls and the reporting of patient response.

2.3.4 *Load word list.* To record results while performing word discrimination tests, the computer must know what words are being presented. To this end, the user selects a word list which is loaded by the program. The user may also load a list using the buttons on the remote-control panel.

2.3.5 *View recorded patient data.* The data recorded can be viewed by pressing the left and right record buttons on the back panel of the remote control. The user may view either word discrimination test results or hearing threshold test results.

2.3.5.1 *Hearing threshold test results.* An example of hearing threshold test results is shown in Fig. 7. Each line represents a recording from a button press. If the left button was pressed, only the left column will have an entry, and likewise for the right. If contralateral masking was used, this is indicated as an entry in both columns

Audiometry environment remote control
Recorded patient data

Pure tone phone Frequency	Attenuation left	Attenuation right
500 Hz		45 dB
1000 Hz	40 dB	
1000 Hz		45 dB
2000 Hz	35 dB	
2000 Hz		45 dB
4000 Hz	45 dB	
4000 Hz		45 dB
1000 Hz	45 dB	45 dB mask NB
1000 Hz	45 dB mask NB	40 dB
2000 Hz	45 dB	45 dB mask NB
2000 Hz	45 dB mask NB	45 dB
4000 Hz	45 dB	45 dB mask NB
4000 Hz	45 dB mask NB	45 dB

Press any key for next screen, 〈b〉 for last screen, or 〈q〉 to quit.

Fig. 7 *Example of the recorded hearing threshold data*

with the attenuation level of the masking, the type of masking noted in the masked channel, and the tone level in the other channel. These data could be presented as an audiogram—an option yet to be implemented.

2.3.5.2 *Word discrimination test results.* An example of word discrimination test results is shown in Fig. 8. The words recognised at each hearing threshold level are shown under that level. The levels are sorted in increasing order, and the percentage of words recognised at each level is given. This percentage assumes that the whole list of words was presented.

3 Preliminary experiences in use of the system

The system has been in use since December 1990. In general, the users have found it much easier to conduct tests while sitting next to or opposite the testee.

The cable connection of the remote control panel has not proved too cumbersome, but the provision of a wireless link is envisaged as a further development. The layout of the visual system control buttons on the panel could be improved by placing these buttons adjacent to the tone present buttons.

A view of the system in use (with conditioning) is shown in Fig. 9.

3.1 *Disadvantages of the system*

(*a*) The more introvert patient may react to the presence of the audiologist and the remote control panel in the test room by inhibiting responses to test sounds—more so than would be the case had only the patient been present. In this case the audiologist would perform the test from the control room.

3.2 *Advantages of the system*

(*a*) The optimum moment for sound presentation in terms of

(i) the child's readiness to respond
(ii) level of ambient noise generated by testee

can be judged better from within the test room.

(*b*) The presence of the audiologist in the test room often helps to keep restless or distractable children in check long enough for a successful test to be carried out; a

Audiometry environment remote control
Word discrimination test results

Left channel Level	Words	Right channel Level	words
45 dB	1 comb	20 dB	1 comb
	2 car		2 car
20 per cent recognised		20 per cent recognised	
50 dB	2 Car	30 dB	1 Comb
10 per cent recognised			2 car
			3 horse
55 dB	1 comb		4 spoon
	2 car		5 tree
	3 horse		6 boat
	4 spoon	60 per cent recognised	
	5 tree		
	6 boat	40 dB	1 comb
	7 bath		2 car
	8 ball		3 horse
	9 shoe		4 spoon
	10 key		5 tree
	3 horse		6 boat
	4 spoon	60 per cent recognised	

Percentage is given for 10 words presented
Press any key to exit, ⟨e⟩ to erase these data

Fig. 8 *Example of the word discrimination test results*

Fig. 9 *The system in use*

goal which is sometimes not achieved with a familiar person acting as distractor.

(*c*) The added appeal of the slide show facilitates an extension of the period of time a child in the 'conditioning' category will co-operate.

(*d*) Remote control of the tape deck makes it possible to perform speech discrimination tests by means of a tape recording on much younger children than would be the case had the tape deck been operated from the control room.

4 Discussion

The concept of testing children with the audiologist, audiometer and reinforcement control in the same room is not new; however, the system described here integrates all these controls into one panel, allowing the test to be performed by one person, and offering that person flexibility in testing a child. The features of this system are as follows:

(i) control of audiometer, tape player and visual system from one panel

(ii) electronic recording of results (with potential for data storage)

(iii) integration of word recognition (picture recognition) test using slides to display pictures, tape player to present words, audiometer to control levels, and computer to record results.

The system described here now offers the audiologist two types of visual reinforcement, namely pictures and toys (which may be animated). It may be of interest to note the responses of children to these two types—some children are very scared of the toys, some respond better to the three-dimensional toys than to the two-dimensional pictures. It is planned to experiment with animated pictures, using the remote-control system.

This system has been developed for a Madsen audiometer, but should be equally applicable to other audiometers. The modules of the software which mimic the operation of the audiometer and communicate with the audiometer would have to be adapted to use this system on another audiometer.

Acknowledgements—The hardware costs of this project were covered by the Carel Du Toit Trust Fund, a welfare organisation which assists hearing-impaired children in many ways. Without their support this project would not have been possible. The valuable advice and input of the users who conceived the idea of the system, and continue to contribute to improvements, are acknowledged.

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ERGONOMIC ASPECTS OF A REMOTE CONTROL SYSTEM FOR USE IN PAEDO-AUDIOMETRY

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ABSTRACT

Audiometric testing in children is a) difficult and b) an often unreliable procedure. Audiologists employ a variety of techniques and strategies to elicit a useful test result. A remote control system has been developed to afford the audiologist closer control over the child by being in the same room as the child while using the full array of audiometric equipment (instead of being behind a one way mirror in the observation room). Consideration of the ergonomic aspects of the design is shown to have contributed to a system which is well accepted by the users. The results of a limited evaluation are discussed. The primary benefit of the remote control system is shown to be a saving in both time and manpower. This should be of interest to audiology screening programmes in all countries, and possibly more so where specialised treatment centres are sparse.

INTRODUCTION

Speech and language are imitative processes, acquired primarily through the auditory sense. A hearing defect, either congenital or acquired early in life, can interfere with the development of concepts that culminate in normal speech and language. Thus, the earliest possible identification of a hearing deficit is crucial. The earlier in life aural habilitative measures can be applied, the greater are the chances for the successful development of speech communication (Martin 1991).

Testing the hearing of co-operative adults is straightforward. However, due to the unpredictable and variable nature of children an audiologist needs many skills and techniques plus patience and experience to secure a reliable result.

This is particularly relevant in children less than 30 months of age. There are several types of tests, some requiring active participation by the child, others measuring neural signals induced by sound stimuli. This paper concentrates on pure tone and speech audiometry, where sound stimuli are presented to a child, and the child is expected to respond with a physical movement such as an eye blink, a startle or a head turn.

A child 7 months of age or older is generally able to turn its head in response to a sound, and it is from this age onwards that audiometric tests can be performed with an acceptable degree of reliability and repeatability. The typical testing setup is as shown in figure 1.

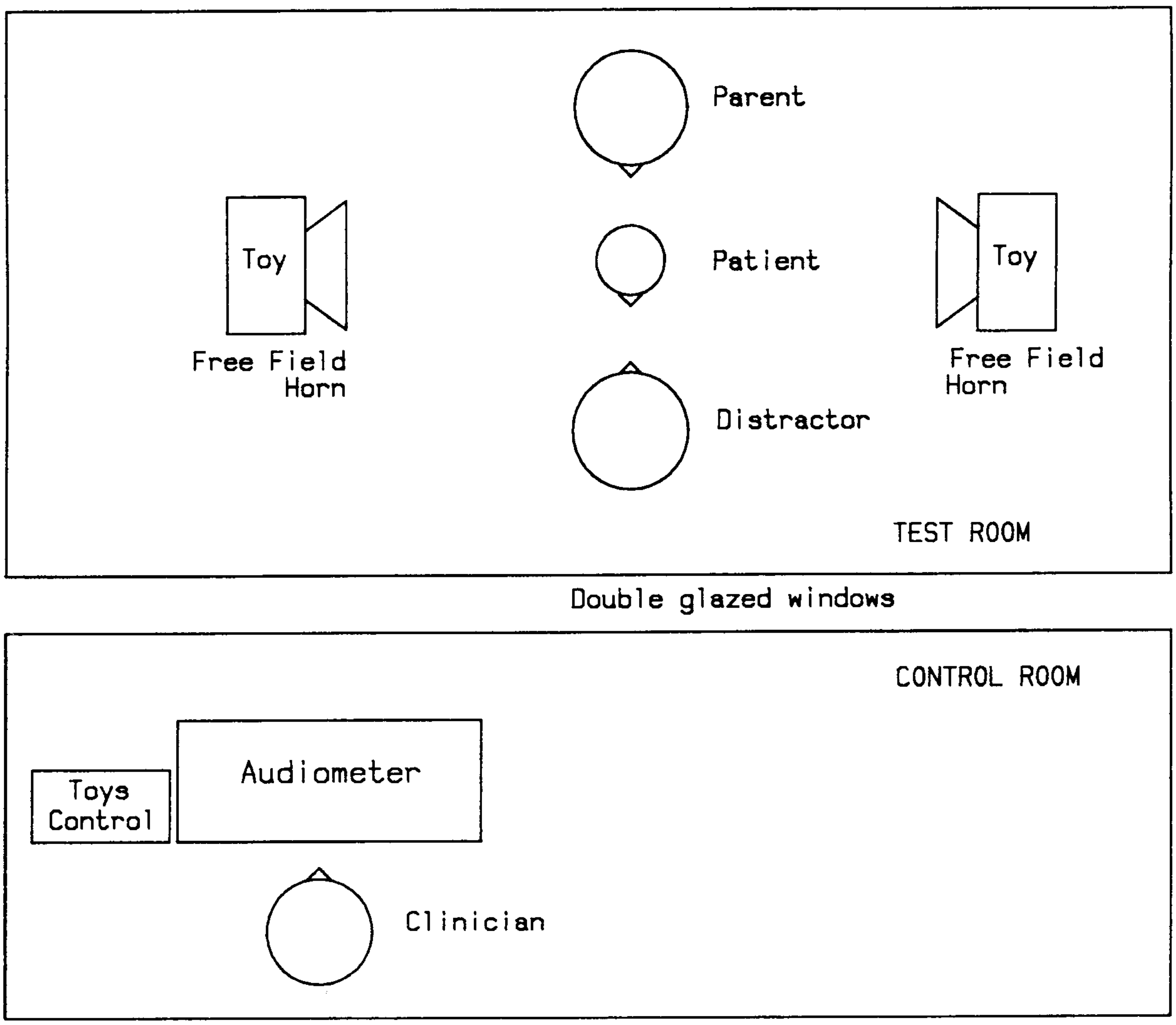


Figure 1. Typical test setup for hearing test of children.

The audiologist conducts the test, using the audiometer to generate sound stimuli at calibrated levels. When the child responds to the stimulus by turning his/her head towards the source of the sound, the child is rewarded to reinforce the response. The reward takes the form of a toy in a box which is only visible when illuminated by the audiologist. This technique of reinforcing the response was termed Visual Reinforcement Audiometry by Liden and Kankunen (1969). An assistant ensures that a valid response is reinforced, maintains the child's interest between stimuli and draws the child's attention back to the centre (ie facing the assistant) after a response. A flow diagram of the task of the audiologist in a basic test is shown in figure 2. The task requirements of each task are listed in table 1.

Task	Description	Requirements
1	Question parent about health and history of child	Face to face conversation
2	Locate assistant	Available trained personnel
3	Describe test about to conducted	Face to face conversation
4	Instruct assistant	Face to face conversation
5	Audiologist moves to observation room	Time
6	Configure audiometer	Familiarity with audiometer, hands on access to audiometer
7	Present stimulus	Child in view, and ready and quiet (can be difficult to judge from observation room)
8	Child responds ?	Child in view
9	Reliable response ?	Clear indication of response (may have to rely on assistant's judgement)
10	Action of parent or assistant interferes with test	Clear view of parent and assistant
11	Audiologist returns to test room to correct problem	Time
12	End of test	Sufficient results obtained
13	Record result on paper	Paper, pen / pencil
14	Reconfigure audiometer for next stimulus	Hands on access to audiometer

Table 1. Task requirements of a hearing test.

Unfortunately, visual reinforcement audiometry is personnel intensive, requiring an assistant in addition to the audiologist. A remote control system to allow the audiologist to conduct the test from inside the test room while seated close to the child was requested. The design, implementation and evaluation of such a

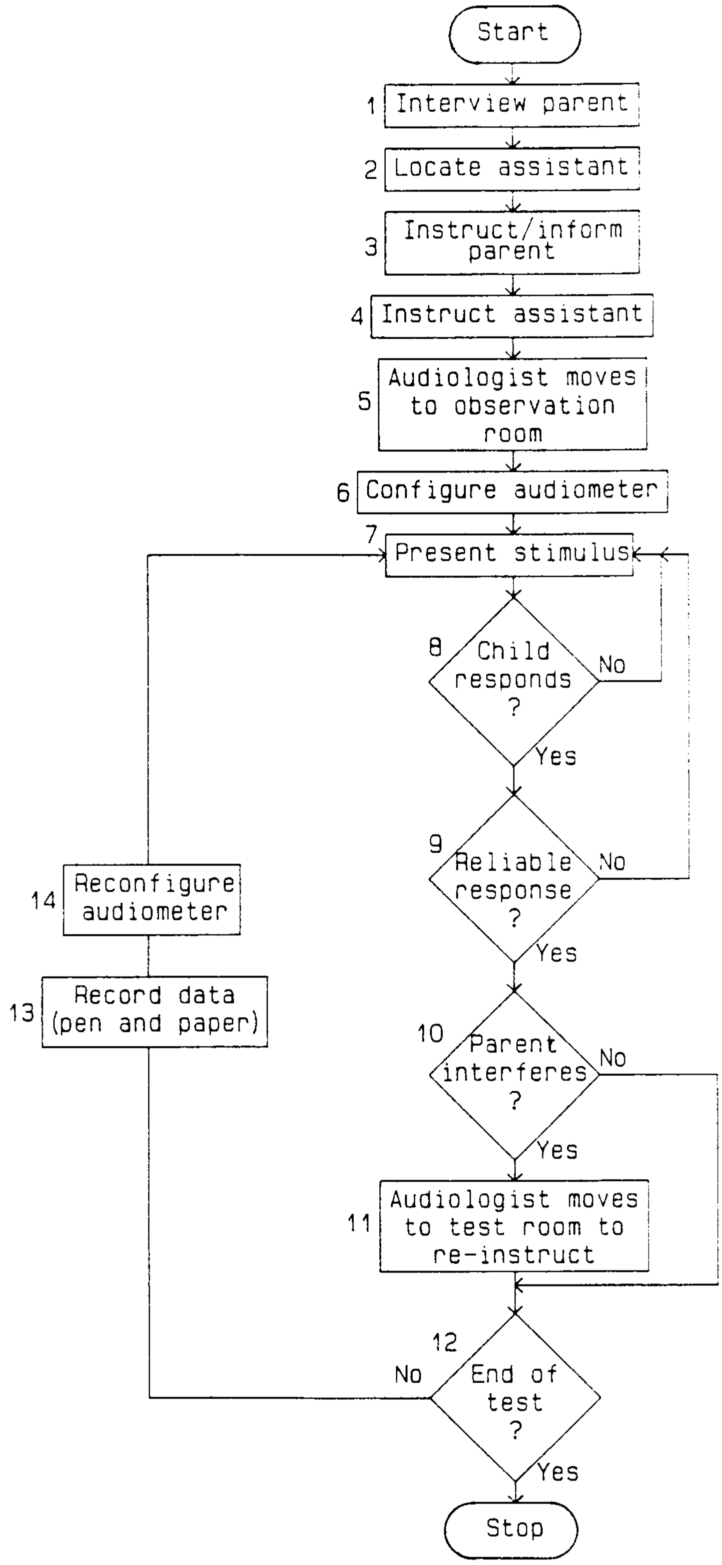


Figure 2. A flow diagram of the task of an audiologist performing a hearing test.

remote control system for use in testing the hearing of children is described in this paper. Attention to the ergonomic aspects was found to be essential in order to arrive at a system which was useful to the audiologist and which solved the problem of controlling the child effectively.

REMOTE CONTROL OF COMPLEX EQUIPMENT

There are several forms of remote control in use in everyday life - the most common being remote control of television or sound equipment. In these cases, the control is achieved via a matrix of buttons, and the feedback to the user of the effects of his / her actions are visible / audible on the equipment which is usually in view. Thus there is a very close link between cause and effect, and the user perceives himself / herself to be in control of the equipment. By contrast, operation of a computer, although not remote control, has been known to give the user the perception of not being in control of the process. Robson and Crellin (1989) asserted that it is possible to apply "locus of control theory" to interface issues (does the user perceive himself to be in control of a system, or does the system have control over him?). This perception of control is very important in the remote control of audiometric equipment for two reasons :-

1. The audiometer is a complex item of equipment and the audiologist needs to know the state of the audiometer at all times.
2. The audiologist conducts the test from the test room while the audiometer is located in a separate room - the observation room (the audiologist cannot see the audiometer).

Further, control of the other devices must be co-located with the controls for the audiometer to allow the audiologist to conduct the test with the minimum effort.

DESIGN OF THE AUDIOMETRY ENVIRONMENT REMOTE CONTROL SYSTEM

In designing medical equipment, there are two sets of users to consider : the clinician who is the "active" user and the patient who is the "passive" user. While the needs of the clinician (in this case the audiologist) can be taken into consideration, it is difficult to consider the needs of the patient, and even more so in this case where the patient is a child. Primary considerations for the child would be to ensure that the remote control system is small, unobtrusive and not intimidating, and to select visual reward objects and pictures which will be of interest to the relevant age group of children.

From the inception of the project, every effort was made to ensure that the needs of the audiologist were addressed. As the audiologists did not have any knowledge of the capabilities of computer based equipment, a comprehensive user requirements analysis (including the analysis of the task of the audiologist) was conducted at the start, and the design was reviewed and amended as the project progressed. The end user was involved in all design decisions, including decisions based on cost. By the nature of the design of the system - computer based with a minimum of dedicated hardware - provision was made for future improvements or modifications. The system has been described in detail in Goemans 1992.

The user interface consists of a custom built panel with labelled buttons, indicator lamps and two alphanumeric displays (16 characters by 4 lines each). Buttons are grouped by function and colour coded - action buttons red, increment/decrement buttons green, colour changes from one logical group to another (light gray, gray and black buttons) (see Figure 3). Detailed information on the configuration of the audiometer is conveyed to the user via the alphanumeric displays. The panel is connected to the computer by a cable and the computer is connected in turn to the devices under control (audiometer, tape player, slide projector and reinforcement toys). Commands issued by the user are received by the computer which takes the appropriate action, and informs the user of the status of the equipment under control. The slide projector is used to display pictures for reinforcement in children up to 5 years of age who might become bored by toys, while the tape player is used to present pre-recorded sounds and in particular, words for speech discrimination tests (for children who have some speech ability).

It is important to provide the audiologist with feedback to indicate that he / she is in control of the system, and that commands are being executed. This feedback takes the form of a short response time (0.1 second or less) in response to a command to update the displays, and an activity indicator to show that the system is active and ready to accept commands. The activity indicator is implemented as a character in the lower right corner of the left display that changes from "*" to "-" at one second intervals.

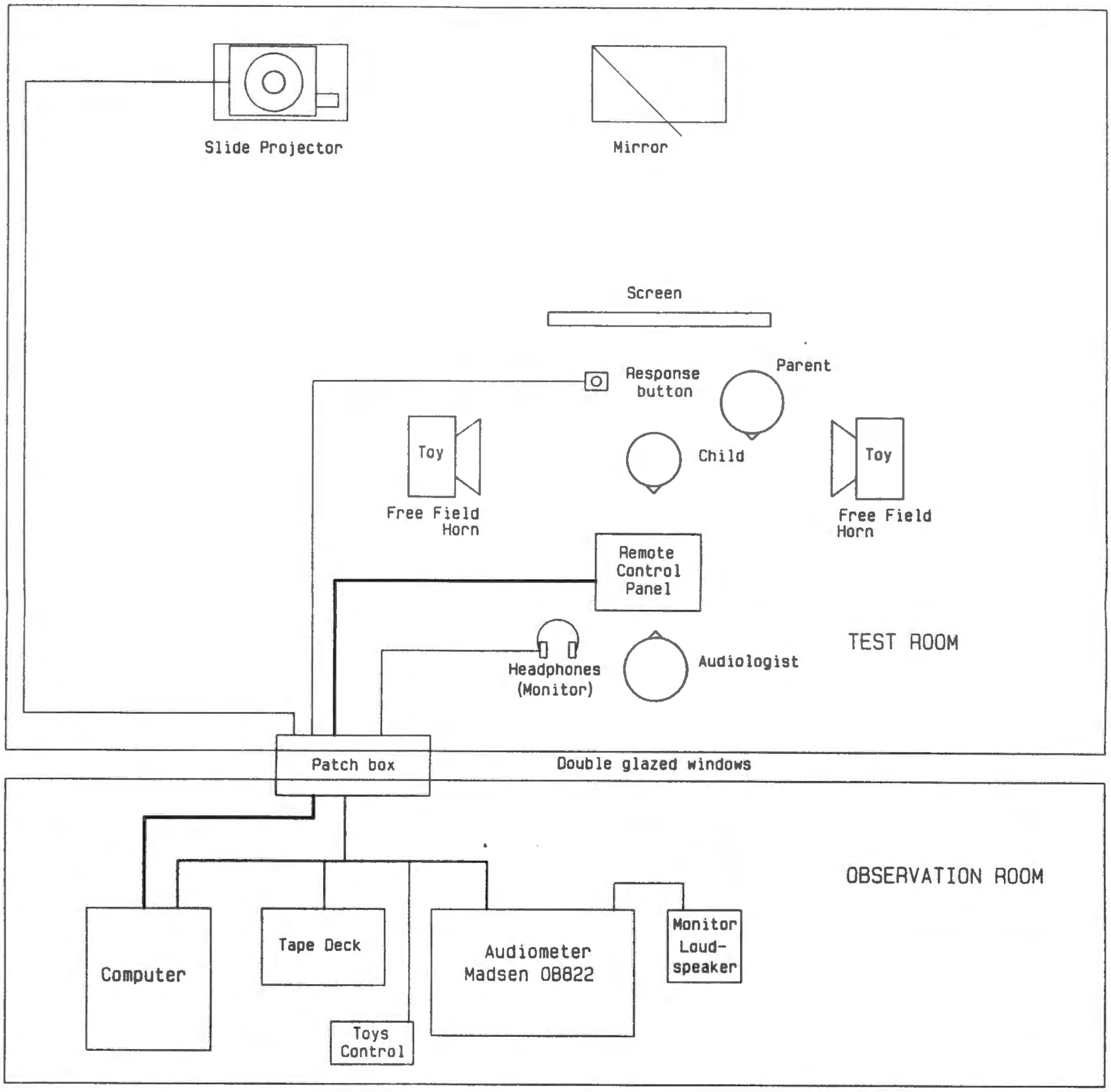
Information presented to the audiologist on the displays is configured to suit the format of the displays on the control panel, and the location of information within the display is consistent. On / off functions of the audiometer and other devices are indicated by a lamp which is integral with the button that activates that function.

Figure 3. The remote control panel.

In addition to the control functions, the computer records the data of the test when instructed by the audiologist, and displays the word lists for word discrimination tests. These functions results in a very high degree of integration of the word discrimination test, reducing the workload of the audiologist considerably. Words are presented by the tape player, with the audiometer controlling the levels. Pictures to be recognised in response to the words presented are displayed by the slide projector, the word list is displayed on the remote control panel, and the computer records the result of the test. Using the remote control, word discrimination tests can easily be conducted by an audiologist, whereas without the remote control, the audiologist would need a trained assistant.

The remote control system equipment layout is shown in figure 4. A mirror is used to extend the projection length of the slide projector in a small room.

The screen is movable and only placed in position when needed. The free field horns are fixed in position, the remote control panel may be used anywhere in the room.



Note :
1. Screen and toys not usually used simultaneously
2. Screen placed in position shown only when needed
3. Child and parent would face screen when used
4. Audiologist can position himself / herself anywhere to have a clear view of the child

Figure 4. The remote control system equipment layout.

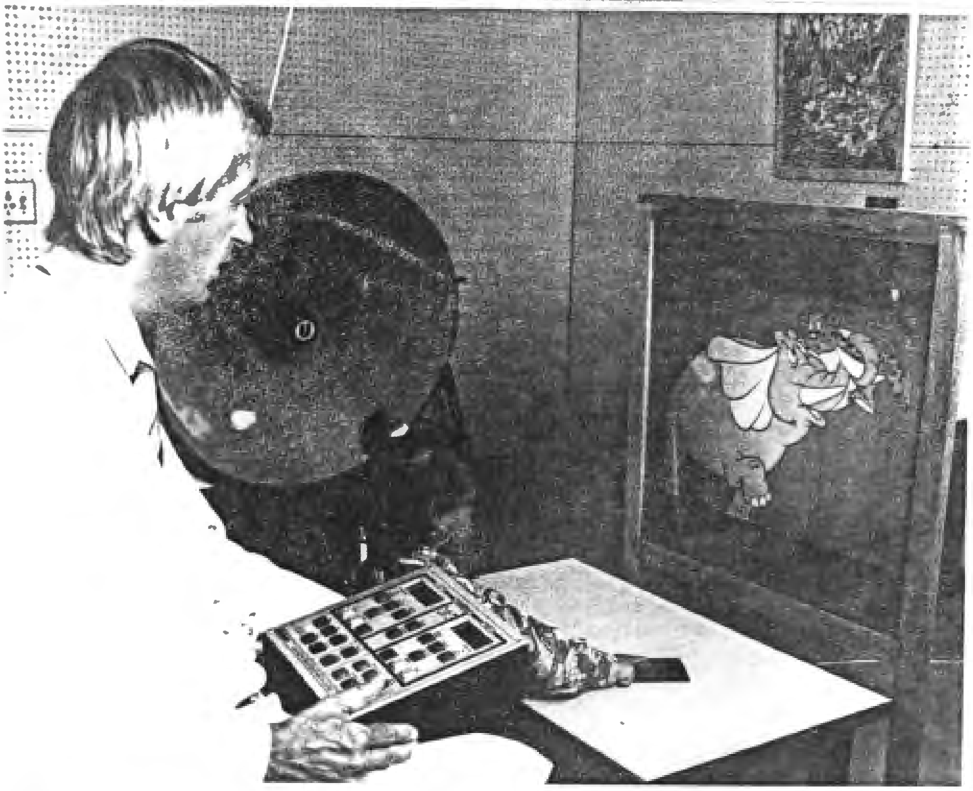


Figure 5. The remote control system in use.

Using this remote control system, the task of the audiologist changes and is depicted in figure 6. The task requirements for the modified task are listed in table 2. To allow comparison with the task requirements without the remote control system, the tasks in these two figures have corresponding numbers, thus some tasks are omitted and one added (number 15).

Task	Description	Requirements
1	Question parent about health and history of child	Face to face conversation
3	Describe test about to be conducted	Face to face conversation
6	Configure audiometer (done in parallel with tasks 1 and 3)	Familiarity with audiometer, hands on access to control panel
7	Present stimulus	Child in view, and ready and quiet (easily judged from test room)
8	Child responds ?	Child in view
9	Reliable response ?	Clear indication of response
12	End of test	Sufficient results obtained
13	Record result	Press a button
14	Reconfigure audiometer for next stimulus	Hands on access to control panel
15	Record results on paper	Paper, pen/pencil

Table 2. The task requirements of a hearing test using the remote control system.

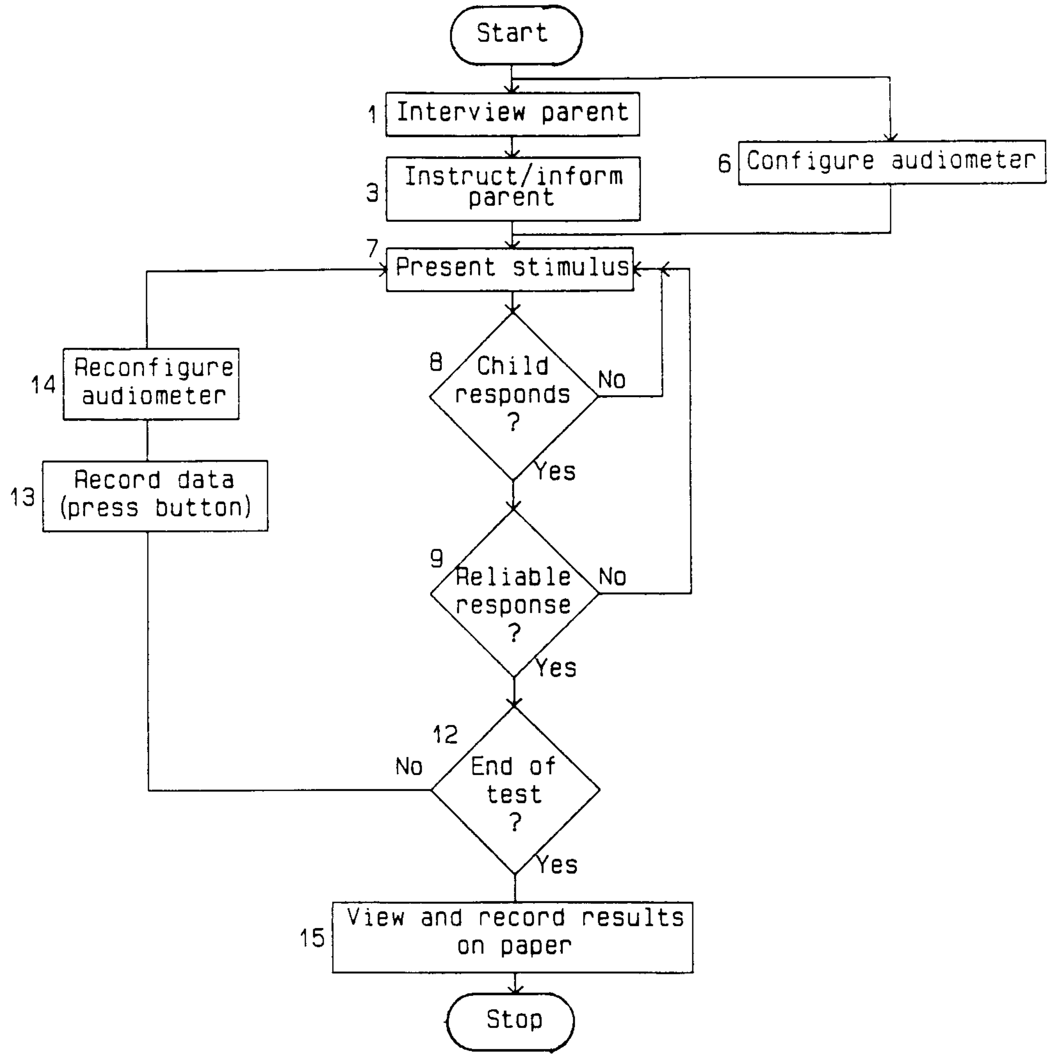


Figure 6. The task of the audiologist using the remote control system.

Notable differences between table 1 and table 2 are listed below :

1. Tasks 2,4,5,10,11 are not present in table 1.

2. Task 6 is performed in parallel with tasks 1 and 2.

3. Task 13 is quicker as it requires only the press of a button to record a result as opposed to writing the result on paper.

4. Task 15 being performed at the end of the test allows the test to proceed smoothly, but requires time to record the results on paper (the logical development of providing a printout from a printer will be implemented when a printer becomes available).

EVALUATION, RESULTS AND DISCUSSION

As mentioned earlier, the initial design was revised and modified during the design stage, and once commissioned, further changes were made as problems arose in the use of the system and as other ideas on the applications of the system were stimulated by its use. After the system had been in regular use for 12 months, a limited evaluation was conducted to provide some objective measurement of the efficacy of the remote control system. There had been some resistance to use of the system by some of the junior members of staff, partly due to a lack of training and a secondary aim of the evaluation was to encourage these members of staff to work with the system, voice their difficulties, and where necessary, modify the system to correct inadequacies.

Evaluation of this remote control system is challenging for the following reasons :-

1. Children of such young ages (7 to 30 months) can not be kept in the test setup long enough to do comparative tests.
2. There is no guarantee that the behaviour of a child will be consistent from one test to the next.
3. Comparison from one child to the next is prone to error due to the variability in behaviour of children.
4. It is difficult to ascertain what the effect on the testing of children will be from a child's point of view (the productivity advantage from the audiologist's point of view is more obvious).
5. It is very difficult to get any data at all from such young children.

Adult subjects were used in the formal evaluation to circumvent these problems of consistency and data gathering, and to provide insights that are not otherwise obtainable or obvious (this is not to say that adults and children perceive things in the same way, and thus we can not make strong claims on the basis of the adults' perceptions of the test). Although the testing technique for adults is very different to that of children, the tests were conducted as for children and the test subjects were instructed to respond as children would respond.

Each of six audiologists (3 novice and 3 familiar with the system) executed two tasks, one with the remote control and one without. The tasks were designed to exercise most of the functions of the remote control, but were not full hearing tests. The primary measure of efficacy of the remote control was the time and personnel (expressed in man minutes) required to complete the tasks. The tasks were recorded on video and reviewed with the audiologist afterwards when the audiologist was interviewed.

The results are presented as a table of the times taken to complete the tasks by each audiologist, and as a table of comments made by the audiologists.

User	Time to complete task Without remote control	With remote control
a	18 man minutes	15 man minutes
b	14	10
c	16	12
1	11:45	11:45
2	17	12:30
3	22	8:30

Note :
expressed in man minutes : number of personnel x time
a,b,c are novice users, 1,2,3 are familiar users

Table 3. Time to complete tasks, novice and familiar users.

Discussion - Table 3.

Data in this table is expressed in man-minutes so as to take account of the number of personnel involved in the test (two without remote control, one with remote control). The times taken by each user to complete the set tasks vary considerably - particularly the times for the task without the remote control which involved no learning or adaptation. Factors leading to these differences include differing levels of experience in audiology, different techniques, and different subjects.

Use of the remote control system in performing the test did not always result in substantial time savings (man minutes) as might have been expected. This is a useful result in that it indicates that the training and practise necessary to use the remote control should not be underestimated.

In the real-life situation, where the patients are children, the time taken to instruct the mother what to do in the test, and to make corrections when the mother does not co-operate, lengthens the test considerably. Using the remote control, the audiologist does not have this problem as he / she is in the test room with the child leading to an additional time saving.

User Comments	Occurrence (maximum 6)
1. Remote control allows better control of patient	5
2. Remote control relieves tester of inconvenience of finding an assistant	2
3. Remote control saves time spent explaining to mother what to do during test	2
4. Remote control not suitable for adults	1
5. Good to have similar functions to audiometer	1
6. Closed set of audiometer buttons on remote control easier to operate than audiometer	1
7. Response to button press is slow	3
8. The buttons make too much noise when pressed	2
9. Tone present duration control poor	1
10. Toy and slide buttons should be adjacent to tone present	1
11. Slide reverse needed	1
12. Inconsistency of press or hold buttons confusing	1
13. Practice will improve performance	6

Table 4. Comments made by users on remote control system.

Discussion - Table 4.

Comments made by the users were unsolicited, and since it was considered likely that some aspects had not occurred to the other users, the list of comments was drawn up as a list of statements, and 5 of the 6 users (one was not available) were asked to respond True or False to each statement. These results are shown in table 5.

Response to user comments		True	False
1.	Remote control allows better control of patient	100%	0%
2.	Remote control relieves tester of inconvenience of finding an assistant	100%	0%
3.	Remote control saves time spent explaining to mother what to do during test	100%	0%
4.	Good to have similar functions to audiometer	100%	0%
5.	Remote control not suitable for adults	80%	20%
6.	Slide reverse needed	80%	20%
7.	Tone present duration control poor	60%	40%
8.	The buttons make too much noise when pressed	40%	60%
9.	Response to button press is slow	40%	60%
10.	Closed set of audiometer buttons on remote control easier to operate than audiometer	20%	80%
11.	Toy and slide buttons should be adjacent to tone present	20%	80%
12.	Practice will improve performance	100%	0%

Table 5. Response to user comments.

As the true/false results show, most of the users agreed with the comments made by the other users. Where practicable, the system was improved in response to the comments (7 and 10), and where not possible, users were advised so as to be able to avoid the problems encountered (9 and 10). A few minor faults and shortcomings in the system were identified and corrected through the assessment exercise. These are listed below :

1. Two buttons added - to remove ambiguity in a dual function of a button and to improve slide control.

2. Response time to button press improved by a change in the communication sequence with the audiometer.

3. Other minor procedural faults which had not previously been found.

As the same subject was used for the test with and without the remote control, the subjects were able to comment on the differences between the two scenarios. These comments are shown in table 6.

Subject Comments	Occurrence (maximum 6)
1. I prefer having tester in test room - I don't know what is going on when tester is in observation room	4
2. Tester in test room distracts me from test	4
3. The word discrimination picture recognition slides are better than the book	1

Table 6. Comments made by test subjects.

Discussion - Table 6.

The first two comments made by the test subjects are contradictory (prefer to have tester in room, but tester is a distraction), and comment 2 would not apply to children. In the second part of the study, the children were noted to be oblivious of the tester's actions (pressing buttons on the remote control), and usually concentrated on the game they were given to occupy them. The children were noted to enjoy the slide show, possibly because of the difference in format to that of a book.

Subjective comments made by the experienced users of the system

Disadvantages of the system

1. The more introvert patient may react to the presence of the audiologist and the remote control panel in the test room by inhibiting responses to test sounds - more so than would be the case had only the patient been present. In this case the audiologist would perform the test from the observation room.

Advantages of the system

1. The test can be performed by one audiologist without an assistant - a saving in manpower.

2. The optimum moment for sound presentation in terms of
   a) the child's readiness to respond
   b) level of ambient noise generated by the child
   can be judged better by the audiologist from within the test room.

3. The presence of the audiologist in the test room often helps to keep restless or distractible children in check long enough for a successful test to be carried out; a goal which is sometimes not achieved with a familiar person acting as distractor.

4. The added appeal of the slide show facilitates an extension of the period of time a child would co-operate.

5. Remote control makes it possible to perform speech discrimination tests by means of a tape recording on much younger children than would be the case had the tape deck and audiometer been operated from the observation room.

CONCLUSION

The remote control system described here has achieved its purpose - to ease the workload of the audiologist, and allow the audiologist to conduct tests without assistance. The issue of locus of control is central to this system due to the complexity of the equipment under control and the physical separation of the audiologist and the equipment under his / her control. Judging from the comments made by the users, the remote control system has addressed this issue with a high degree of success, and been generally well received by the users, mainly through the application of ergonomic principles.

The evaluation of the system, although limited, was useful in highlighting some of the shortcomings of the system and in emphasizing the training effort required for new users of the system. Experience shows that a training and practice period of 5 hours is usually adequate. Once familiar with the operation of the system, the audiologist can expect to conduct a test successfully alone and in less time than was previously necessary.

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APPENDIX B. USER'S MANUAL

AUDIOMETRY ENVIRONMENT
REMOTE CONTROL

USER MANUAL

Revision 2.4

12 February, 1992

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1. FEATURES OF THE AUDIOMETRY ENVIRONMENT REMOTE CONTROL

- Remote control of audiometer, tape deck, slide projector and toys
- Electronic recording of results
- Integration of word discrimination (WIPI) test
- Tape deck (now located in test room) can be operated from control room

2. DEFINITIONS

Since this document will be used by users with different backgrounds, a common set of reference terms is needed.

Audiometry environment : the test room, control room and the equipment therein used in testing the hearing abilities of patients.

Remote Control : a means of controlling equipment from a position which is remote to that equipment.

Control room : the room from which a test is usually conducted, where the audiometer stands.

Test room : the room where the patient sits for the test.

Computer keyboard : alphanumeric keyboard in front of the computer

Remote Control panel : panel with buttons and displays, used in test room

Patch box : plate with sockets where all cabling passes from the control room through to the test room.

Monitor headphones : headphones for the user to monitor the test procedure while in the test room.

3. INTRODUCTION

The Audiometry Environment Remote Control is designed to give the user control over the equipment used in testing patients in PaedoAudiology (viz. OB822 Audiometer, Tape deck, Slide projector and Remote Controlled Toys) from the test room. From the remote control panel which is 30cm square, the user can control the audiometer, the tape deck, the slide projector and the reinforcement toys, and instruct the computer to make recordings of the test results while the test proceeds. The tape deck is now located in the test room to allow the changeover of tapes when using more than one word list in a test session. However, the tape deck is still fully controlled by the remote control system, and can also be controlled from the control room by using the computer keyboard.

Word discrimination tests can also be performed successfully without all the additional equipment usually required (i.e. word lists, pictures, tape player). The words are usually recorded on tape, and played back to the patient, allowing control of the presentation levels. To be able to record which words are recognised, a word list corresponding to the list being played on the tape player is loaded into the computer, and the computer displays the words in the list, one at a time, on the remote control panel. The user ensures that the word presented corresponds with the word displayed on the remote control panel before making a recording of recognition of a word.

The remote control panel is linked to the computer by a cable, and a software program running on the computer performs the instructions as requested by the user. The user has a limited amount of control over the operating parameters of the system. Control of the audiometer is somewhat different under remote control to direct control, as will be explained, and the user should expect to have to adapt to this difference. Operation of the system is fairly straightforward and should not present any difficulties. A user familiar with this manual will be able to use the system with ease. It is recommended that the reader "plays" with the system while reading this manual and relates the sections of this manual to the corresponding modes of the system. Reading this manual in isolation away from the system may not have much benefit.

4. SYSTEM SETUP

The cabling should all be in place as specified in the installation procedure document, however it may be worth checking the following :

1. Toys Remote control connector plugged into transmitter unit.
2. Headphones jack plugged into headphones socket of tape deck.

With the cabling in place, all that is needed is the following :

Plug the patient response button cable in at the patch box, and place the patient response button on a table in front of the patient.

Ensure that the slide projector is switched on - both at the wall socket and the power switch on the back panel of the projector. Note that the projector will not work until the computer provides the necessary instructions to enable the projector.

Ensure that the disk marked "Audiometry Environment Remote Control - System disk" is in the A (top) drive, and the disk marked "Log disk" is in the B (bottom) drive, and that both drive doors are closed. Switch on the computer : oval push button switch on right hand side of front panel of computer. The program should start up automatically.

If, for some reason the program needs to be restarted, the following commands should be entered on the computer keyboard.

a: <ENTER> - to change to A drive

aerc <ENTER> - to start AERC program

Alternatively, the round Reset button on the front panel of the computer may be pressed. This has the same effect as switching the computer off, then on again.

Once the remote control system is active, it may be necessary to enter the slide projector setup mode to setup the slide projector and screen, if not already done.

5. SYSTEM OPERATION

5.1 Active Mode

5.1.1 GENERAL

The system is configured to record the age of each patient tested using the system, and will ask for the patient's age to be entered before the test can continue. Note that the right attenuation up and down buttons increase or decrease the age in one month steps, the frequency up and down buttons increase or decrease the age in 12 month steps, and the right range extend is used to enter the age. Only these five buttons will respond until the age is entered. The age of the patient is stored with the test data and will be used to compile statistics on the system and its use. The users are earnestly requested to enter this data correctly. The program continues as follows.

If recorded results from an earlier test exist, the user is offered the option to erase these results. The left display shows a message "Erase old results ?" and the right display shows "Atten Up = yes", "Atten Down = no". As indicated, pressing the right attenuation up button causes the stored results to be erased. If the right attenuation down button is pressed, the stored results are retained, and new results will simply be appended to the existing results. If no recorded results were present this step would be skipped. The system continues as follows.

The setup of the audiometer, and the user parameters are retrieved and the system comes up in the mode last used. The computer screen display in the active mode will be similar to that shown below.

```
                 Date 19/10/1990  Time 15:02:11

 Left user display                        Right user display
 +----------------+   Audiometry          +----------------+
 |Freq  1000 Hz   |   Environment         |Freq  1000 Hz   |
 | 20 dB to phone |                       | 20 dB to phone |
 |                |                       |                |
 +----------------+     Remote            +----------------+
                        Control

                  press any key to disable ...

Buttons pressed by user
Left tone present
```

The two rectangles are replicas of the displays on the remote control panel. Note that the date and time are displayed on the top line of the computer screen. The time will be updated every second if all is well. A further activity indicator is provided in the bottom right corner of the left display in the form of a character which changes from "*" to "-" at one second intervals.

The remote control is now active, and will remain active until any key is pressed on the computer keyboard. Note that the audiometer's panel is "dead", except for the Talkover button which allows someone in the control room to speak to the patient and or operator in the test room. The yellow lamp above the "Data transfer" button is lit, indicating that the audiometer is under remote control.

When pressing the buttons, note that a button should be pressed once and released before the next button is pressed. The exceptions to this principle are the toy control buttons, and the tape stop button. These exceptions will be discussed later.

The blue knob on the back panel of the Remote Control is the viewing angle adjustment for the two displays.

5.1.2 AUDIOMETER CONTROL

The audiometer controls are a subset of the controls on the audiometer itself. The input button cycles through tone, masking NB, masking SN, masking WN and tape. The output button cycles through phone, bone and free field. The unlabelled buttons on the Remote Control panel are the left and right Reverse functions. The Tone Present function on the remote control operates in a different mode from the function on the audiometer control panel. On the audiometer, the tone present button is held as long as desired, however, due to the communication protocol of the audiometer, the computer must instruct the audiometer to present a tone for a given length of time. The program allows the user to present multiple tones in a tone sequence, where the length and number of the tones is variable. Once a tone sequence has commenced, it can not be stopped. The number of tones in the sequence and the progress of the sequence are displayed on the relevant user display (left or right) as "Tone 1 of 3", "Tone 2 of 3" etc. If the option is utilized, the computer will vary the number of tones in a sequence, and the length of each tone in a sequence in a random manner. The user provides the limits of the random variation. The entry of these parameters is described in section 6.1.

5.1.3 RECORDING RESULTS

The two buttons on the back panel of the Remote Control are the left and right Record buttons - when one of these is pressed, the attenuation level, input, output, frequency and contra-lateral masking of the respective channel is recorded by the computer. This feature allows the user to continue with the test procedure without having to take notes of the results. As a record button is pressed, there will be delay of about 2 seconds before the activity indicator continues flashing and the system will respond to commands. This delay is caused by the computer writing the result to the diskette in the A drive - in the event of a system failure, the data is retrieved from the diskette - thus recorded data is never lost. On completion of the test, the user may view the recorded data on the remote control panel displays or on the computer screen. When recording word recognition results, the maximum number of recordings is 200. If the user exceeds this limit, the "Recorded" message is replaced by a message "Record list full" and no more records will be stored. When recording hearing threshold test results, the maximum number of recordings is 60. If this limit is exceeded, the first records are overwritten.

5.1.4 VIEWING RESULTS ON THE REMOTE CONTROL PANEL

The test results recorded during a test may be viewed on the remote control panel displays instead of on the computer screen. The view results mode may be activated at any time by pressing the view results button on the rear of the remote control panel.

The view results mode commences with the most recently recorded result on the bottom line of the displays. The left display shows left channel results and the right display shows right channel results. Where a result is shown on the left display, the corresponding line on the right display will be blank, and vice versa. The displays can only show 4 recordings at a time. If more recordings are available above those shown, this is indicated by up arrows in the top corners of the displays "^". Pressing either left or right attenuation up buttons will cause the data to be scrolled down, bringing the next recording onto the top line of the displays. As one (or more) recording (s) have now disappeared from the bottom line of the displays, arrows "v" appear in the bottom corners of the displays to indicate that more recordings are available below those shown. Pressing either left or right attenuation down buttons causes the data to be scrolled up, bringing the next recording onto the bottom line of the display.

The list of recordings could be considered to be a list in chronological order, the first recording at the top of the list, the most recent at the bottom, and the displays are windows through which the user can only see 4 recordings at a time. These windows can move up and down the list of recordings, using the attenuation up and down buttons respectively. When the window is positioned at the top or bottom of the list, the up or down arrows (respectively) are not shown.

The data of a recording is presented as the frequency (where applicable) followed by the attenuation. If narrow band masking to free field is used, a correction factor is added where necessary, and this is indicated as a "c" before the "dB". Note that the input and output used for the recording are not displayed on the remote control panel. This information is only provided on the computer screen.

Once the results have been viewed, the user terminates the view records mode by pressing the view results button again. The user will now be offered the option to erase the results just viewed. The left display shows a message "Erase old results ?" and the right display shows "Atten Up = yes", "Atten Down = no". As indicated, pressing the right attenuation up button causes the stored results to be erased. If the right attenuation down button is pressed, the stored results are retained, and new results will simply be appended to the existing results.

5.1.5 WORD LIST DISPLAY AND CONTROL

The word lists to be presented are pre-recorded on tape, and the required tape is inserted into the tape deck. The word list display is activated and used as follows :

If words are to be presented on the right channel, select Tape input on right channel, and switch Reverse function on. This combination enables the word list display on the left channel display. The user must first indicate which list is to be loaded by the computer. The name of the first available word list is displayed on the bottom line of the display. The attenuation up and down keys now advance or step back (respectively) through the lists. When the required list is displayed, pressing the Tone Present extend button will cause the computer to load that list. Note that you would have loaded a new tape into the tape deck or wound the tape forward in order to present the words of the new list. Word lists may also be loaded using the computer keyboard in the control room (see section 6.3).

The word list name is displayed on the third line of the left display, the current word on the bottom line. Displayed on lines 1 and 2 are messages to indicate that attenuation up causes the list to advance to the next word, attenuation down causes the list to step back to the last word, and range extend loads a new list. The number before the word indicates the position of that word in the list. The tape player is activated to present the word to the patient. If the word is recognised by the patient, the right record button is pressed. The message "Recorded" appears in the right display. As the slide advance button is pressed to show the next slide, the word list is advanced as well. This feature reduces the number of buttons the user has to press, however the user must ensure that the word list remains synchronised to the slides and thus retains the ability to step the list forward or backward.

Note that the other audiometer controls on the channel where the list is displayed (left channel in this example) are disabled. The format of the word list files for the computer is given in the appendix.

5.1.6 VISUAL SYSTEM CONTROL

In the usual hearing threshold test mode, pressing the slide advance button causes a slide to be displayed on the screen. After the number of seconds specified by the user have elapsed, the computer dims the slide so that it is not visible, and advances the slide projector to the next slide.

When performing word discrimination tests, with the words displayed on the remote control, the operation of the slide advance button is different from what was mentioned above. If the slide projector lamp is dimmed, pressing the slide advance button causes the slide to be displayed on the screen. The slide projector lamp will stay on at full power until the word discrimination test is terminated. Each successive press of the Slide advance button will cause the next slide to be displayed.

The toy buttons may be held as long as desired.

If no remote control buttons are pressed for 15 minutes, the slide projector will switch off to conserve the globe. As soon as any button on the remote control is pressed the slide projector will be switched on again.

5.1.7 THE SLEEP MODE

When not in use, the system enters a sleep mode. This mode ensures that the patient age will be re-entered, the data recorded by the system is stored to disk and that the computer screen is protected from burning due to the same image being on the screen for extended periods. The system will enter the sleep mode automatically if no buttons are pressed for 5 minutes, or the user may force the system into sleep mode by holding the tape stop button for 5 seconds. When in sleep mode, a message is displayed on the remote control panel indicating that the system is asleep and that pressing any button will cause it to wake up. On the computer screen, a box showing a similar message is displayed, and the system will also wake up if any key on the computer keyboard is pressed. The box on the computer screen moves to a new location every minute to protect the computer screen.

5.1.8 USER ACTIONS LOG FILE

As the user presses buttons on the remote control panel, the actions are reported on the computer screen. These actions are also recorded in a log file which is written to the disk in the B drive. The purpose of this log file is to assist in trouble shooting in the case of errors, and to assist in optimising the design of the system in the future. This log file will be updated when no activity is detected for 15 minutes, and when the program is terminated.

The disk in the B drive will eventually fill up, and need replacing. The program will report that the disk is full. After replacing the disk, the error should be cleared. A supply of disks will be provided; if exhausted, or if problems are encountered, contact the technical support staff for assistance.

5.1.9 ERROR RECOVERY

It is possible that the system will "hang up" and cease to operate. In this extreme case, it is necessary to reset the computer as from power up. This is achieved by pressing the round "RESET" button on the front panel of the computer, - a duplicate of this button is provided on the underside of the Remote Control, in a recess in the back left corner. When either button is pressed, the computer will take approximately 30 seconds to re-enable the Remote Control. Note that recorded data is retrieved from disk.

5.2 Inactive Mode

When a key is pressed on the computer keyboard, the remote control is disabled, and the audiometer panel enabled. The computer now presents the following menu :

```
            Date 3/12/1991  Time 15:32:52

Left user display                          Right user display
                      Audiometry
  Audiometry          Environment
  Environment                              disabled ...
    Remote               Remote
   Control
            User Menu             0/91

         Enable system            disable ...
         User Parameters          isabled
Buttons presse View results
Right range ex Load list
         Control Tape             [ Help : Enable System ]
         Setup projector
         Build dB table           Enables remote control system
         Edit dB table            to allow user to control
         Test panel               equipment from the test room
         Exit to DOS              using the remote control
                                  panel.  The audiometer panel
             = select             is disabled except for the
         ┘  = confirm             talk over button.
        F1 = help on/off
```

Each of these options is to be described in detail in the next section. On completion of each option, the program returns to the remote control active mode.

When the user has completed the tests for the day, the program must first be terminated by selecting the "quit" option in the disabled mode. The log file is then copied to the disk in the B drive, and the system configuration is stored on the disk in the A drive. The computer should be switched off overnight.

6. USER OPTIONS

The menu offering the user the options described in the following sections is a bar menu where a cursor is placed over the required option and ENTER pressed to select that option. The arrow keys are used to move the cursor. Note that the Home key moves the cursor to the top of the list and the End key moves the cursor to the bottom of the list. A help panel is displayed to the right of the menu. This panel displays information on each item of the menu. As the cursor is moved to each option, the help panel is updated to reflect the help information for each option. This help panel can be switched off and on with the F1 key.

6.1 User Parameter Entry

Selected by pressing <ENTER> in response to the options offered by the computer, this mode allows the user to modify the following parameters :

Period of slide presentation - when the Slide Advance button on the remote control is pressed, a slide is shown for this period which may be between 1 and 15 seconds. On expiry of this period, the picture is turned off, and the slide projector moves on to the next slide (this will be audible as a series of movements in the slide projector).

Maximum number of tones in a sequence - as described earlier, pressing the tone present button once will generate a sequence of tones. The maximum number of tones can be any number between 1 and 10.

Minimum number of tones in a sequence - any number between 1 and 10. The number of tones ina sequence will vary in a random manner, with normal distribution (i.e. equal probability) between the minimum and the maximum. Note that if the same number is entered for the maximum and minimum number of tones, the random variation feature is effectively disabled and every tone sequence will consist of the specified number of tones. If the maximum is 4 and the minimum 3, then 50% of tone sequences will be 3 tones, and the rest 4 tones.

Maximum tone length in a sequence - each tone in a sequence can be between 0.1 and 5 seconds in duration.

Minimum tone length in a sequence - anything from 0.1 to 5 seconds. The length of successive tones will vary in a random manner, with normal distribution (i.e. equal probability) between the minimum and the maximum. If the minimum and maximum are entered as the same value, the random feature is effectively disabled, and all tones will be of the specified length.

Period between tones in a sequence - only required if more than one tone per sequence. This period will be the same between all tones in any sequence, and may be anything from 0.1 to 10 seconds.

Transpose Audiometer - if the user is facing the control room, as opposed to having his/her back to the control room, left and right are transposed. Answering "yes" to this option will cause the left channel of the audiometer to be activated by the right buttons and vice versa.

Transpose Toys - as for the audiometer, the left toy will be controlled by the right buttons and vice versa.

Report on patient response - the audiometer reports on the timing of the tone presented and the patient's response to the presentation. The following are reported : Response early, Response late, No response. A report is provided when the patient presses his/her response button and if another tone is presented before a response is detected. Answering "no" to this option will disable all patient response reports.

6.2 View Recorded Patient Data

The data recorded by pressing the left and right record buttons on the back panel of the Remote Control is viewed using this option. Once this option has been selected from the main menu, a timeout is activated to step through the viewing procedure and ultimately return the system to the active mode. This feature ensures that the system cannot be inadvertently left in the view results mode, and will be ready for use from the test room again. Note that the system will remain disabled indefinately while the main menu is displayed on the computer screen.

Both word discrimination test results and hearing threshold test results may be recorded. Once this option to view the recorded data has been selected, the user must choose to view either the hearing level data or the word discrimination test data. A bar menu is presented with the two options, the arrow keys move the cursor to the desired option and ENTER selects that option. Note that this menu has a timeout - after 5 minutes of no keyboard activity the option highlighted by the cursor is selected.

6.2.1 HEARING LEVEL DATA

The data is sorted by input (tone, tape, masking NB, masking SN, masking WN) and output (phone, bone, FF), a separate screen for each combination. The user is only presented with screens for which data has been recorded, and can cycle through the screens. The data is presented in three columns, Frequency (where applicable), Attenuation Left and Attenuation Right, ordered in increasing frequency. Each line represents a record from a button press. If the left button was pressed, only the left column will have an entry, and likewise for the right. If contra-lateral masking was used, this is indicated as an entry in both columns with the attenuation level of the masking, and the type of masking noted in the masked channel, and the tone level in the other channel. If a second (or further) recording is made with the same settings, the recordings will be shown with the earliest recording first. The user will have to select the correct records when viewing.

A bar menu is provided at the bottom of the screen to allow the user to select the Next screen of data, the Last screen of data or to Quit. As before, the arrow keys move the curssor to the required option and ENTER selects that option. When Quit is selected, a beep is heard and the user is asked to confirm erasing of the results or may view the results again. Note that these two menus also have timeouts to return the system to active mode.

Up to 60 records may be made in one session - if this number is exceeded, the earliest records are over-written.

6.2.2 WORD DISCRIMINATION TEST DATA

The words recognised and recorded are sorted by attenuation level, for left and right channels. The words recognised at each attenuation level are shown in the chronological order in which the recordings were made. The number before each word is the position number of that word in the list. The number of words at each attenuation level is counted and the percentage of the total number of words in the list given. Note that the percentage is calculated on the assumption that the full list was presented. The total number of words in the list is given at the bottom of the screen. If the number of words recorded is more than can be accommodated on one screen, the user is asked to press a key may erase the data by pressing, or return direct to active mode. A bar menu is provided to make this choice, the arrow keys move the cursor, and ENTER selects the option. This menu also has a timeout to return the system to active mode. If the data is not erased, new results are appended to the list. The maximum number of records is 200, when this limit is reached, further recordings are not possible.

6.3 Load a Word List

The user may select this option (load word list) to load a word list, or the list can be loaded using the remote control panel as described in section 5.1.5. If this option is used from the menu, the user is presented with a list of word lists. Using the arrow keys, move the cursor to the word list which you wish to use, and then press Enter to select that list. The computer will load the list and return to active mode.

6.4 Calibrate Tape

This option is provided to enable the user to control the tape deck from the control room, so as to set the signal level on the audiometer, or to use the tape deck in a test conducted from the control room.

The user is provided with a bar menu - the arrow keys move the cursor to the desired option and ENTER selects that option.

6.5 Slide Projector Setup

Since the slide projector has been modified internally and will only work under control of the computer, this mode is necessary to enable positioning of the screen, focussing and loading of slide trays.

When this mode is activated, the slide projector will be turned on for a 15 minute period to enable setup. At the end of this period, the projector will be switched off, but the period may be restarted simply by pressing any of the buttons on the remote control.

This mode may be terminated at any time by pressing any key on the computer keyboard.

6.6 dB Table Edit

This facility is provided to edit the dB table manually or to check on the results of the computer's interrogation of the audiometer. After the table has been displayed on screen, the user is prompted for a password which is 8 characters long. The controlled access is to prevent accidental or unauthorised modification of the table. If the password is entered incorrectly, the user is denied edit access, and may only view the table.

The table is arranged as frequency versus the various output options (bone, phone, Free Field, and each of these with Range Extend on) for pure tone, and repeated for Narrow Band Masking. The other input options (Tape, Masking WN and SN) are found at the bottom of the frequency list for each of the output options.

Modifying the entries in the table is simply a matter of moving the cursor to the relevant entry with the arrow keys on the right of the computer keyboard, and typing in the new attenuation level. The audiometer could be set to the various settings while the table is onscreen. Note that if one channel can have a higher setting than the other, the lower setting is taken.

Refer to the system manager's manual for recovery when the password is lost or forgotten.

6.7 Build dB Table

The maximum attenuation levels of the audiometer may be modified when the audiometer is calibrated. The audiometer on which this system was first installed had been pushed up to its maximum for testing severely hearing impaired patients. The maximum attenuation levels are entered into this table, and the program then uses this table to keep track of the audiometer's settings.

If the table is incorrect, the program could get out of step with the audiometer, giving the user incorrect information of the remote control displays. It is therefore vital to the successful operation of this system that this table be correct.

The computer can interrogate the audiometer and so determine the maximum dB settings for all inputs and outputs. This facility is activated automatically on the first day of each month, or may be activated by selecting this option from the disabled menu. The computer switches the audiometer through all options, recording the maximum attenuation levels as it proceeds. This process takes approximately 10 minutes to complete.

6.8 Remote Control Test

The remote control itself is a slave unit - that is it is under control of the computer. If any errors occur on the remote control, they will not be detected

6.8 Remote Control Test

The remote control itself is a slave unit - that is it is under control of the computer. If any errors occur on the remote control, they will not be detected by the program. This option is provided to test the remote control functionality. While executing the test, it will be necessary to have the remote control alongside the computer to follow the prompts and observe the results of the test.

This testing can be done by the user, following the prompts on the computer screen, or it can be done by technical staff who can rectify the fault.

6.9 Quit and Return to DOS

Selected when the user wishes to terminate the program, this option causes the log file and the configuration file to be saved on disk, and the program returns control to the operating system, DOS. Other work may then be performed on the computer, or the computer may be switched off.

7. SYSTEM ERRORS AND RECOVERY

As mentioned above, errors on the remote control panel will not be detected, thus if the user is unsure of the correct operation of the panel, the test procedure can be run.

The communication link with the audiometer is intolerant of faults, and should data be corrupted, the communication link will cease to function. Further, after every 20 key presses on the remote control, the audiometer's setup is verified against the setup recorded by the program to ensure that the two are not out of step (could be caused by an incorrect dB table). In either case, the error condition is detected by the program, and the program will reset the audiometer and attempt to recover the current setup. Recovery may take some time (5 seconds) - during this time an appropriate message is displayed on the remote control asking the user to wait. If after 5 attempts, the program is not successful, the program will terminate and ask the user to check the serial link. If the cabling is correct and the program will not function, the user must inform the technical support personnel.

In the worst case, when the Remote Control ceases to function, the user can reset the computer using the button which is recessed on the base of the Remote Control. After a delay of approximately 30 seconds the remote control will be active. This action is a last resort and the frequency of its occurrence should be recorded and reported to the technical support personnel.

8. CONCLUSION

The essentials of operation of the Audiometry Environment Remote Control have been described. The user should feel confident in the use of this system, and if it meets its design criteria, the system will facilitate the audiometric testing of hearing impaired children. Further modifications of this system will depend heavily on the experience gained with this prototype system, thus the user is encouraged to report any and all shortcomings, merits or problems encountered in using this system.

9. APPENDIX FORMAT OF WORD LIST FILES

The file must be a simple text file, with each word on a new line. A number may precede each word to indicate the position of that word in a list. The maximum number of words in a list is 100. No punctuation should be added. The file must have the extension ".TXT". The files must be stored on the disk in the A drive of the computer. If the disk is full, old word lists will have to be deleted.

Example of a word list file :

```
1 comb
2 car
3 horse
4 spoon
5 tree
6 boat
7 bath
8 ball
9 shoe
10 key
```

APPENDIX C. CLINICAL EVALUATION : TASKS AND INTERVIEW QUESTIONS

Procedure for evaluating AERC

1. Draw up a test schedule
2. Select a group of users, novice(3), familiar(3) and experienced (2). Users are familiar with OB822 audiometer and paedo audiology.
3. Execute task without aerc - video
4. Provide short training session (FJVZ)
5. Execute task with aerc (subject : adult ?) - video
6. Provide short training session on control room (FJVZ)
7. Execute task on computer - video
8. Interview user

Task - Test room - without aerc

The subject is an adult, but has been instructed to behave as a child would behave, thus the test must be conducted as if you were dealing with a child. Use all equipment at your disposal, including the reinforcement toys.

Note - an assistant may be used

1. Measure HL Tone to phone at 2000 Hz, left ear, right ear; at 4000 Hz, left ear, right ear
2. Measure HL Mask NB to FF at 500 Hz, left ear, right ear; at 1000 Hz, left ear, right ear
3. Set up for WIPI test - The hearing level is not important in this test, thus assume that the hearing level has been determined and proceed at a level at which the patient will be able to recognise the words. Present on left channel to FF.
4. Test first ten words of english list which starts with the word "school".

Task - Test room - With AERC

The subject is an adult, but has been instructed to behave as a child would behave, thus the test must be conducted as if you were dealing with a child. Use all equipment at your disposal, including the reinforcement toys.

Note - an assistant is not available, and you are on your own.

1. Measure HL Tone to phone at 2000 Hz, left ear, right ear; at 4000 Hz, left ear, right ear

2. Measure HL Mask NB to FF at 500 Hz, left ear, right ear; at 1000 Hz, left ear, right ear

3. View results. Answer "NO" to erase results question.

4. Set up for WIPI test - The hearing level is not important in this test, thus assume that the hearing level has been determined and proceed at a level at which the patient will be able to recognise the words. Present on Left channel to FF.

6. Test first ten words of english list which starts with the word "broom".

7. View results. Answer "NO" to erase results question.

Task - Control Room

Perform the following tasks on the computer. You are on your own. Remember to speak your thoughts as you proceed.

1. Wake up AERC

2. Disable AERC

3. View results : word list results - do the results displayed agree with your notes ? ; hearing threshold results - results shown are only a sample.

4. Modify user parameters : enter the following parameters :
   a. 3 seconds for slide presentation
   b. maximum 2 tones per sequence
   c. minimum 1 tone per sequence
   d. maximum 2 second tone
   e. minimum 1 second tone
   f. pause between tones 1 second
   g. No to transpose audiometer
   h. No to transpose toys
   i. No to report on patient response

5. Load a word list : load the list EP_BROOM

6. Control the tape deck : rewind to start and play tape for 1 second, then quit.

Interview Questions - User

Name : date :

AERC :

1. Did you find the task easy to complete
2. Were you confident of your actions
3. Did the AERC respond correctly to your commands
4. Was the WIPI test easy to coordinate
5. What skills, ability, knowledge would help / would have helped you to complete the task ?

Computer :

1. Did you find the task easy to complete
2. Were you confident of your actions
3. Were you able to find the information you needed on the screen (keys to press, options to choose, recorded results) ?
4. Was the control of the computer easy or difficult
5. Did you understand what you were doing and why you were doing it ?
6. Have you had any experience of using a computer
7. Are you comfortable using a computer
8. What skills, knowledge, ability would help / would have helped you to complete the task ?

Review video of control room

9. Was it easier to use the AERC than not, and why ?

Interview Questions - Subject

Name :

1. Did the tester appear confident, know what he/she was doing ?
2. Did you notice any differences in manual vs remote control test ?
3. When was the tester most in control of you ?
4. Was anything in the test room or the test intimidating ?