AUDIX: Using Java-based software for remediating auditory perceptual deficits.

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Abstract

AUDIX is a knowledge-based multimedia system for auditory discrimination exercises. The aim of AUDIX is to deliver computer-based cognitive rehabilitation therapy to patients, which they can use independently at home on an 'on-demand' basis. Specifically, AUDIX provides computer-based auditory discrimination training. This training is intended for adults who have auditory-perceptual deficits or ‘word sound deafness’ (e.g. Howard & Franklin, 1988), as a result of acquired brain injury. The nature of this perceptual problem is an inability to perceive differences between phonemes in speech. This deficit requires a type of therapy called ‘auditory discrimination training’. A knowledge-based approach to the design of AUDIX ensures that the domain dependent therapy knowledge is separated from the system core and provides flexibility. For example, the clinician can add new knowledge (e.g. new therapy items or stimuli), or create a new knowledge base in order to provide exercises for an individual patient. This paper describes the AUDIX architecture and outlines the advantages of cognitive rehabilitation therapy over more conventional computer-therapy programs.

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Introduction

AUDIX[2] provides a knowledge-based system for auditory discrimination exercises. The system is designed to deliver computer-based cognitive rehabilitation *therapy*. This is in contrast to many existing programs, like the MINDS software tool from Brand (1992) or the software program from Lopez-Bascuas et.al. (1999), which are designed for use in patient *assessment*.

AUDIX is designed to facilitate the amelioration of auditory deficits in brain injured patients. This training is intended for adults who have auditory-perceptual deficits or ‘word sound deafness’ (e.g. Howard & Franklin, 1988), as a result of acquired brain injury. The nature of this perceptual problem is an inability to perceive differences between phonemes in speech. This deficit requires a type of therapy called ‘auditory discrimination training’, described by numerous researchers (e.g. Luria, 1980; Kertesz & Wallesh, 1993; Gielewski, 1983; Morris, Franklin, Ellis, Turner, & Bailey, 1996; Morris, 1997).

AUDIX is designed to give patients with word sound deafness the option of accessing an intensive auditory-training therapy regime at home, ‘on-demand’. AUDIX presents auditory discrimination exercises (phonemic contrasts) and is designed for use by adult aphasic patients who need to re-learn auditory discrimination skills.

There are several advantages of computer-based therapy. Using computers in research on the efficacy of therapy allows the actual processes and procedures of therapy to be delivered independently of the clinician. This, in turn, allows the process of therapy to be described more objectively, compared to traditional face-to-face therapy. The patient may also practice as much as s/he wants, away from the clinician. Computer-based therapy exercises are available to the patient at any time and can be used as little or as often as the patient wishes. For example, a patient may do more exercises on a day when s/he feels well and fewer on days when s/he feels less well. Patients may also experience therapy more as a partnership of equals rather than the often asymmetrical ‘clinician-patient’ relationship. This helps the self-confidence of the patients, as discussed in Crerar and Ellis (1995).

Computer-based therapy programs can also provide rich information about a patient’s test results and provide a way of tracking improvement over time. Therapy software is also more interactive, dynamic and responsive compared with the paper-based exercises that clinicians typically set for patients between face-to-face therapy sessions.

Computer-based therapy systems also provide a rich source of data for research purposes, including data that human clinicians cannot gather, such as the patient reaction times. This kind of information was recorded in a controlled single-case experimental study using AUDIX in which its effectiveness in the auditory training of patient with word sound deafness was evaluated (Lum, Grawemeyer, Roy & Cox (submitted).

Therapeutic intervention using AUDIX

AUDIX was designed to train an adult aphasic patient (CB) to discriminate (i.e. hear) the difference between 'minimal pair' sets of words. Minimal pairs are words which sound the same except for a change in either the initial or final sound of the word (e.g. pay, may, bay or cup, cub, come).

Aphasic patients can have auditory discrimination problems despite having normal hearing acuity – it is a difficulty in perceiving the some speech sounds in the presence of normal hearing. As mentioned above, the condition is often referred to as "word sound deafness" (e.g. Howard & Franklin, 1988). The patient may no longer able to distinguish between, for example "pat" and "bat". Therapeutic techniques to improve the patient's ability to discriminate sounds are based on providing auditory discrimination exercises. The patient is trained with minimal pair sets of words. These are words which sound the same except for a

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The source code for AUDIX, and java class files for a demonstration version (compiled for PCWindows 95/98) are downloadable using a Web browser from http://www.cogs.susx.ac.uk/users/richc/audix.zip (file size 4.6 MB, 11.9 MB uncompressed).

change either in the initial, medial or final phoneme of the word, e.g. "pie", "bye", "my" or "cup", "cub", "come".

AUDIX therapy involves presenting the patient with sets of words (often 3 sometimes only 2) that have close phonemic contrasts. Typically, a speech clinician works first with words, which contrast initial, then final and then medial positions. When the patient's performance improves, the clinician may increase the complexity of the task by increasing the number of choices (e.g. 2 to 3 words) presented to the patient. A future version of AUDIX will also allow the therapist to increase the length of time (delay) between presenting the word and when the patient is allowed to respond.

Design of AUDIX

The design of AUDIX reflects the contributions of the patient during development. Although every effort was made to anticipate the patient's requirements, ultimately it is the patient (user) who has the final say on whether or not the program is usable from his/her point of view. The system design has changed considerably over time. For example, in an early version of the system, clickable pictures of lip-shapes with their associated sounds were presented only at the beginning of each exercise. In later versions, these interactive 'audio diagrams' were made available to the patient at any time during an exercise, i.e. for reference at any time. The performance accuracy criteria for moving forward through sequences of exercises were also fine-tuned.

Figure 1 shows the basic screen from AUDIX for a typical auditory discrimination exercise. It displays the written representation of minimal pairs in **p/b/m** phonemic contrasts. The top of the screen shows clickable images of relevant lip-shapes, as discussed above. AUDIX highlights the first trial (the first line) and selects randomly a target stimulus for this trial. The relevant sound file is then played. The patient hears the sound over headphones connected to the computer's sound card output. A "play again" button gives the user the option of repeating the stimulus sound.

The user's task is to discriminate the target stimulus of the actual trial from one, two or more distracter items, and to select one of the written representations. If the patient selects the correct written stimulus, the system reacts with a rewarding "applause" sound and changes the "play again" button into a "next" button. Following an erroneous response, the system reacts with a neutral "beep" sound and the patient is required to re-respond until the correct response item is chosen. The patient then presses the "next " button and the next trial is presented. When the patient has completed 3 consecutive exercises with a 90% or greater accuracy rate, the next exercise from the selected order is presented to the patient. This sequence is repeated until the exercise sequence is finished.

All responses and target stimuli data, including erroneous response sequences, are time-stamped and stored in a data log file for later evaluation by the clinician. Information about the selected items and the reaction times from the patient is stored in an ASCII file. Figure 2 shows an example.

AUDIX also provides a means by which the clinician can select the order of exercises for therapy. Figure 3 shows the clinician set-up screen. Here, the phonemic contrast position and type can be selected and the order of administration specified. The clinician can modify or create a new type of exercise for a particular patient (discussed below).

Implementation

AUDIX is developed in Java and is therefore platform independent and flexibly reconfigurable (Flanagan, 1997; Linden, 1998). It can run on a PC under Microsoft Windows 95/98, a Macintosh computer (under MacOS) or on a UNIX machine. The auditory discrimination exercises could also be provided via the Internet, as Java applets running in a web browser. These features represent a significant advantage over previous systems, which tend to be platform and operating system dependent, pre-internet and therefore out-of-date.

Most currently available rehabilitation software is platform specific and can therefore only be used (typically) on either Macintosh computer or IBM compatible PCs. An example of current software is RehaCom[3]. The software claims to provide computer-aided rehabilitation of cognitive functions, providing adaptive and individualized training. RehaCom is designed for PC's (486 or Pentium) and runs under MS-DOS version 5.0 (or higher).

Java, AUDIX's development language, provides a way to focus on the data in the application and the methods that manipulate that data. In an object-oriented system such as AUDIX, the source code can be organized efficiently, e.g. through inheritance. Subclasses can inherit behavior from the referring superclass, which is efficient from the point of view of code re-use and organization. Another advantage of Java is its platform independence (architectural neutrality). AUDIX can be used on any systems for which a Java runtime environment is available. It can run over the Internet and on UNIX workstations, Macintosh computers and PC's under the Microsoft Windows operating system.

The following software was used in the development of AUDIX: Java JDK 1.2 from Sun Microsystems[4] and SoundEdit 16 version 2 from Macromedia[5]. The system was implemented on a PC with an AMD K63 Processor (400 MHz), 64 MB RAM, an ATI video card 128 GL, and a Sound Blaster 16 PCI sound card.

Sound Recording Procedure

As mentioned above, AUDIX provides a means for the clinician to specify the auditory discrimination exercises for each individual patient. To add or create new exercises, the relevant sound files and descriptions of the exercises in the knowledge base have to be prepared. The sound recording procedure will be explained in this section. Knowledge-base modification procedures are discussed in the following section.

Spoken stimuli were recorded by a speech clinician on to digital audio (DAT) tape in an acoustically dampened audio laboratory. The DAT tape was replayed into the audio line input of a Macintosh G3 computer. SoundEdit 16 version 2 (Macromedia) was used to digitize the audio clips, and they were saved in AIFF format. This sound format is a common audio format and allows the storage of high quality digitized samples at 22 kHz or 44 kHz (CD quality). To provide an appropriate sound for each stimulus in CD quality, the AIFF files have a sample depth of 16 bit, are recorded in stereo at a sampling rate of 44 kHz. High quality sound output is important because of the nature of the patient's task (auditory discrimination).

Because AUDIX is implemented in Java JDK 1.2 (Sun Microsystems), the developed system can be used with several audio file formats. Java JDK 1.2 is capable of handling the following audio formats:

AIFF, AU, WAV, MIDI (type 0 and type 1 files), RMF

Java (JDK 1.2) can handle 8-bit and 16-bit audio data at virtually any sample rate. In AUDIX, audio files are rendered at a sample rate of 22 or 44 kHz in 16-bit stereo[6].

When the sound files have been prepared, the knowledge base of AUDIX can be adapted. The next section describes the way in which new stimuli or phonemic contrast sequences (exercises) are added to AUDIX.

The knowledge-based system

The idea behind this knowledge-base system is to provide a way for the clinician to specify the behavior of the exercises, for example to add more stimuli relevant for a particular exercise or to create a different kind of exercise (different kinds of exercises are described below). The knowledge base is an ASCII file, which can be easily modified with the use of any basic text editor. All the domain dependent therapy knowledge is stored outside the system

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Sun Microsystems, Inc., 901 San Antonio Road, Palo Alto, CA 94303-4900, USA

Macromedia Inc., 600 Townsend St, San Francisco, CA 94103, USA

If the runtime hardware doesn't support 16-bit data or stereo playback, the audio output is 8-bit and/or mono.

core in a knowledge base. If the domain dependent therapy knowledge was "hard" coded inside the AUDIX system, the program code would have to be re-implemented following any change to an exercise, and would require a programmer. AUDIX was therefore implemented as a knowledge-based system, where the domain-dependent knowledge is stored in an independent file. The system core of AUDIX is therefore independent of any particular type of exercise output by the system, as shown in Figure 4.

A special knowledge representation language was developed to express the domain dependent therapy knowledge in the knowledge base. A knowledge-based system contains a knowledge base where the knowledge used by the system is explicitly coded and not implicitly "hidden" in the program code. This makes expanding or modifying the domain knowledge straightforward. The central task of a knowledge-based system can be seen in the representation and processing of knowledge.

A knowledge base is a symbol structure, which represents a set of facts about the domain of discourse methods (Berg & Fritzinger, 1997; Guida & Tasso, 1994). The term object is used to refer to elements in the knowledge base that are expected to indicate entities in the domain. For example a knowledge base which contains humans as its domain of discourse might contain an object which represents Socrates as a human. Objects are also used to represent abstract concepts such as the concept of humans and like sets of entities such as the set of philosophers. A property of an object is a statement that certain relationships hold between entities denoted by some objects. For example a property of the object which represents Socrates might be his birthplace in Athens.

Frames can be used to represent common sense knowledge so that the knowledge can be used by the computer system. Frames were developed in the seventies (e.g. Minsky, 1974). They are tools for representing knowledge in a structured and flexible manner. A frame is a complex data structure which contains information about the components of the concept being described, links to similar concepts, as well as procedural knowledge on how the frame can change over time. The common schemata of a frame can be seen in Figure 5.

A frame consists of slots that define its constituent parts. Each slot can be split into facets that specify local information, like the value of the slot, or the inferences and consistency checks that should be performed when the slot value is retrieved or updated.
An AUDIX frame has the following structure:

```
(defframe <framename> (superframe <framename>)
      <attributes>
      (parts (<partname> (frame <partframename>))
```

The name of the defining frame is represented after the keyword `defframe`. In a `superframe`, a frame can be specified from which a defined frame inherits all of its properties. Inside a `slot`, various `parts` can be defined. Each part is characterized through its name (`partname`). The following list represents the referring frame of the part.

For example:

```
(defframe initial-pbm-01 (superframe initial-pbm)
      ...
      (parts
            (pay-item (frame pay))
            (bay-item (frame bay))
            (may-item (frame may)))
...   )
```

This means that frame `initial-pbm-01` is a part of an exercise of minimal pairs in the initial position with **p/b/m** contrasts of voice and manner (`initial-pbm`). It includes the parts `pay-item`, `bay-item` and `may-item`, which represent a set of stimuli. The structure of the stimulus of `pay-item` is described in the frame `pay`.

A frame definition includes all the information about a particular object. A frame consists of attributes. To add a new stimulus, another contrast or to create a new exercise, frames have to be defined to expand the knowledge base. For example the following steps are involved in adding a new stimulus. First, a new frame is created for each new stimulus as follows:

```
(defframe bay (superframe initial-pbm-01)
      (voice "initial-pbm-bay.AIFF")
      (item "bay"))
```

Each stimulus is represented by its voice and item. By means of the attribute "`voice`", it is possible to state which sound file refers to the current stimulus, e.g. "initial-pbm-bay.AIFF", which includes the name of the sound file for stimulus bay. In attribute "`item`", the word, which represents the stimulus, can be expressed as a string, e.g. "bay".

The knowledge base has an important influence on the kind of exercise presented in the system. One way to modify the knowledge base is to add new knowledge, as described in this section, e.g. to present a set of contrasts in the referring contrast position. This design of knowledge base permits the clinician-user to set up exercises in which particular sets of contrasts are presented (e.g. selected on the basis of initial, medial or final position in the word, and/or on the basis of particular voice characteristics, etc).

Interface

AUDIX provides an environment that emulates the concrete (paper-based) material that the users (patients and clinicians) are already familiar with. Traditional therapy material consists of illustrations of, for example, words and sounds with their associated lip shape(s), or cards showing the written representation of the stimuli as words. Figure 6 gives an example of a card presented to a patient for the discrimination of **p/b/m** contrast stimuli.

These physical cards formed the basis of the design of the computer-based system. The system user is confronted with minimal pair sets of words that have to be discriminated. As described earlier, a typical exercise consists of listening to an aurally presented word (e.g. "pie") and then selecting a written representation of the word from an array of words – e.g. between "pie", "bye" and "my". Figure 1 shows an example of an AUDIX exercise on the same contrast as that shown on the card in Figure 6.

AUDIX gives performance feedback in the form of applause (audio clip) or a neutral beep sound (on an error). If the patient makes an error, s/he can retry and the system logs such repeat attempts and factors them into the scoring. All patient -system interactions are logged electronically for later review by patient and clinician. The patient is presented with a performance summary and a history of recent performances after each contrast session. Figure 7 shows such a summary.

The patient can practice exercises at home, in the absence of the clinician, between therapy sessions, using a Laptop PC and headphones. The interface design of AUDIX has taken into account that people who use this system for therapy have usually not had very much experience with computers. All interactions are via mouse-based “point and click” operations. Therefore the interface is very clear and easy to use. Because it is important that the patient understands how the auditory discrimination exercise system works, at the beginning of each session AUDIX provides a short explanation about the system and gives some instructions about the exercises which are to be undertaken by the user later on. The feedback at the end of each session provides the patient with an overview about the progress s/he has made while completing the auditory discrimination exercises.

AUDIX in use

The software has been trialled with an aphasic patient to evaluate its effectiveness in remediating the patient's auditory comprehension deficit. A controlled single-case study of a stroke induced aphasic patient who has moderate difficulties in understanding speech was conducted. The patient used AUDIX for therapy sessions several times at home over a two-week period. Single-case study research methods (Kratochwill & Levin, 1992), were used in order to investigate whether AUDIX-based intervention selectively improves the patients auditory discrimination performance on trained versus untrained contrasts.

The case study patient-participant was a 44-year old man (CB) presenting with persistent and stable word sound deafness was subjected to a full cognitive-neuropsychological assessment. The results provide strong evidence for the diagnosis of word sound deafness with a concomitant syntax problem in comprehending reversible verbs (e.g. shoot, push). These results contribute to forming baseline measures before therapy commenced.

Just prior to the commencement of the therapy program, the patient was administered a minimal pairs set. The items (i.e. the phonological contrasts) which he found most difficult were divided into two lists of minimal pairs for therapy. One list of phonological contrasts was treated (via AUDIX), with the other list the 'untreated' set. The treated and untreated lists were matched on word length, type, phonological contrast and place of contrast. The patient worked at home supported weekly by a clinician and one of the investigators (CL). Other pre-therapy assessments included measures of syntax comprehension and production such as the PALPA sentence-picture matching test (Kay, Lesser & Coltheart, 1992). The control conditions were test performances on the untreated phonological contrasts and the comprehension of reversible verbs (the latter were not treated during the course of the training program).

Several outcomes were studied:

i) The patient's improvement as a consequence of the auditory training therapy.

ii) The patient's response to a home-based therapy program which can be used "on demand" (under direction of the clinician).

iii) The log files of the patient's use of AUDIX during therapy.

At the end of the 6-week therapy program, the patient was reassessed on the pre-therapy tests. Improvement on the treated but not on the untreated list of phonological contrasts or the syntax tests, suggest that the patient benefited from treatment. The results of this study are currently undergoing analysis (Lum, Grawemeyer, Roy and Cox, submitted).

Conclusion

There is clearly a role for computers in *therapy*, as opposed to *assessment* (which has been the focus of most research to date). A system (AUDIX) was designed and implemented for one specific kind of therapy according to sound principles from both software design and engineering and on the basis of scientific research in cognitive neuropsychology. Clinician and patient feedback informed the design, which emerged iteratively as successive versions of AUDIX were trialled.

The evaluation study revealed that the patient liked the feedback and felt a great sense of achievement as he saw his performance improve.

A patient (CB) used AUDIX for 6 weeks and the rich data from the system logs permitted new kinds of research question to be addressed. The use of systems such as AUDIX should contribute substantially to knowledge about treatment efficacy.

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Figures and Captions

Figure 1. AUDIX window for a typical auditory discrimination exercise.

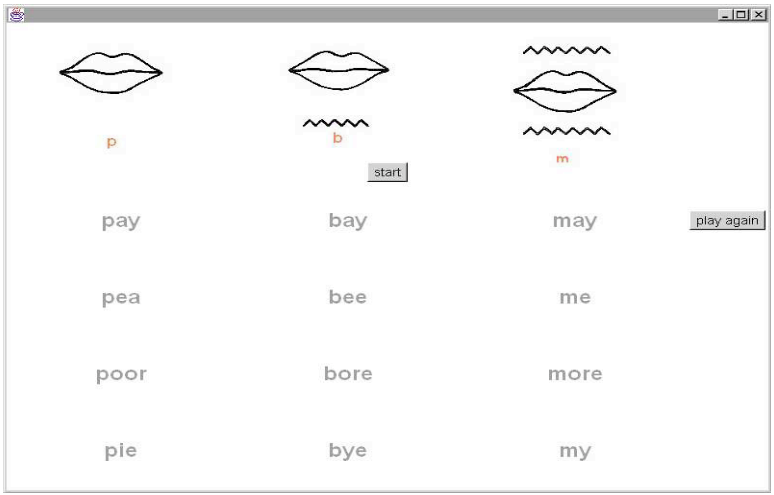


Figure 2. AUDIX summary of the user's responses.

```
auditory discrimination
exercises
date: 28 Jun 2000
start time : 11:40:19 AM
end time : 11:41:07 AM
user name: brmic-test
sess. no.: 1
trial no.: 2

pressed item: pay
response: true

pressed item: me
response: false
pressed item: bee
response: true

pressed item: more
response: true

pressed item: my
response: true
...
```

Figure 3. AUDIX set-up screen (used by clinicians/therapists).

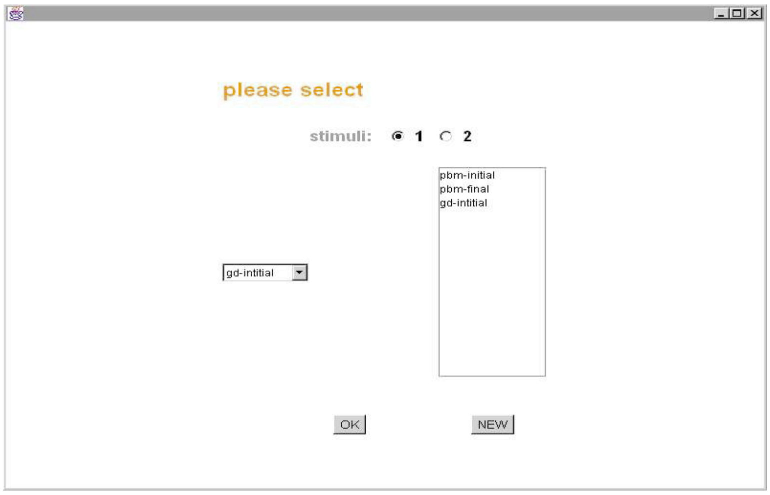


Figure 4. System overview of the Knowledge-Based AUDIX system.

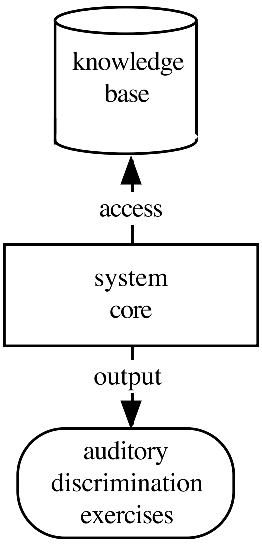


Figure 5. The common schemata of a frame.

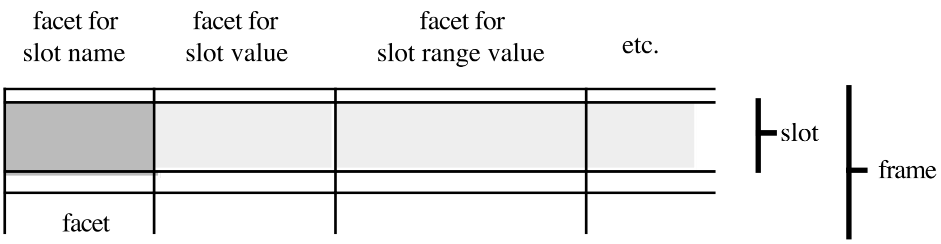


Figure 6 Example of a card presented to a patient for the discrimination of **p/b/m** contrast stimuli

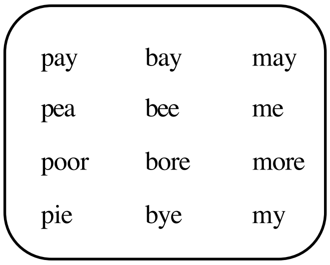
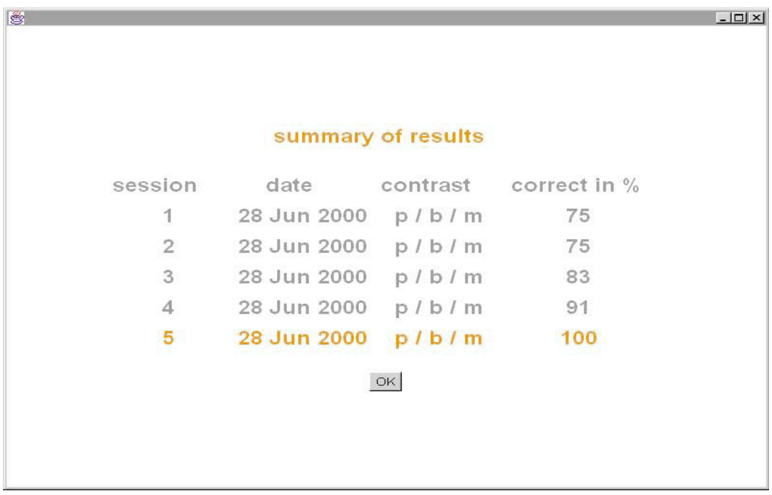


Figure 7. AUDIX summary of user response results.


summary of results

session	date	contrast	correct in %
1	28 Jun 2000	p / b / m	75
2	28 Jun 2000	p / b / m	75
3	28 Jun 2000	p / b / m	83
4	28 Jun 2000	p / b / m	91
5	28 Jun 2000	p / b / m	100

OK