A DIX s n J v s so t r or

r t n u tor p r ptu ts

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CSRP - 521

October 25, 2000

A str t

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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Intro u t on

AUDIX2 provides a knowledge-based system for auditory discrimination exercises. The system is designed to deliver computer-based cognitive rehabilitation *t er py* 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.

D s n o A DIX

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** 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.

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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.

oun or n Pro ur

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.

no s s st

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 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).

Int r

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** 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 ma 0 0 seaudio clipstimulusexercin12 Tf -yting a w2ich rame m 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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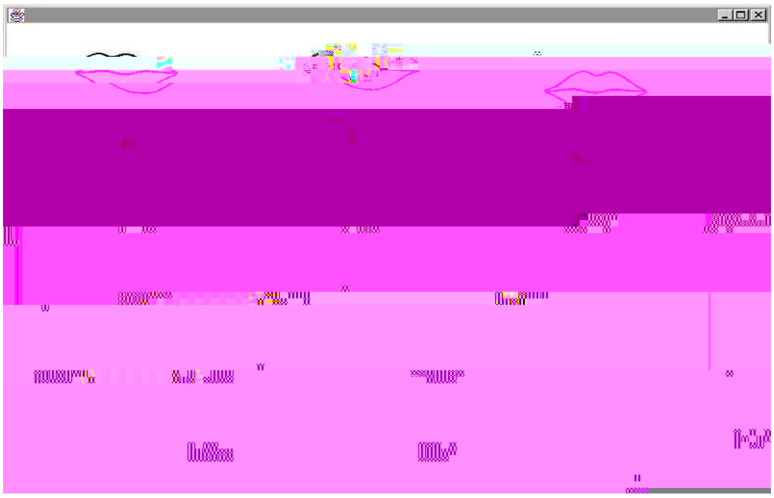
F ur s n C pt ons

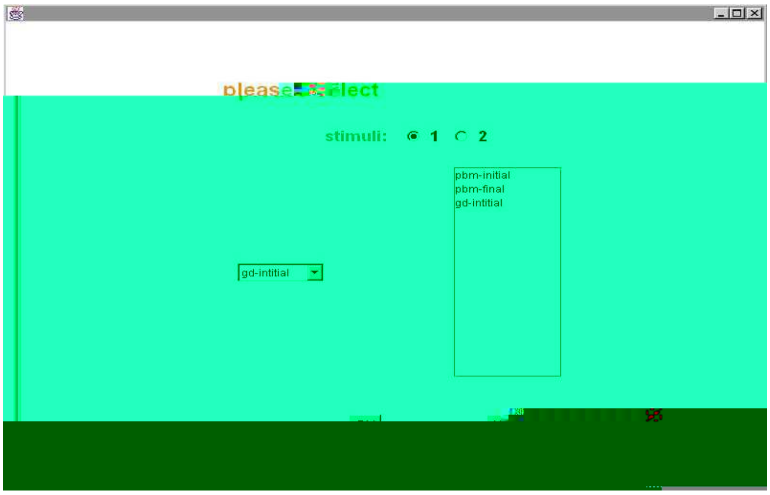
F ur AUDIX window for a typical auditory discrimination exercise.



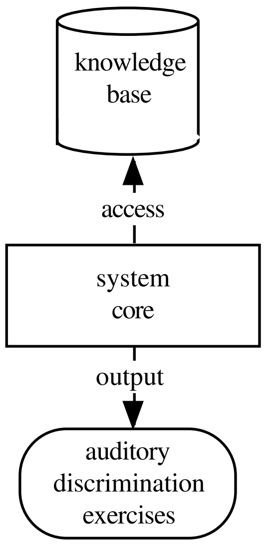
F ur . AUDIX summary of the user's responses.

```
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
...
```

F ur . AUDIX set-up screen (used by clinicians/therapists).

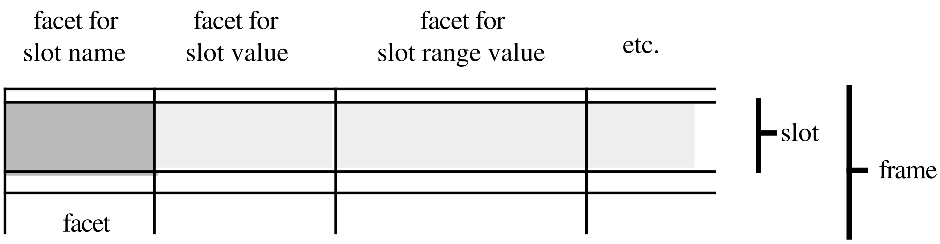


F ur 4 System overview of the Knowledge-Based AUDIX system.



b -1 0 0 8 v67 1908.67 100 1006 116.668 100 re W n 0 g 8.33333 0 0 8.33333 0 0 cm BT 18.052 Tc /R8 10 Tf -1 0 0 -7 0.43G0 0Omb -1 0 0 8 v67

F ur The common schemata of a frame.



F ur Example of a card presented to a patient for the discrimination of **p** contrast stimuli