AUDIX: A Knowledge-based System for speech-therapeutic auditory discrimination exercises

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Abstract AUDIX is a knowledge-based multimedia system for auditory discrimination exercises. The aim of AUDIX is to provide patients with a computer-based therapy system which they can use between sessions with the human therapist, at home on an 'on-demand' basis. It is centered around computer based cognitive rehabilitation *therapy* whereas most existing programs in this area are only used for *assessment*. The auditory discrimination exercise system is designed for adult people who are speech-impaired as a result of a stroke. These people have auditory perceptual problems. The nature of the perceptual problem is an inability to perceive differences between phonemes. This requires a type of therapy called auditory discrimination training. The system provides computer-based auditory discrimination training. Through the knowledge-based design the domain dependent therapy knowledge is separated from the system core and provides a way for the therapist to add new knowledge, as new stimuli, or to create a new knowledge base to provide special exercises for an individual patient. The AUDIX architecture is described and the advantages of computer-based therapy are discussed.

1. Introduction

As the cost of individualised face-to-face language therapy increases, there is a growing interest in computerized resources. Some work where the computer is used for *assessment* has been carried out, but, to date, there have been very few computer systems developed for cognitive rehabilitation *therapy*.

The aim of AUDIX, therefore, is to provide such patients with a computer-based therapy system which they can use between sessions with the human therapist, at home on an 'on-demand' basis. AUDIX provides **au**ditory **di**scrimination e**x**ercises and presents a mixture of visual stimuli (words, pictures), together with digital audio (voice) clips. The therapy program is intended to train an adult aphasic patient to learn to discriminate between minimal pair sets of words. These are words, which sound the same except for one phoneme of the word, e.g. pie and bye.

Some language therapy patients have an inability to distinguish between such closely sounding phonemes. This can be due to brain damage resulting from stroke and it can lead to difficulties in the understanding of spoken dialogue.

2. Computer-based systems in speech therapy

At the current stage, there are only a few computer-based systems in the area of cognitive rehabilitation. Most existing systems in the speech therapy domain, like the MINDS software tool from Brand [1], are designed for assessment and not for therapy.

There are several advantages of using computer systems in the area of cognitive rehabilitation. Using current technology it is possible to provide patients with access to therapy exercises in their own homes. In fact, there are even several advantages of using computer systems over and above *human* therapy.

Computer-based therapy exercises are available to the patient at any time of the day or night 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. A computer program can also provide the patient with full information about his/her test results and offer the patient a way to track their improvement over time. Interactions with therapy software is also more dynamic and responsive than the paper-based exercises that therapists often set for the patient to complete. Computer-based systems also free therapists from having to prepare paper-based exercises in advance. A computer-based system can also score the patient's performance dynamically, so that the therapist has more time to concentrate for example on the interpretation of the findings and the formulation of the therapy. Computer-based therapy systems also provide a rich source of data for speech and language therapy research purposes, including data that human therapists cannot gather, such as the patient's reaction times. Finally, the patients can use the software themselves and experience therapy more as a partnership of equals rather than a more asymmetrical 'therapist/patient' relationship. This helps the self confidence of the patients, as discussed in Crerar and Ellis [3].

AUDIX is developed in Java and is therefore platform independent and flexibly reconfigurable. It can run on a PC, a Macintosh computer or on a UNIX machine. The auditory discrimination exercises can also be provided via the internet. These features represent a significant advantage over previous systems, which tend to be platform and operating system dependent, pre-internet and out-of-date.

3. AUDIX architecture

AUDIX presents auditory discrimination exercises (phonemic contrasts) and is designed for use by an adult aphasic patient who needs to re-learn auditory discrimination skills. Such patients have an inability to distinguish between closely sounding phonemes leading to difficulties in the understanding of spoken dialogue. The patient is no longer able to distinguish between, for example Pat and bat. Another consequence of this disorder is that these patients have problems naming objects, recalling words and writing or distinguishing the meaning of a word with similar phonemes. Therapeutic techniques to improve the patient's ability to discriminate sounds is to provide auditory discrimination exercises. The patient can be trained with minimal pair sets of words. These are words which sound the same except for a change either in the initial, medial or final phoneme of the word, e.g. **p**ie, **b**ye, **m**y or cu**p**, cu**b**, co**m**e. Patients can have this problem despite having normal hearing acuity. For aphasic patients it is a difficult to comprehend the speech sounds in comparison to those with normal hearing. This condition is called word sound deafness. For more information about this condition refer to Franklin [4] or Morris et. al. [7].

3.1 Knowledge base

The system contains a knowledge-base consisting of the crucial therapy knowledge. With this kind of separation (of the domain knowledge from the system core), the therapist can influence the exercises which will be presented through the system. This design offers a way for the therapist to flexibly customize exercises for individual patients, e.g. to add more stimuli which are relevant for the exercise or to create a different kind of exercise. To achieve this behavior, all the domain dependent therapy knowledge is stored outside the system core in a knowledge-base. The system creates the auditory discrimination exercises with the domain dependent therapy knowledge of the knowledge-base. The knowledge-base is represented through a frame structure. The following example shows the expression of the minimal pair sets of words **p**ie, **b**ye, **m**y in the knowledge-base:

```
(defframe initial-pbm-01
        (superframe initial-pbm)
        ...
        (parts (pie-item (frame pie))
                (bye-item (frame bye))
                (my-item (frame my)))
        ...
)
```

This means that the frame initial-pbm-01 is a part exercise of minimal pairs in the initial position with pbm contrast of voice and manner (initial-pbm). It includes the parts pie-item, bye-item and my-item, which represents a set of stimuli. The structure of the stimulus of pay-item is described in the frame pay.

This approach allows the therapist to add new stimuli or create a complete knowledge base, e.g. another contrast like kt/d/n, within this frame-based knowledge representation language.

3.2 Interface

AUDIX provides an environment, which emulates the concrete (paper-based) material that the user is 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 1 gives an example of a card, which will be presented, for the patient to discriminate p/b/m contrast stimuli.

pay	bay	may
pea	bee	me
poor	bore	more
pie	bye	my

Figure 1 minimal pair sets of words
in initial position with p/b/m contrast of voice & manner

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, which have to be discriminated. A typical exercise consists of listening to an auditorily presented word (e.g. pie) and then selecting a written representation of the word from an array of words - between pie, bye and my, for example. Figure 2 shows an example of an exercise in the same contrast as the card in Figure 1.

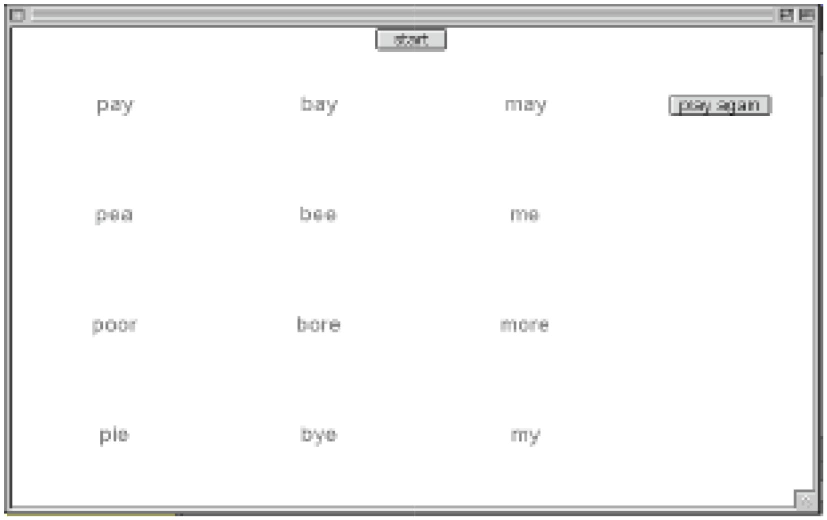

Figure 2 window exercise page

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 but 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 therapist. The patient is presented with a performance summary and a history of recent performances after each contrast session.

The patient can practice exercises at home, in the absence of the therapist, 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, AUDIX provides at the beginning of each session a short explanation about the system and gives some instructions about the exercises which are to be undertaken by the user later on.

4. Evaluation

In Nov. / Dec. 1999 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. The data are currently undergoing analysis. Initial results suggest positive training outcomes from AUDIX which seem to generalise to the sentence level of language production. Full results will be published in due course. Single-case study research methods (Kratochwill & Levin, [5]), has been used in order to investigate whether AUDIX-based intervention selectively improves the patients auditory discrimination performance on trained versus untrained contrasts. Following feedback from the patient and therapist, the system design has changed over time. For example, in an early version of the system, clickable picture of lip-shapes with their associated sounds were presented only at the beginning of each exercise. In later versions, these interactive diagrams were made available to the patient at any time during an exercise, i.e. for reference at any time. The accuracy performance criteria for moving on through sequences of exercises has also been fine tuned.

5. Future research

The aim of future research is to extend AUDIX and introduce more 'intelligent' functionality (I-AUDIX). This will involve adding a representation of a 'therapeutic curriculum' to AUDIX. The therapeutic curriculum will be used by I-AUDIX in order to structure therapy exercise sequences. The knowledge-base of AUDIX will also need to be greatly extended to in terms of the number and variety of phonemic contrasts available, with a range of difficulty levels for each contrast, i.e. minimal pairs that remain ambiguous to the patient.

Patient performance modelling will also be added to AUDIX. This subsystem will record the patient's performance on all contrasts and difficulty levels attempted and will be used in conjunction with the therapeutic curriculum module to 'drive' the sequence of exercises presented to the patient. Patient modelling is analogous to student modelling in intelligent tutoring systems (ITS) (e.g. van Lehn, [6]). A characteristic shared by many ITSs is that they infer a model of the student's current understanding of the subject matter and use this individualized model to adapt the instruction to the student's needs.

Another important development of AUDIX will be a facility whereby the system will be able to organise stimuli (contrasts) for therapy. The system could be expanded with an 'intelligent' component, capable of selecting suitable therapy items or stimuli from lexicons and psycholinguistic databases dynamically, in real-time.

6. Conclusion

AUDIX provides a knowledge-based system for auditory discrimination exercises. It is centered around computer based cognitive rehabilitation *therapy* whereas most existing programs in this area are only used for *assessment*.

The advantages of computer-based therapy are several. It allows the patient to practice as much as they want away from the therapist. The patients can use the software themselves and experience therapy more as a partnership of equals, which therefore evolves the self confidence of the patients. It also offers the therapist ways to provide additional data about the patient, like the reaction times of the patient for every response. It is also possible to provide a communication network, which might enable patients to contact each other despite their physical immobility or geographical distance. Computer-based therapy systems can record patient performance and are therefore very useful research tools.

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