Computing and Informatics, Vol. 29, 2010, 303–318

IMPROVING COMPUTER BASED SPEECH THERAPY USING A FUZZY EXPERT SYSTEM

Ovidiu-Andrei Schipor, Stefan-Gheorghe Pentiuc
Maria-Doina Schipor

Stefan cel Mare University of Suceava
str. Universitatii, nr. 13, RO-720229
Suceava, Romania
e-mail: {schipor, pentiuc}@eed.usv.ro, vmdoina@yahoo.com

Manuscript received 19 September 2008; revised 25 September 2008
Communicated by Milan Rusko

Abstract. In this paper we present our work about *Computer Based Speech Therapy* systems optimization. We focus especially on using a fuzzy expert system in order to determine specific parameters of personalized therapy, i.e. the number, length and content of training sessions. The efficiency of this new approach was tested during an experiment performed with our CBST, named *LOGOMON*.

Keywords: Computer based speech therapy, fuzzy expert system, personalized therapy, exercises for dyslalia

1 INTRODUCTION

There is a great European level concern for helping people with speech disorders and there are a lot of Computer Based Speech Training Systems (CBST), for both commercial and research purposes. According to [1], a CBST is a system for teaching and training speech production for people with speech and hearing impairments. Computer-based speech therapy aids can be seen as clinical tools. Speech therapy software can aid diagnosis of speech disorders and provides visual feedback during treatment [2]. A CBST system could not replace SLPs (Speech and Language Pathologists or *Speech Therapists*), but would “facilitate their assessment of speech by helping them better target therapeutic intervention, augment their efforts in highly repetitive articulation drill and training, and assist in record keeping and reporting" [3].

Our CBST system has been developed for Romanian pre-school children, to improve assessment of speech disorders, which affect pronunciation of one or many sounds. There are two different types of such disorders: *dysarthria* and *dyslalia*. Although they are similar in terms of symptoms, these two speech problems have different causes. While dysarthria is an articulation disorder produced by peripheral or central nerve damaged, dyslalia is a functional articulation disorder. Thus, dyslalia may be produced by a maturation delay of certain organs involved in pronunciation, by some wrong speech habits or by some hearing problems [4].

We start with classic CBST architecture and we design and implement an improved CBST system, named *LOGOMON (Logopedics Monitor)*. This CBST contains classical modules as *Children Manager, 3D Articulator Model, and Homework Manager* (installed on the child's PC or PDA) [5]. Our main contribution is to improve the classical architecture with a *fuzzy expert system*. The role of this module is to suggest *optimal therapeutic actions* for each child (number, length and content of training sessions). For each subject, our expert system can generate *optimal exercises set*, based on specific information (tests' scores and social, cognitive and affective parameters).

1.1 Literature Review

Statistics [6] show that 10 % of children between 4 and 7 years of age present different levels of these two types of speech problem: dyslalia and dysarthria. Although these impairments do not create major difficulties in basic communication, it has been noticed that problems are likely to appear affecting negatively the child's personality, as well as his social skills [7, 8, 9].

From the computer science point of view, the development of an intelligent system capable of doing assisted therapy can be included in a very important research area: informational technologies in response to society challenges (for health: early diagnosis, personalized therapy). Taking into consideration the fact that Romanian language is a phonetic one that has its own special linguistic particularities, we consider that there is a real need for the development of audio-video systems which can be used in the therapy of different pronunciations problems.

Research has shown [10, 11, 12] that there is a need of CBST systems that can support specifically therapeutic tasks without the presence of a speech therapist. In this context, we consider that our attempt to *automatically establish personalized therapy* is a step forward.

Selection of most important CBST systems is not an easy task. However, two recent projects have a special place in speech therapy field: OLP and ARTUR. For both projects, experimental results are available [13, 14].

The OLP (*Ortho-Logo-Paedia*) project [15] has been started in 2002, involving the Institute for Language and Speech Processing in Athens and seven other partners from the academic and medical domains. The project aims at accomplishing a three-modules system (OPTACIA, GRIFOS and TELEMACHOS) interactively capable of instructing the dysarthria suffering children. The proposed interactive environment is a visual one and it is adapted with the age of subjects using different games and animations. The audio and video interface with the human subject is the OPTACIA module, the GRIFOS module makes pronunciation recognition and the computer aided instructing is integrated in the third module – TELEMACHOS.

One of the most recent CBST system is ARTUR (Articulation Tutor) [5]. The goal of this project is to obtain an integrated speech therapy system with an intuitive graphical interface named Wizard-of-Oz and a virtual speech tutor named Artur. Based on audio (user's utterance) and video (facial data) information, the system can recognize and reproduce mispronunciations. After that, Artur suggests the correct pronunciation (audio data) and the correct speech elements' position (virtual articulator model).

At the Romanian national level, only a few researches have been conducted to the therapy of speech impairments, and most of them are focused on traditional areas such as voice recognition, voice synthesis and voice authentication. We can mention the studies made by the *Psychology and Education Science Department* from "Al. I. Cuza" University, Iasi. These studies carry out the development of a software, in order to provide stammer witness therapy [16].

As far as we know, there are no applications of fuzzy expert system in CBST field. That is why we consider our approach is a step forward. The system was developed and tested for Romanian language, but our proposed method is not limited to this language.

1.2 Overall Organization of the Paper

In order to improve the computer based speech therapy using a fuzzy expert system, we analyze first the opportunity of fuzzy logic approach (Section 2.1). Then we present the place of expert system in the therapy's diagram of dyslalia (Section 2.2) and the integration of the expert system in LOGOMON architecture (Section 2.3). Knowledge base details are given in Section 2.4.

The validation of this approach (Section 3) was performed by a three month experiment that involves two equivalent children groups, taken from RSTC – Regional Speech Therapy Center of Suceava, Romania. The first group used LOGOMON, but the expert system was deactivated, so all therapeutical decisions were taken only by the speech therapist. The second group used LOGOMON with inference facilities, so that a part of therapeutical decisions was offered by expert system and the other one was offered by speech therapist. Comparing the results of these two groups at the end of the twelve weeks period, we obtained some interesting conclusions regarding the expert system utility.

2 TECHNICAL SYSTEM PRESENTATION

2.1 Fuzzy Expert System Overview

One of the main objectives of our CBST system was the development of an expert system for personalized therapy of speech impairments, which will allow the designing of a training path for pronunciation, being individualized in accordance with the defect category, previous experiences and the child's therapy previous evolution. The expert system is based on a therapy guide, written in natural language. This guide was formalized using fuzzy logic paradigm. In this manner we obtained a knowledge base with over 230 rules and 22 linguistic variables [17].

The therapeutical guide formalized in knowledge base consists of [18]:

- the muscular of phonon-articulator system development methods (e.g. setting up exercises for cheeks, lips and tongue);
- the rhythm of respiration controlling methods (e.g. supervised inspiration and expiration from the temporal and intensity standpoints);
- the phonomatic hearing development methods (e.g. the onomatopoeic pronunciation, rhythmic pronunciation exercises, distinguishing along the paronyms);
- the method for sound consolidation (e.g. the pronunciation sound of direct, inverse and complex syllable, of words, of paronyms, etc);
- the sound's utilization in complex contexts (e.g. sentence, short stories, poems, riddles).

The objectives of the speech therapy expert system developed by our team are as follows [19]:

personalized therapy – the therapy must be in accordance with child's problems level, context and possibilities;

speech therapist assistant – the expert system offers some suggestions regarding what type of exercises are better for a specific moment and for a specific child;

(self) teaching – when system's conclusion is different than that of the speech therapist, the latter should have the possibility to change the knowledge base.

The specific advantages of an expert system addressing therapy of children with speech impairments are as follows:

- the automatic personalized therapy system stores the precise evolution and progress of each child and, by adapting the exercises to each child's current level and progress, the speech therapy may take less time to achieve its result;
- patience, flexibility and unlimited working time whenever the child desires;
- the possibility offered to the speech therapist in order to accurately find out why the system generated some therapeutic proposals;

- an exact evaluation of the progress is difficult to achieve for a human expert; instead, the system is designed to analyze in an objective manner the evolution of each case on small time intervals.

In order to implement our expert system, we choose the *fuzzy logic paradigm* [20]. With a fuzzy approach, we can create a better model for speech therapist's decisions. Fuzzy logic has the ability to create accurate models of reality because ambiguity and contradictions are part of human reasoning. "It's not an imprecise logic. It's a logic that can manipulate imprecise aspects of reality" [21]. In the last years, many fuzzy expert systems were developed and tested [22].

Another very important advantage of this approach is the representation of linguistic variables and fuzzy rules in a closer way to natural language. Due to the use of *linguistic variables*, *linguistic terms* and *linguistic hedges* represented in a natural language, fuzzy rules are easy to be read and understood by the human expert.

A linguistic variable is formed by the following entities, shown in Figure 1:

- the name of linguistic variable (e.g. *"child's age"*);
- names of linguistic terms (e.g. *"young"*, *"intermediate"*, *"old"*);
- one membership function is assigned to each linguistic term (this function is usually defined on the real axis and indicates the actual level of membership of each number from the definition domain).

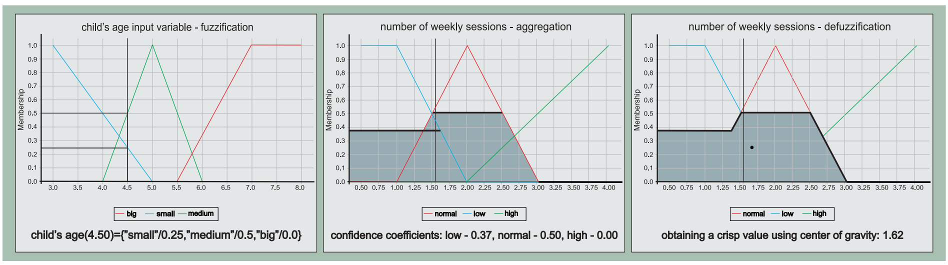


Fig. 1. Stages of a fuzzy process

The stages of a fuzzy inference process are indicated in Figure 1:

fuzzification: fixed values of input variables are transformed into membership functions coefficients;

rules evaluation: fuzzy rules sets are evaluated using fuzzy logic approach;

aggregation: the inference results are mapped on output linguistic variables;

defuzzification: each output variable can be transformed into a crisp value.

One example of fuzzy rule used by our system is as follows: *IF defect of speech IS small AND child's age IS old AND family involving IS advanced THEN the number of weekly sessions IS reduced.*

2.2 The Place of Expert System in the Therapy's Diagram

Psychological researches [4, 19] have indicated the main aspects regarding dyslalia therapy (Figure 2). In the first step, which is *Complex Examination*, the speech therapist collects the base data set of information used for the child's diagnostic and future therapy. Part of this data is obtained from specific speech tests (9 scores from each affected sound). The other part, more than 50 variables, refers to cognitive, affective, and social parameters. If in this stage the speech therapist detects other problems like specific illness or affective trauma, s/he may require additional analysis.

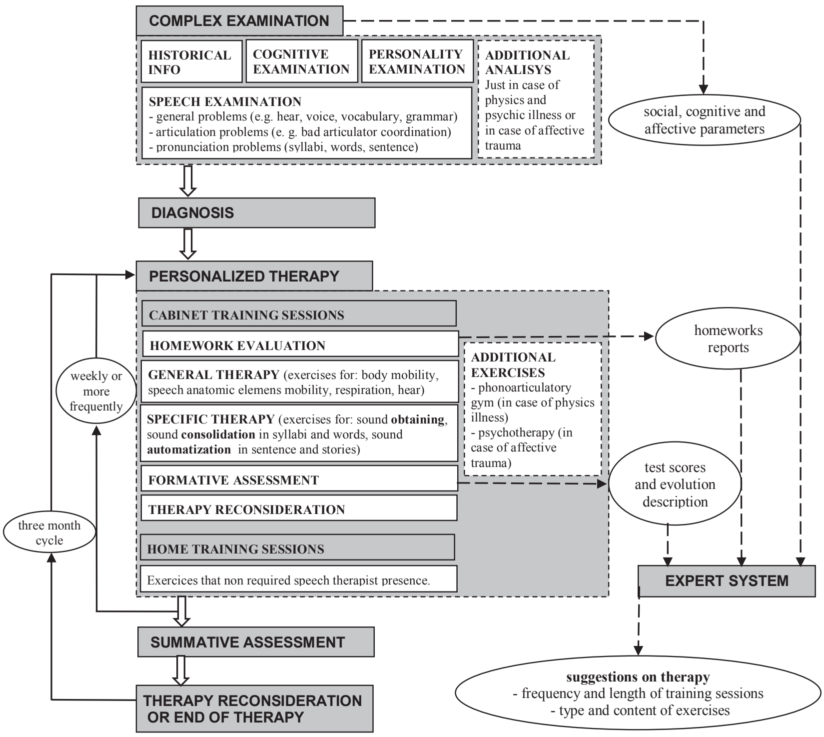


Fig. 2. The dyslalia therapy diagram and the expert system role

All kind of exercises are grouped in two main categories:

General Therapy (mobility development, air flow control, hearing development);

Specific Therapy (sound obtaining, consolidation and regular utilization).

Each therapy session contains a formative assessment and will be followed by home training. After three months, the speech therapist can finalize the treatment or can consider continuing it.

There are three types of information used by expert system:

- social, cognitive and affective parameters, taken from complex examination;
- homework reports, resulting from homework evaluation;
- test scores and evolution description, obtained from formative assessment.

Based on this information, encoded using fuzzy paradigm, the expert system provides answers to the following questions:

- How frequent should the training sessions be?
- How long should each session take?
- What type of exercises should be used and what content should they have?

2.3 The Integration of Expert System in LOGOMON CBST

In Figure 3 there is a scheme presenting the main modules of our CBST architecture. Assisted therapy is based on the interactions between six functional blocks: *child, speech therapist, lab monitor program, expert system, 3D model, child monitor program* [23].

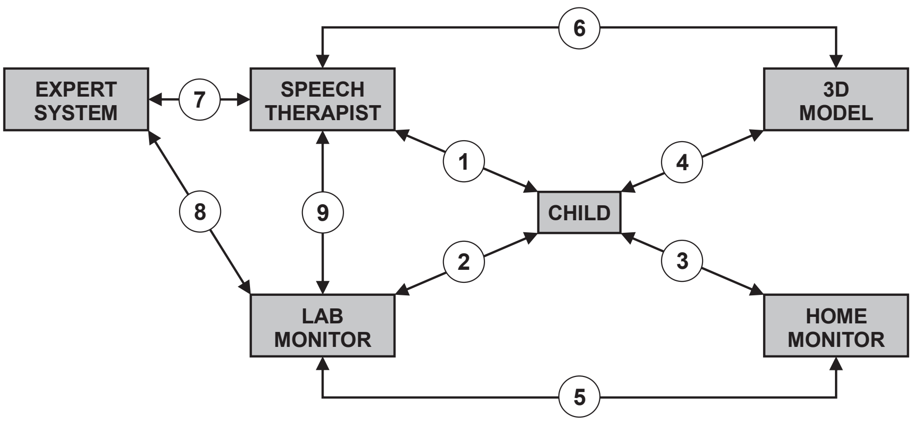
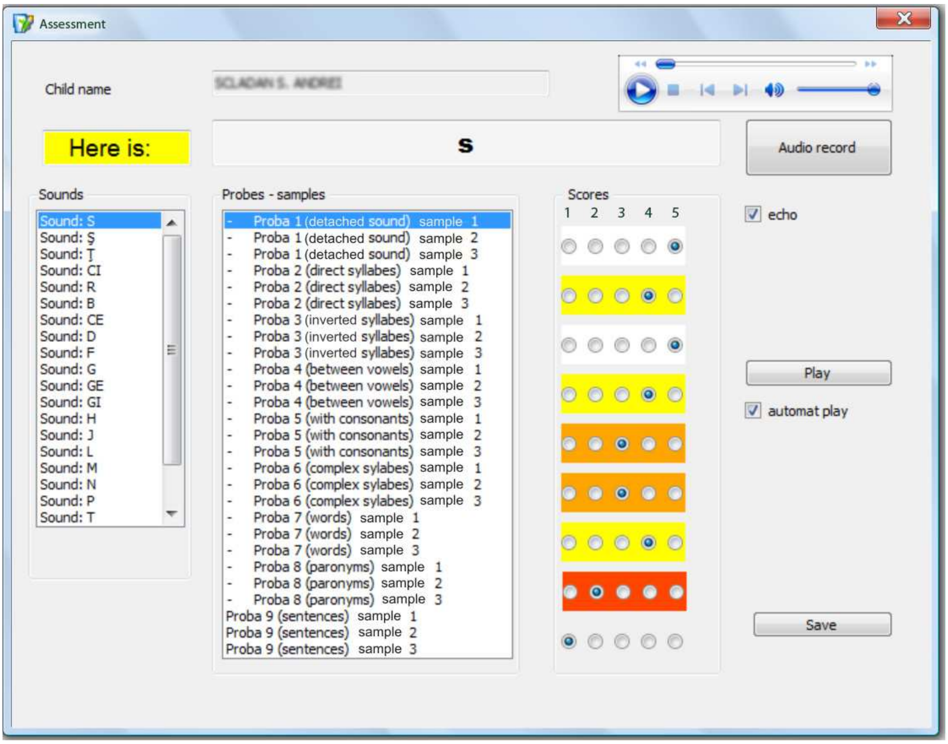


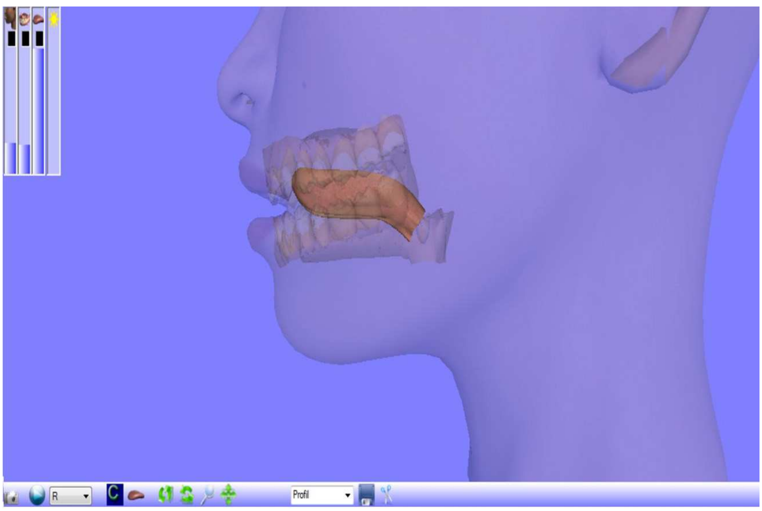
Fig. 3. LOGOMON system's architecture

This image also contains the system's information flow:

1. There is a close interpersonal relationship between the speech therapist and the child. All the other modules assist the teacher in his/her therapeutic action.



a)



b)

Fig. 4. Example of child's view: a) Child's assessment, b) 3D model view

2. The monitor program allows the introduction of a complex examination's information and offers the possibility of making periodically records of the child's speech (Figure 4 a)). The child receives an instant audio feedback and s/he can see the history of his/her audio recordings.
3. The role of home monitor program is to create a virtual interface between teacher and child (home speech therapy). This component is implemented both for PC and PDA. It can run exercises in a game manner, can offer feedback and can perform statistics base on current subject scores [24].
4. The 3D model provides viewing of the correct positioning of tongue, lips and teeth for each sound. The child may change the transparency of these items (Figure 4 b)).
5. The monitor program performs homework transmission to the child's PC or PDA. Later, when the child comes back, s/he can receive the activity report.

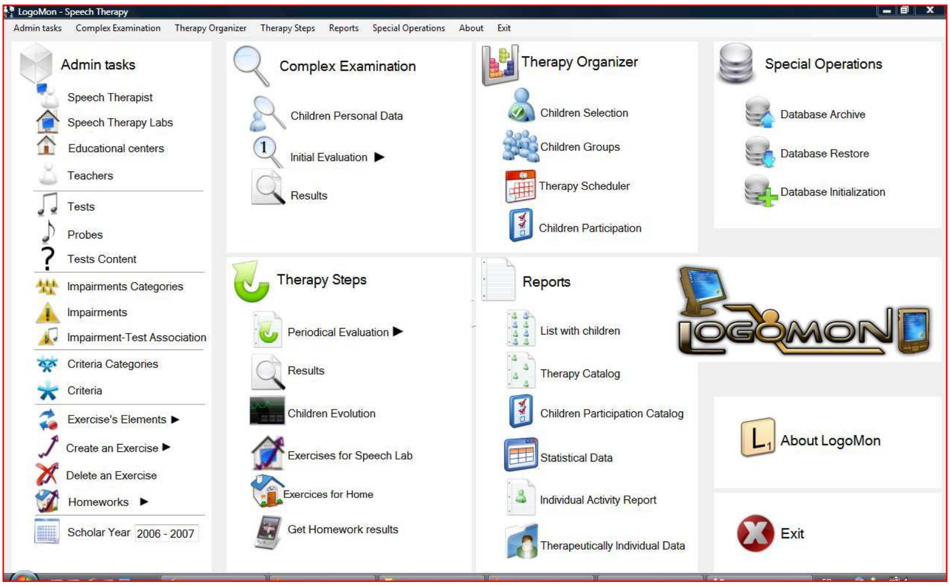


Fig. 5. Example of speech therapist's view (monitor program)

6. The professor will analyze the images offered by the 3D model and can correct some of the mistakes.
7. The expert system, if is activated, makes suggestions regarding some training parameters like session frequency, length and content (exercises) according to some input variables. If the teacher observes erroneous conclusions, s/he can view the inferential route and can change the knowledge base.
8. The expert takes the data input from the monitor program and generates, upon request, sets of personalized exercises.

9. Monitor program is an interface between the speech therapist and other components like data base, expert system and child monitor program. At this level, speech therapist can collect both textual and audio information regarding each child, can administrate exercises and can manage all therapy aspects: selection of children, scheduling for therapy, can offer all statistical reports that are required (Figure 5).

2.4 The Knowledge Base

Expert system receives information from the monitor program (children's personal data and pronunciation scores) and from the speech therapist (recalibration of knowledge database). It offers specific information referring to the next optimal therapy steps: number and content of training sessions, the need for collaboration with the family and a specialized doctor (Figure 6).

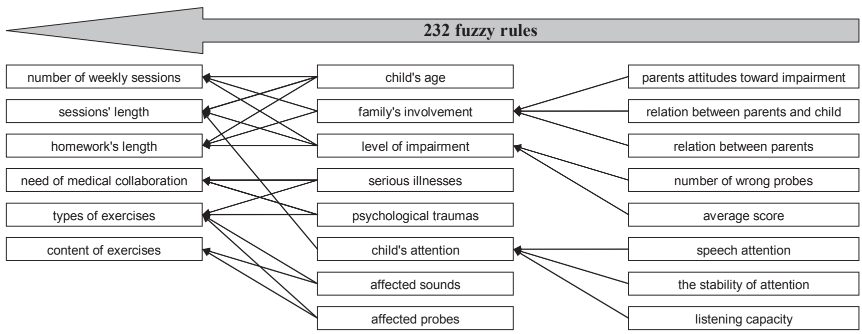


Fig. 6. Fuzzy variables and inferential connections

The expert system used in the LOGOMON CBST is based on forward chaining. We have limited the number of blocks of rules to 2 because each step added to the chain typically increases the ambiguity of linguistic variables, i.e. confidence coefficients of linguistic terms tend to become close in value [25]. According to [26] there are three possibilities to transmit values between fuzzy rules blocks:

1. We can fetch first fuzzy set directly to input of the second inference block. This approach increase ambiguity so different linguistic terms tent to have very appropriate values.
2. We can make some deffuzification operations and then we can transmit crisp values. Several fuzzification and deffuzification processes imply specific loss of information.
3. We can obtain new linguistic variables for each inter-block transfer using a linguistic approximation technique.

We find the third possibility optimum for our fuzzy expert system application [27].

The graphic representation of the 22 linguistic variables (Figure 6) and the 232 rules were tested and adapted by speech therapist in a six month practical work period. Therefore, the expert system has been optimized to provide the same results as the speech therapist. Expert system can generate exercises starting from 36 exercises types, over than 1 500 image files and over than 10 000 audio files [28].

3 THE EXPERIMENT

3.1 Methodology

The objective of the research is to study the possibility of automatic selection of exercises during the training sessions, using a fuzzy expert system. We used an unifactorial experimental plan $S_{10}\langle A_2\rangle$ where *factor* is the choice of exercises. This factor has two modalities: a_1 – the selection of exercises is made at the beginning of the session by speech therapist and a_2 – exercises are generated by the expert system.

As a dependent variable correctness of pronunciation was used. This variable consists of the 9 test results (scores from 1 to 5) obtained from children (following examples refer to 'S' sound):

- detached pronunciation of the sound (e.g. sss, s);
- the sound pronunciation in direct syllabes (e.g. sa, se, si);
- the sound pronunciation in inverted syllabes (e.g. as, es, is);
- the sound pronunciation between vowels (e.g. asa, ese, osi);
- the sound pronunciation together with consonants (e.g. stra, stre, stri);
- the sound pronunciation in complex syllabes (e.g. sas, ses, sis);
- the sound pronunciation in words (e.g. street, house);
- the sound pronunciation in paronyms;
- the sound pronunciation in sentences.

These scores were completed for each child and each of two session, using LOGOMON (Figure 4 a)). They were stored in the database along with voice samples.

The subjects were 20 children, boys and girls selected from RSTC Suceava, with age between 5 and 6 years, with difficulties in pronunciation of R and S sounds. They were divided into 2 equivalent groups: control group – modality a_1 of factor A and program group – modality a_2 of factor A. Each child attended two meetings weekly and was rated weekly. The two lots were constructed so as to be equivalent in terms of characteristics (Table 1) and in terms of pretest assessment scores. We tried that the sessions' length and course were the same in both cases. That is why the preparatory actions, including the exercises selection, had not been realized during the session.

The research hypothesis was that the two modalities of factor A do not lead to different effects on the dependent variable (correctness of pronunciation).

group	affected sound	age	boy	girl
control	*R*	5	2	1
		6	2	1
	S	5	1	1
		6	2	1
program	*R*	5	2	1
		6	2	1
	S	5	1	1
		6	2	1

Table 1. The structure of control and program groups

The instrument used to measure dependent variables is an observation table, integrated in the monitor program (Figure 4 a)). Thus it is possible to score each of 9 dependent variables on a Likert-type scale with 5 points. The first assessment, noted as "session 0", corresponds to the initial diagnostic stage. The last assessment, made at the end of the 24 session, corresponds to the final diagnostic stage.

It is important to mention that the results of a previous investigation pointed out the significant difference between the effects of classical and assisted therapy.

3.2 Results and Discussion

Because of small number of subjects in each group (under the limit of 30), scores' distribution was not normal in general. That is why statistic data were processed using nonparametric tests: *ManWitney* test for the difference between groups and *Wilcoxon* for the difference between pretest and posttest scores.

The experimental results, i.e. Z scores and significance levels, are presented in Table 2.

dependent variable	ManWitney session 0	Wilcoxon		ManWitney session 24
		program	control	
detached sound	$Z = 0.40$ (0.68)	$Z = 2.76(< 0.01)$	$Z = 2.88$ (< 0.01)	$Z = 0.84(0.39)$
direct syllables	$Z = 0.40$ (0.68)	$Z = 2.76(< 0.01)$	$Z = 2.87$ (< 0.01)	$Z = 0.75(0.45)$
inverted syllables	$Z = 0.08$ (0.93)	$Z = 2.85(< 0.01)$	$Z = 2.88$ (< 0.01)	$Z = 0.59(0.55)$
between vowels	$Z = 0.44$ (0.65)	$Z = 2.81(< 0.01)$	$Z = 2.85$ (< 0.01)	$Z = 0.75(0.45)$
with consonants	$Z = 0.64$ (0.52)	$Z = 2.72(< 0.01)$	$Z = 2.91$ (< 0.01)	$Z = 0.54(0.58)$
complex syllables	$Z = 0.62$ (0.53)	$Z = 2.87(< 0.01)$	$Z = 2.91$ (< 0.01)	$Z = 0.75(0.45)$
words	$Z = 0.08$ (0.93)	$Z = 2.87(< 0.01)$	$Z = 2.85$ (< 0.01)	$Z = 0.75(0.45)$
paronyms	$Z = 0.44$ (0.65)	$Z = 2.81(< 0.01)$	$Z = 2.85$ (< 0.01)	$Z = 0.75(0.45)$
sentences	$Z = 0.64$ (0.52)	$Z = 2.85(< 0.01)$	$Z = 2.87$ (< 0.01)	$Z = 0.21(0.83)$

Table 2. Statistic results

According to these experimental results, we can observe that:

- groups were parametrically and statistically equivalent (ManWitney, session 0);
- both groups have progressed (Wilcoxon);
- both groups have arrived at the same performance (ManWitney, session 24).

Because no significant differences between the two groups have been achieved at the end of the 24 meetings, we may consider that the exercises' choice can be performed either by speech therapist or by expert system. This result can be explained by the existence of a period of 6 months earlier, in which the expert system has been tested. In this period, the speech therapist has compared his/her decision with those suggested by the expert system and has adjusted the knowledge base.

During the experiment certain advantages of expert system utilization have been observed:

- the speech therapist has the possibility to be more concentrated on therapy because s/he does not spend time creating exercises (average time is 7 minutes per session);
- rigor and predictability.

4 SUMMARY AND CONCLUSIONS

In this article we presented the possibility of using a fuzzy expert system for automatic generation of exercises within a CBST. To validate this approach we have developed an experiment in which two groups of subjects participated for 12 weeks, 2 sessions per week.

The first group used LOGOMON, but expert system was deactivated, so all therapeutical decisions were taken only by the speech therapist. The second group used LOGOMON with inference facilities, so part of therapeutically decisions was offered by expert system and the other by the speech therapist. Comparing these two groups' results at the end of the twelve weeks period we observed that there was no significant difference; but there are other advantages of using an expert system to generate exercise: more therapy time, predictability, explanation of results.

Although we demonstrated our technique and experiment with the Romanian language only, we believe that the same methodology should lead to some improvements for other languages as well. We believe that the use of expert systems in the CBST is possible and will add certain advantages. In the future we want to extend the knowledge base to provide information about other aspects of therapy.

Acknowledgements

This research is a part of TERAPERS project financed by the National Agency for Scientific Research, Romania, INFOSOC program, contract number: 56-CEEX-II-03/27.07.2006.

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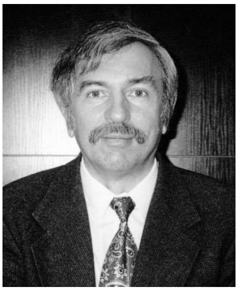
Ovidiu-Andrei Schipor is Eng. Assistant Drd. at the University "Stefan cel Mare" of Suceava, Romania. Teaches the laboratory courses Programming Languages, Data Structures and Algorithms, Numeric Methods. Ph. D. studies: Contributions for developing of computer based speech therapy systems. Research interests: fuzzy expert system, computer based speech therapy systems, distributed artificial intelligence, programming on the Internet. Projects participation: TERAPERS – Personalized therapy of dyslalia affecting pre-scholars, INTEROB – Gestures based interaction with information and robotics systems.



Stefan-Gheorghe Pentiuc is Professor at the University "Stefan cel Mare" of Suceava, Romania. Teaches the courses Pattern Recognition, Distributed Systems and Data Structures and Algorithms. Visiting Professor at the University of Lille, France, and invited researcher at Institute Galilee, Paris. Since 2001 Associate Editor of the journal Advances in Electrical and Computer Engineering. Research interests: pattern recognition, distributed artificial intelligence, programming on the Internet, algorithms, Java technologies.

Maria-Doina Schipor is a lecturer at the University "Stefan cel Mare" of Suceava, Romania. Teaches the courses Intercultural Education, Educational Psychology and Developmental Psychology. Ph. D. studies: Strategies and Techniques of Intercultural Teacher Training. Research interests: intercultural social psychology, social and cultural identity, teacher training methods, critical and creative thinking. Projects participation: TERAPERS – Personalized therapy of dyslalia affecting prescholars, INTEROB – Gestures based interaction with information and robotics systems, CENTROS – Unemployed support center.