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A proposal of an ecosystem based on intelligent ICT tools to support the diagnosis and intervention of patients with communication disorders

Una propuesta de un ecosistema basado en herramientas TIC inteligentes para apoyar el diagnóstico y la intervención de pacientes con trastornos de la comunicación

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Resumen

La intervención temprana en personas con discapacidades de comunicación (PWCD) es una estrategia fundamental que tiene el objetivo de mejorar varias habilidades relacionadas con el habla, el lenguaje y la deglución. Sin embargo, las herramientas existentes se centran en el diagnóstico o el tratamiento de trastornos específicos, y por lo general, no cubren las diferentes necesidades de las personas que proporcionan rehabilitación, asistencia sanitaria y servicios educativos para los pacientes (médicos, patólogos, y los familiares de los pacientes).

Abstract

Earlier intervention on People With Communication Disabilities (PWCD) is a fundamental strategy that has the aim of improving several skills related to speech, language, and swallowing. However, the existent tools are focused on the diagnosis or treatment of specific disorders, and commonly, they do not cover the different needs of people that provides rehabilitation, healthcare and educational services for patients (doctors, pathologists, and patient's relatives).

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Por estos motivos, en este trabajo se presenta una visión general de las herramientas existentes para el diagnóstico y la intervención de PWCD, y sobre esta base, se propone un ecosistema que implementa herramientas TIC inteligentes y un sistema experto capaz de generar automáticamente planes de terapia de lenguaje. El sistema experto ha sido evaluado previamente y ha alcanzado resultados alentadores.

Palabras clave: Terapia del lenguaje; systema experto; TIC.

On those grounds, in this paper, we present a general overview of existing tools for diagnosis and intervention of PWCD, and on this basis, we propose an ecosystem that implements intelligent ICT tools and an expert system able to automatically generate therapy plans. The expert system has been previously evaluated and has reached encouraging results.

Keywords: Speech-language therapy; expert system; ICT tools.

1. Introduction

Nowadays, the developing countries must face several difficulties and problems for providing health care and education services for PWCD. Some of the most critical problems are the lack of personnel, resources, and the non-existence of intelligent ICT-based tools to provide effective support in the several activities that should conduct the Speech-Language Pathologists (SLPs).

Another problem is that there exist several disabilities that can affect the communication skills, like Down syndrome, autistic disorder, Cerebral Palsy (CP), intellectual disabilities, etc. This circumstance makes a more complex situation, given that a SLP should be able to handle accurately several activities like the following:

- To design specific intervention strategies for each patient, bearing in mind his/her particular profile: medical and Speech-Language (SL) diagnosis, affected skills, family situation, environment (at school and at home), among others.
- To carry out an effective monitoring of each patient's progress, with the aim of making decisions to adjust the therapy long term plans, and intervention strategies.
- To provide counseling services for patients and their relatives.
- To provide remote support, and telerehabilitation services for those patients that are not able to assist to special education centers.
- To generate reports in different degrees of detail.

On those grounds, in this paper, we present a comprehensive ecosystem able to handle a wide spectrum of disabilities and services required by patients, SLPs, doctors, and patient's relatives.

The rest of the paper is organized as follows. A general overview of existing tools to provide support in the diagnosis and intervention of SL disorders are presented in detail in Section 2. The proposed ecosystem and its design (architecture) are described in Section 3. Some conclusions and ideas for future work are presented in Section 4.

2. Related work: a general overview

Over the last decade, there have been several approaches to apply information and communication technologies (ICT) to support SLT. Next, we describe some of the most interesting proposals, according to the disorder in which are focused.

2.1. Language disorders: aphasia

Aphasia is a disturbance of the comprehension and expression of language caused by dysfunction in the brain. Its effects range from having difficulty remembering words, to losing the ability to speak, read or write. It also affects visual language, such as sign language. Some authors have worked to develop "virtual therapists" to support the different activities involved in the treatment of this disorder. Abad et al. [1] presents an online tool that incorporates automatic speech recognition and conducts exercises of word naming recognition, for Portuguese native speakers. Another approach was developed by Teodoro et al. [2] to evaluate the quality of the interaction with aphasic patients, by means of an avatar with basic animation and expressions of visual emotions. Given a real situation (booking a flight, at the doctor's office, etc.) and a script of what should each one should say the system records the interaction between the patient and the virtual clinician, for subsequent analysis.

The use of gestures in aphasia as a compensatory communication strategy is another field of study [3, 4]. Some researchers have found that gesture and speech have a trade-off relationship, and thereby suggested opportunities for gestures as targets of aphasia therapy. In this line, a computer gesture therapy tool (GeST) was developed by Marshall et al. [5], aimed at improving the gesture production and/or spoken naming. The experiments revealed some positive effects on the patients' gesturing skills.

Another technique used in the treatment of naming deficits is Semantic Feature Analysis (SFA). The approach presented by Davis and Stanton [6], showed that patients improved in the naming of targeted items (with generalization to control stimuli) and learned a process for accessing semantic networks. Likewise, Higgins, Kearns, and Franklin [7] investigated the potential of SFA therapy programs in domestic and clinical settings, using a mobile-web paired application to support the therapy and implementing some features like a rapid data entry, aggregation and remote analysis.

2.2. Speech disorders: dysarthria, dyslalia and laryngeal disorders

Dysarthria is a motor speech disorder resulting from neurological injury, characterized by poor articulation of phonemes, whereas dyslalia relates broadly to difficulties in talking due to structural defects in the speech organs. Laryngeal disorders, for example, can affect the voice quality and cause difficulties such as hoarseness, limitations in pitch and loudness, etc.

These disorders have motivated the application of Automatic Speech Recognition (ASR) techniques for diagnosis tasks. For example, a model for automatic assessment of pronunciation quality for children was presented by Schipor, Pentiuc, and Schipor [8], using a Hidden Markov Model (HMM) and implementing a modified correlation measure to compare the level of intelligibility of new utterances presented to the system, previously trained by experts with reference utterances. Likewise, Saz et al. [9] used HMM and a subword-based pronunciation verification method to design and develop a semi-automated system to provide speech therapy. The aim of that proposal was to provide support in the acquisition of basic phonatory skills, phonetic articulation and language understanding in children and young speakers ranging in age from 11 to 21 years. In the same line of research, a new contribution presented by Caballero-Morales and Trujillo-Romero [10] improves the recognition rates in ASR systems for dysarthric patients. They present a model to integrate multiple pronunciation patterns using a novel weighting method based on Genetic Algorithms (GA).

In the realm of planning sessions of speech therapy for dyslalia treatment, Schipor, Pentiuc and Schipor [11] developed an expert system based on fuzzy logic. Their system uses three types of information to define the inference rules: (i) social, cognitive and affective parameters; (ii) homework reports; and (iii) test scores. With the inference rules, the system provides outputs about the frequency, duration and type of exercises of therapy sessions. As regards laryngeal defects, it is important to mention the proposal presented by Verikas et al. [12], which conducts a comparative study between voice analysis systems and questionnaires, in order to classify healthy patients and those suffering from diffuse and nodular mass lesions. This research has found evidence that the questionnaire data provide more information for the disease categorization than the voice data.

2.3. Hearing loss

The Auditory Verbal Therapy (AVT) is based on the use of residual hearing on children with hearing disorders. These children generally use cochlear implants and need to develop several speech abilities such as elementary productions (sounds, vowels or phonemes) or complex productions (spontaneous speech). In this context, Loaiza et al. [13] introduced the use of a video game based on AVT to provide support in voice interaction and reinforcement of voice production. Moreover, Alamoudi et al. [14] presented an interactive multimedia program for AVT in Arabic language, providing exercises aimed to improve perceptual skills in children with auditory-related problems and learning difficulties. The exercises were grouped in three categories: auditory discrimination, articulation and auditory attention.

2.4. Swallowing disorders: dysphagia

Dysphagia is a disorder that produces different difficulties like the impossibility of safely swallowing liquids, food or saliva, the presence of pain in the swallowing process or the impossibility to swallow at all. Nowadays, the approaches to provide dysphagia therapy are focused on the telerehabilitation area, with some promising results. For example, a pilot experiment to provide telerehabilitation for dysphagia treatment was performed by Sharma et al. [15], where ten patients suffering from a range of swallowing difficulties were provided with two types of assessment: face-to-face and telerehabilitation. The results showed the good acceptance of patients to use the telerehabilitation-based therapy. Yeh, Hou and Chang [16] presented an intelligent approach to classify a wide range of problems, including some related to swallowing, in order to provide occupational therapy to children. This approach uses Artificial Neural Networks (ANN) and Classification and Regression Trees (CART) along 127 attributes of children's profiles to assist the therapists for precise assessment and appropriate treatment. Most recently, Ward, Burns, Theodoros and Russell [17] conducted an experiment to perform a Clinical Swallowing Examination (CSE) on 100 patients (25 nondysphagics and 25 mild, 25 moderate, and 25 severe dysphagics) using a telehealth system. Their research reported good levels of acceptance in each group of patients during the clinical decision making for safety of oral intake and the clinicians' perceptions of CSEs conducted via telerehabilitation.

2.5. Communication disorders: selective mutism

Selective mutism (SM) is an anxiety disorder in which a person who is normally capable of speech does not speak in specific situations or to specific people. Selective mutism usually co-exists with shyness or social anxiety. Cognitive-Behavioural Therapy (CBT) defines some techniques that have shown excellent results in the management of these and other problems, with noticeable improvements in the patients' general well-being and distress [18]. An approach to web-based CBT for the treatment of children with selective mutism (SM) was presented by Ooi et al. [19]; the proposal was tested with 5 children during 14 weeks, and the results showed significant progress in the speech frequency in social situations (school and home) in 4 of them. Likewise, Bunnell and Beidel [20] described a case where the traditional therapy (intensive exposure based on an extinction paradigm) was not helpful, whereas the use of mobile applications for engagement in amusing tasks and the pairing of vocalization with positive emotions obtained much better results.

3. Proposed ecosystem

Our ecosystem has been designed with the aim of providing a comprehensive set of functionalities that allow extending services, applications and components that

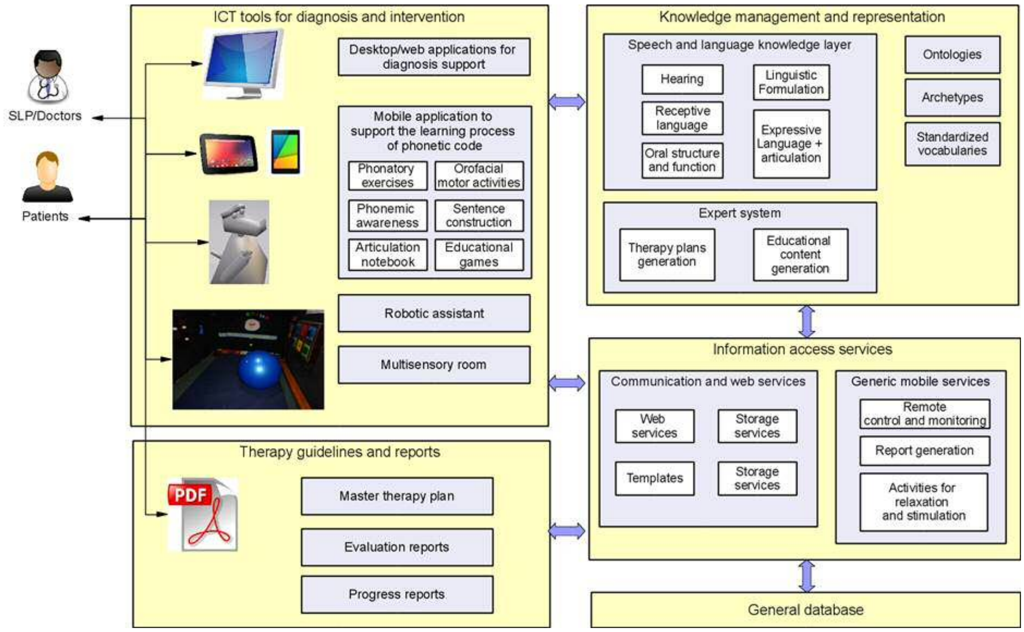

Figure 1. General overview of services, layers and components that make up the proposed ecosystem.

constitute it. In the Figure 1 are depicted the most relevant elements of each layer.

- A set of ICT tools to provide support during the diagnosis and intervention of patients with communication disorders. Through these tools a SLP is able to conduct the initial screening, the evaluation of the patient progress, and provide counseling and rehabilitation services. The applications for desktop and web environments are commonly used with patients that can interact with computers (sitting in front). On the other hand, the mobile applications are very useful to conduct activities with those patients that suffer from motor disabilities and must use wheelchairs. In order to support the therapy, this layer provides three different ICT tools: a mobile application to support the learning process of phonetic code, a robotic assistant, and a multi-sensory room.

The mobile application contains phonatory exercises (breathing exercises), phonemic awareness (perception and discrimination of letters and syllables), articulation notebook (learning and using consonants, vowels and phonemes), orofacial motor activities, sentence construction, and educational games based on therapy exercises. The robotic assistant is able to recognize faces, and interact with patients through sounds, games, relaxation activities as well as several therapy activities (motor, visual, and auditory stimulation). The multi-sensory room is used to provide early stimulation, relaxation activities, and several stimulation exercises of hearing, touch, and sight.

- With the aim of representing and managing the information, the ecosystem implements a layer that models five speech and language areas through ontologies, archetypes, and standardized vocabularies [21]. These areas are the following: hearing, linguistic formulation, receptive language, oral structure and function, and expressive language and articulation. Using this information a SLP is able to determine the patient's skills in each of the five areas mentioned above. Likewise, the expert system can generate therapy plans containing general guidelines to conduct activities for long-term periods (6 months) [22]. Each therapy plan consists of an ensemble of sub plans in each of the five areas previously mentioned and is generated using a multilevel cluster approach based on Partition Around Medoids and K Nearest Neighbors criterion. Another important feature of the expert system is the automatic generation of educational content according to each patient profile (currently not yet implemented).

- All information generated is stored in the device database, and subsequently is synchronized through the web and storage services with a central database. The ecosystem provides a set of templates based on Open Electronic Health Records (www.openehr.org) to access, share and enter information related to SLT process.

The relatives of each patient can use some templates to conduct reinforcement therapy activities using a computer or mobile device. Likewise, the ecosystem provides services to carry out a remote evaluation and monitoring of the therapy activities conducted with patients. The remote control can be used by SLPs to perform reinforcement activities like improving the spontaneous speaking, evaluate psychological patterns, and provide remote assessment and counseling services, among others. Once the therapy activities are done, is possible to generate a complete report that contains the areas that must be improved, the achieved goals,

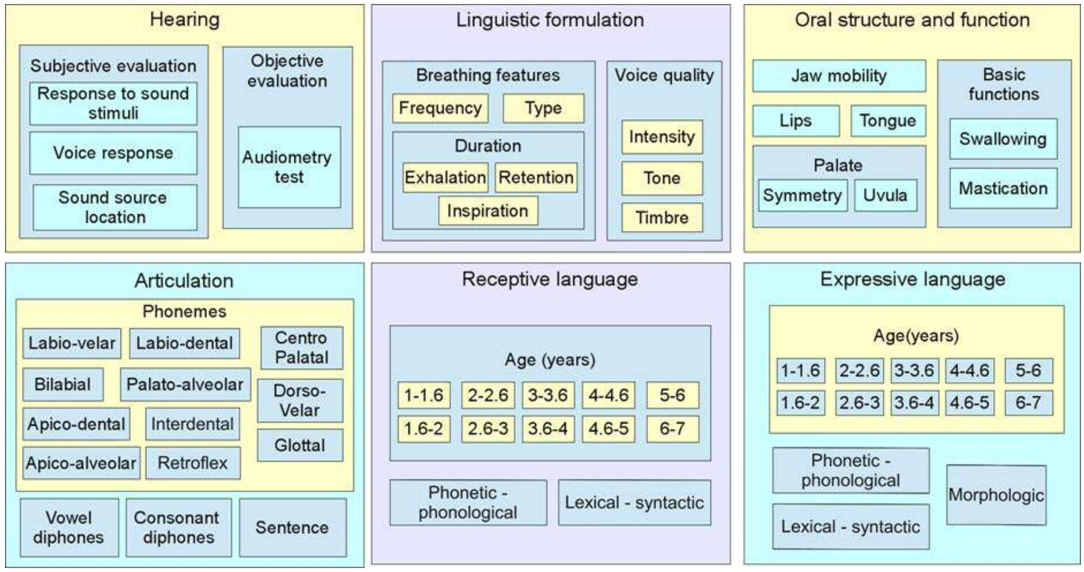

Figure 2. The different areas and concepts of the SLT knowledge model.

and a therapy plan automatically generated by the expert system, among other features.

- The therapy guidelines and reports are presented in PDF (Portable Document Format) or Word® formats, and contain information related to patient progress, the results that he/she has obtained in each test, clinical data, medical information, and personal data.

As can be seen, one of the most important elements of our ecosystem is the SLT knowledge model. In the following lines we will describe the main goal of each area depicted in the Figure 2.

- The hearing area allows to determine whether a patient present hearing problems through two different tests. The first one is a subjective evaluation based on response to voice and sound stimuli, and the patient's ability to locate sound sources. The second evaluation is objective, and is based on the results that are provided by an audiometry test.

- The linguistic formulation is an area that defines the parameters required to evaluate the patient's phonatory-respiratory system. In this area are defined the following characteristics: breathing frequency, thorax's symmetry, breathing duration (inspiration, exhalation, and retention), and voice quality (intensity, tone, and timbre).

- The main characteristics of the oral peripheral mechanism are described in the oral and structure function area. Some of the most relevant are the following: tongue (size, ability to move laterally, alternating movements, etc.), lips (symmetry, ability to protrude, retract, and move), palate (symmetry), uvula (position, size, and shape), teeth (state, occlusion, etc.), and the basic functions of mastication and swallowing.

- The articulation layer defines the several characteristics to evaluate the point and manner of articulation on phonemes (labio-velar, labio-dental, bilabial, apico-dental, etc.), vowel diphones, and consonant diphones. Likewise, in this area are defined the basic sentence features (number of words, structure, etc.).

- The receptive language allows to evaluate whether a patient is able to understand orders (questions, concepts, and size and use of the objects), identification and discrimination of objects (pictograms, parts of an object, etc.), among others. The level of difficulty of these elements is defined according to receptive language's age.

- The expressive language allows evaluating if a patient is able to perform the following activities: imitate language, to use pronouns, repeat sentences, maintain dialogs, use phonemes, etc.

In the Figure 3 is depicted an example of a report automatically generated by the system. This report contains a resume of the personal data of the patient, and a complete description of the problems found in the 5 areas mentioned previously.

The menu to collect the patient's anamnesis (clinical story) is depicted in the screen capture of the Figure 4. As can be seen, the application allows feeding the database with the information related to the early childhood, the parents and relatives, the diseases and surgeries, etc. This information is very important, given that allows for an expert system to analyze which patient's skills could be affected, and which strategies are best for a specific profile.

4. Conclusions and future work

In this paper, we have presented an intelligent ecosystem based on several layers able to handle a wide spectrum of disabilities related to communication disorders. Our proposal can easily incorporate new tools and methodologies to handle other kinds of disabilities by the implementation of ontologies, archetypes, and intelligent ICT tools. Likewise, our ecosystem allows pathologists conducting several activities in a more comfortable way, given that they can use mobile devices, desktop applications, robotic assistants, or web-based environments, according to specific situations and the patient's needs.

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DIAGNÓSTICO DE LENGUAJE: Retardo en desarrollo del lenguaje

Áreas de Evaluación	Estado Actual
MOTRICIDAD BUCOFACIAL	- Lengua de tamaño Medio: - Los Movimientos alternos: de Saque y meta la lengua Rápidamente es nula - El vibramiento de la lengua es nula - No Tiene temblores en la lengua - Los labios Si tiene simetría - El estado es Bueno
FORMULACIÓN LINGUISTICA	- La fuerza respiratoria es Normal - No tiene obstrucción nasal - Trabajar fuerza respiratoria - La cualidad de la voz tiene un timbre Hiporrinofonía
LENGUAJE COMPRENSIVO	- La edad de comprensión auditiva es de 1 años 1 meses

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LENGUAJE EXPRESIVO	- La edad de habilidad verbal es de 1 año 1 meses - La edad de lenguaje es de 1 año 1 meses - roblemas al Medio con el fonema: /ch/ - Problemas al Medio con el fonema: /k/ - Problemas al Medio con el fonema: /x/ - Problemas al Medio con el fonema: /x/ - Problemas al Final con el fonema: /b/

Figure 3. A screen capture of a patient's report generated by the system.

As lines of future work, we propose the following ones:

- Develop a module to automatically evaluate several features related to the patient's voice quality.
- Develop a module to automatically evaluate the quality of spontaneous speaking of patients suffering from speech disorders.

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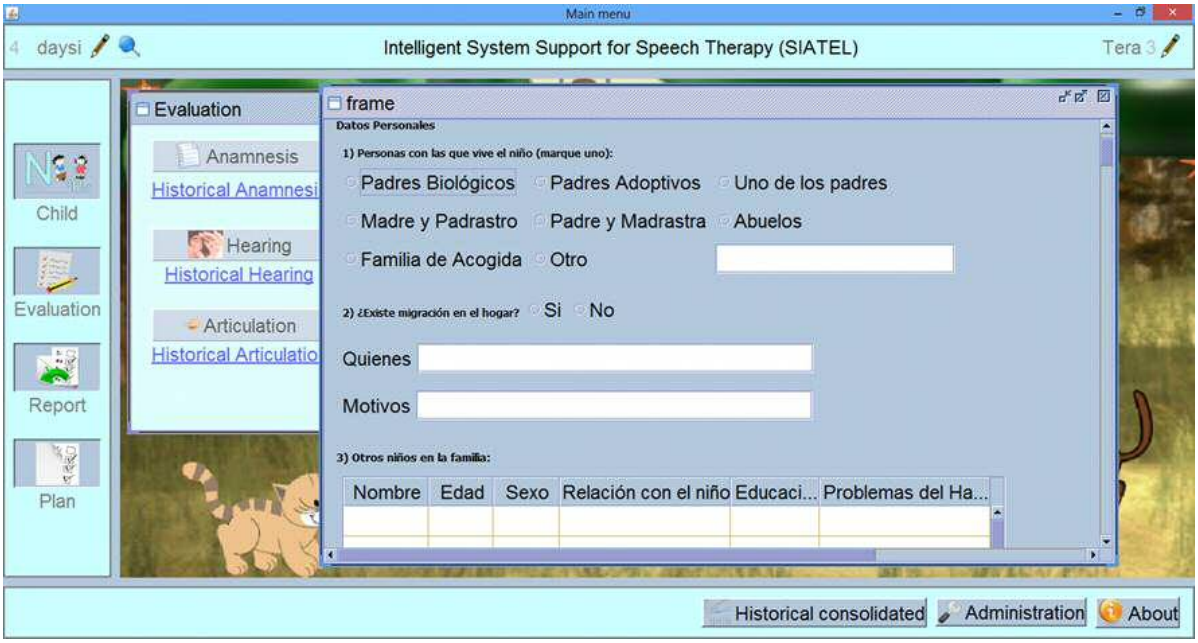

Figure 4. A screen capture of the anamnesis menu of the desktop application.

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