A clinical tool for prognosis and speech rehabilitation in dysarthric patients: the DESIRE project

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Abstract. Dysarthria is a motor disorder of speech characterized by alteration of articulation and intelligibility of speech. The goal of dysarthria management is to optimize communication effectiveness for as long as possible. To help clinicians in monitoring disease progression and rehabilitation outcomes, the DESIRE tool analyzes several reading sessions in which the patients pronounce predetermined selected words aloud, elaborating a measure of how much the patient's pronunciation deviates from those of previous sessions and the expected performance. In addition, the electronical record offers a comprehensive view of patient's status, and the web access allows the care team to remotely monitor progresses, so that they can tailor rehabilitation programs over time. Through the possibility to understand the patient difficulty about specific phonemes, word length, consonant clusters, this innovative tool offers a method to assess and monitoring dysarthria, to address therapeutic strategies, and to provide useful requirements for clinical trials readiness.

Keywords: dysarthria, speech rehabilitation, tele-monitoring

1 Introduction

Speech is a very complex behavior requiring the synchronous activity of muscle groups associated with respiration, laryngeal function, airflow transit, orofacial movements and prosody. In several neurological disorders an alteration of these complex motor processes induces dysarthria, a dysfunction in the execution of speech conditioning its intelligibility. It has been estimated that at least 40% of patients suffering from different neurological disorders involving central or peripheral nervous system (e.g stroke, amyotrophic lateral sclerosis, myotonic dystrophy) present an associated speech disorder [1].

An accurate evaluation of the pathophysiological aspects of the different sources of the motor speech disorder and the analysis of their interaction are mandatory to better define clinical characteristics of the impairment. In doing that, diagnostic tools used up to now in clinical practice are not always able to promptly detect small changes which impair speech function and can be quite invasive [2]. To define follow-up programs and, when possible, to trace a prognostic trajectory of the speech impairment, should be desirable, also to address tailored rehabilitation treatment plans.

Obtaining valid clinical outcomes measures needs the application of rigorous and repeatable assessment protocols able to quantify, confirm and refine highly subjective perceptual ratings often unreliable within and across evaluators. In fact, as observed in patients affected by amyotrophic lateral sclerosis [3], acoustic, kinematic and strength variables of the speech are to be considered and the use of tools able to catch and analyze speech signals and recognize specific dysarthric pattern should be recommended [4].

The aim of this work is to provide neurologists, phoniatrists and speech language therapists (SLT) with an ICT-based aid tool to be exploited both in the diagnostic field and in the evaluation and rehabilitation field of dysarthria for a targeted classification of the patient's language difficulty. Such a tool offers the possibility of creating a specific electronic health record, containing the patient's clinical information deriving from neurological and phoniatric visits and from the speech therapy assessments carried out. Additionally, the results of questionnaires, examinations and tests carried out can be entered, in particular those that evaluate the articulatory and perceptive aspects of the patient's dysarthria (e.g. speech and respiration, resonance, articulation and prosody, etc.). Moreover, it is possible to take notes on the communication strategies adopted and the subjective analysis of the SLT allowing to monitor patient performance over time and also to have a reference baseline shared among all clinicians involved in the patient management. Indeed, it is possible to record the patient's voice during each treatment session proposing a set of standard words, starting from the first medical-speech therapy interview. By obtaining automatic feedback on the quality, quantity and type of words articulated by the patient, the SLT is supported in the functional classification of the patient's dysarthria and in monitoring the patient's performance over time.

An accurate evaluation of dysarthria includes both an objective and subjective analysis of the speech subsystems, as well as their interactions with one another [5]. So, the acoustic parameters evaluated with the DESIRE tool will permit to have a numerical and objective quantification of severity and progression of speech disorders [6].

In order to have a precise view of the patient clinical status, the tool must propose an appropriate set of words to be monitored and the construction of the database is an important activity that, especially in some early stages, must include a review of the linguistic features. First of all, it is important that the recorded speech includes words that can actually be pronounced by patients in

real circumstances. Furthermore, the words must be selected to cover the repertoire of Italian phonemes, taking into account factors such as dialectal variation.

The set of words has been defined in the context of the realization of the IDEA database [7]. IDEA is the first Italian dysarthric database, whose aim is to improve the performance of automatic speech recognition (ASR) tools. These systems, in fact, are difficult to use for people affected by dysarthria, because they are trained using data not representing the peculiar characteristics of the dysarthric speech. IDEA is composed by the recordings of the selected words said aloud by different patients, during multiple sessions spread along time. The tool used to perform and manage such recordings is called RECORDIA and it is the starting point of our project, called DESIRE, which aims at expanding its feature in order to meet doctors' need in treating dysarthria.

2 Materials and method

The DESIRE tool is based on RECORDIA [7], a Java software originally developed to build the IDEA database and to provide patient characterization and voice recording features. RECORDIA provides a Graphical User Interface (GUI) that helps medical professionals to manage recording sessions, presenting the set of words to be said out aloud, allowing the user to stop, resume and repeat the session and to later listen to the recordings. Patient characterization includes a basic registry person and clinical information, such as pathology and its assessment scale, impairment level [8] and dysarthria classification [9], a measure of the quality of life [10] and measure scale of the therapy outcome [11]. This information and all the recordings (.wav files) are stored in the user's local PC, and the user can send them to a server, placed at the University of Pisa, using a File Transfer Protocol (FTP) client external to the RECORDIA software.

In order to meet doctors needs in treating dysarthria, while increasing the usability of the software, RECORDIA has been enhanced with some functionalities and integrated with a server featuring web application for user interactions and data consultation, REST web services for bi-directional data exchange and a centralized relational database for data storing. Fig. 1 shows the DESIRE tool architecture, in which the RECORDIA and IDEA modules are highlighted.

In this new configuration, the RECORDIA client is used not only to enroll new patients in the system and to perform the recording sessions, as already described, but also to actively support clinicians during therapy sessions. In addition to local storage in the file system, data is also sent to the centralized database using a dedicated REST service, so that they can be later requested for consultation using the web application or the client itself.

Indeed, the web application gives to authenticated users, using any internet browser, the access to patient's registry, medical records and recording sessions as they are working on RECORDIA client. The main difference is that an internet connection is required to use the web application with respect to RECORDIA software. Two different professional user profiles are provided: medical doctor and researcher/scientist. In the former case, the user has full access to the in-

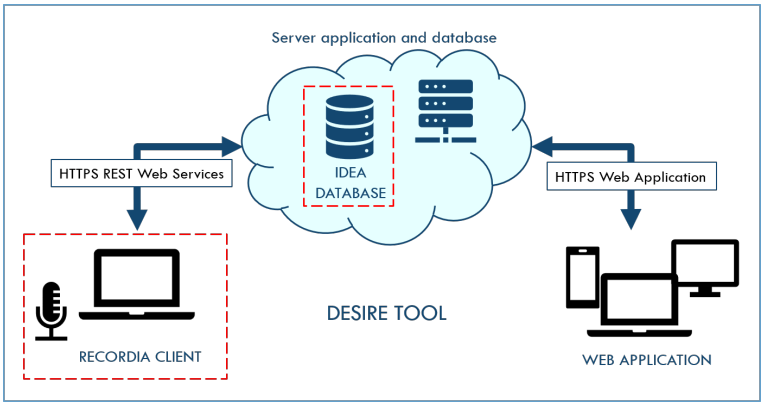

Fig. 1. The DESIRE tool architecture

formation of his/her followed patients, whereas, in the latter, only anonymized recordings and clinical data (with patient characterization) are provided. Additionally, also the patient (possibly with the help of a care giver) can access the DESIRE web application to perform personalized exercise sessions at home.

In order to facilitate the work of SLT, the application has been enriched with the real-time computation of statistics on the single recording, such as:

- Duration of the recorded sound
- Average sound frequency
- Syllables duration

Since these are indicators of dysarthria progression, for each patient, it is useful to compare them among different recordings of the same word and with respect to expected values. For this reason, both the RECORDIA client and the web application allow the user to compare and visualize their trend over time.

Such indicators are first computed when recording the voice, and further sent to the REST service when uploading the entire session results. With this approach it is possible to keep RECORDIA temporarily independent from the presence of the internet connection, while providing full functionalities. Moreover, this architecture facilitates the sharing of patient's data among all the members of patient's care team.

Overall, for each recorded word the information stored comprehends the .wav file (44.1 KHz sample rate, 8 bit sample size), the indication of the target word and the statistics computed over it. As a result, the gathered data can expand the IDEA database, hence enabling the scientific community to further exploit such a data for example to improve ASRs systems accuracy for dysarthric people.

3 Discussion

In general, clinical practice is based on the definition and analysis of outcome measures derived from subjective different sources (patients self-reported, observer-

reported (caregiver), clinician-reported) and objective performance-based parameters derived by use of standardized clinical scales or specific tools.

The identification of digital biomarkers offers the advantage to continuously and carefully assess at the same time in a smart and not intrusive manner, functional motor parameters also in real-life settings. These can represent more reliable and repeatable measure indexes, reducing errors derived from methodological bias related to more classic clinical measurements [12].

In fact, the DESIRE tool also has potential for speech therapy rehabilitation: it is possible to propose exercises, tests and specific tasks, tailored to the patient, on the basis of the performance found in the evaluation. Considering that the management of the patient with dysarthria is complex and requires careful customization, it is possible to insert some activities to work on specific tasks such as slowing down speech or reading balanced phoneme sentences with gradually progressing target phonemes according to the objectives, in favor of a better intelligibility, also reading of words and phrases with different intonation for a work on prosody, exercises on the voice (tonal pitch, intensity). The SLT can also monitor the patient remotely, favoring work in tele-medical mode (avoiding movements of complex patients) with real-time feedback to the patient who can thus try to find useful strategies to complete the exercise and be motivated, and the SLT can also maintain a history of the treatments carried out over time. It is useful to monitor the voice even remotely, where not in a therapeutic environment but at home, as the voice can vary many times throughout the day and it is possible for us to have important indications for the treatment (e.g. fatigue, times of the day where the patient is most tired, help from the caregiver, communication strategies adopted and so on).

Another important aspect will be the possibility to provide effective requirements for clinical trial readiness, which firstly need a deep understanding of disease mechanisms and evolution over time, allowing a correct identification and stratification of study populations to set targeted interventional clinical trials.

At present the tool have been successfully used by five medical doctors and STL at Pisa University Hospital with about thirty patients. In addition to the medical treatment benefits already mentioned, the tool was highly rated by both therapists and patients for ease of use, which is very important for daily examination in the hospital visit and compliance to at home exercise.

4 Conclusion

There is still little experience in identifying useful digital biomarkers for clinical practice to trace the evolution of speech disorders. DESIRE may challenge evidence in a gray area in which the phenotypic heterogeneity and still lack of unconfutable biomarkers makes difficult to choose what type, time interval, sequence and combination of diagnostic and therapeutic interventions can be appropriate. The additional advantage is to have an objective tool able to give clinicians objective measures of language production to be added to the subjective evaluations of the speech therapist, which may limit diagnostic and clinical

errors. When used appropriately in combination, perceptual and objective measures allow for the correct identification of speech features that most severely affect naturalness and intelligibility, dysarthria type and severity, and therapeutic targets. They also enable clinicians to track change over time [13].

Our current limit is to evaluate only the articulation of words, but we set ourselves as a future goal the evaluation and monitoring of articulation in connected language (i.e. sentences and passage) in order to evaluate other parameters that can interfere in the intelligibility of speech (e.g. respiratory support, breath pauses, articulation speed rate, prosody, fatigue, and so on).

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