ReadLet: Reading for Understanding

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***Abstract*—This paper focuses on motivation, objectives, design issues and preliminary results of ReadLet, an ICT platform for assessing reading efficiency in primary school children. Test data are discussed on a sample of 200 early graders, reading French, Italian and Standard Modern Arabic (SMA).**

***Index Terms*—Reading, text comprehension, Specific Learning Disorders, multimodal signal processing, cloud computing, portable assistive technology**

I. Introduction

ReadLet is an ICT platform specifically designed to provide accurate, evidence-based assessment of reading efficiency in early grade children. It is intended to offer an ecological, non-invasive protocol for extensive data elicitation, storage and analysis. With Readlet, early graders at school can read a one or two page text displayed on a tablet touchscreen, either silently or aloud. Children are asked to slide their finger across the words as they read, to guide directional tracking. After reading, the child is prompted with a few multiple-answer questions on text content presented one at a time, while the text remains displayed on the screen for the child to be able to retrieve relevant information. In the process, the tablet keeps track of time-aligned multimodal data: voice recording, finger sliding time, time of reading, time of question answering, and number of correct answers. Data are recorded, stored locally, sent to the ReadLet server through an internet connection, and processed remotely by a battery of cloud-based services, analysing data automatically to produce a detailed quantitative signature of each reading session. A server-based database aggregates anonymised data to make them available for specialists. Also individual's longitudinal profiles are stored, for them be queried and inspected upon authorised access. Security issues are addressed by means of secure connections along all the communication paths, and collected data are anonymised to ensure privacy.

II. ReadLet Background Motivation and Rationale

Unlike learning to speak, which develops spontaneously and nearly effortlessly, learning to read requires conscious effort, dedication, focused attention, systematic instruction and corrective error feedback. We still know comparatively little about the basic mechanisms involved in learning to read fluently and efficiently. Besides, assessing reading skills is an extremely laborious and time-consuming task, which requires monitoring a variety of interlocked abilities, ranging from accurate word rendering, word-in-context reading fluency and lexical access, to linguistic comprehension [1], [2], and interpretation, management and inference of complex events in working memory [3], [4].

To examine levels of reading proficiency in the Mediterranean area and assess appropriate remedial strategies, we started focusing on very different socioeconomic, cultural and linguistic countries such as Italy, Morocco and the Italian speaking area of Switzerland. Results of a study on reading skills carried out in the "Programme for International Student Assessment" (PISA 2012) show that in Italy, on average, about 21% of fifteen-year-old students have poor literacy skills, defined as "understanding, evaluating, using and engaging with written text to participate in society, achieve one's goals and develop one's knowledge and potential". This is in line with evidence that higher education students with early reading problems continue to have specific problems with text comprehension, which become a serious learning issue because of the much higher study load. These figures are bound to increase due to the rising immigration rate to Italy: in 2009, the gap between native students and students with a migrant background was already much higher than in EU countries (72 vs 38 EU-average, the equivalent of about two years of schooling). Similarly, the proportion of adults performing at or below level 1 in Italy is 28%, much higher than the EU-17 average (16.4%) (OECD's PIAAC 2012). In 2007, the Progress in International Reading Literacy Study (PIRLS) Report ranked Morocco in second-to-last place among the participating countries. The same report showed that 74 percent of students do not reach the minimum threshold required to develop their reading skills. A later report (2011) shows an even lower result, with a steadily downward trend in the level of reading of Moroccan students in both primary and secondary education.

On the research front, technological progress in language assessment has considerably advanced our evidence-based knowledge on language abilities [5], [6]. We know that word structure, length, frequency, perceptual salience, age of word acquisition, articulatory complexity, size of lexical neighbourhood and distribution of words in context conspire to affect children's reading accuracy and speed. Factors and their interaction are understood in considerable detail within labs [7]–[9], but they are elicited and investigated in conditions that are often far from being child-oriented. In many cases, the research focus is on isolated linguistic features and tasks with limited ecological validity (e.g. recognition of phonemes in isolation, naming of images shown on computer screens), coupled with a wide battery of fairly heterogeneous sub-tasks (including general intelligence, non-verbal reasoning, visuo-motor skills, verbal and visual perception among others). Data are elicited in artificially-restrained settings, mostly research and clinical labs with potentially invasive equipment (e.g eye-trackers). Multi-dimensional responses (e.g. word decoding accuracy, familiarity judgement and comprehension) are typically assessed independently. Besides, the need to control test conditions requires children to be tested in small groups, for a comparatively short time. Text samples are unnaturally short, and behavioural data are typically collected cross-sectionally, as longitudinal samples are more costly and difficult to collect. In our view, a better support to children with reading difficulties requires substantial advances in our understanding of the basic mechanisms involved in learning to read connected texts, as well as better modelling of the dynamic interaction of these mechanisms and their impact on linguistic comprehension in natural reading conditions. All these requirements call for bigger and better data to be collected in naturalistic tasks, in different environments, through multiple modalities, and with minimally invasive equipment.

To meet these requirements, we launched ReadLet, a project leveraging the full potential of ICT methods and tools with the ultimate objective to put in place a ubiquitous infrastructure with a simple tablet as terminal equipment. The infrastructure was designed to deploy and validate ecological screening protocols, portable technology and cloud computing to collect, time-align, integrate and analyse large amount of data of children reading at home or in the classroom. Functional requirements and design issues descended from careful consideration of task protocols, learning and reading models. Technical solutions capitalise on advanced multimodal signal recording and processing technologies, and automated linguistic assessment of text readability. Our methodology intends to establish a virtuous circle between fundamental, knowledge-oriented research on reading and application-oriented research. Reading models are used to design and implement an easy-to-use, low-cost screening technology at the service of real educational and clinical needs. The new technology will be used to collect, store and classify large evidence, which will in turn form the basis of more advanced knowledge, for better reading models to be developed.

A. Reading Models

Reading is not just the ability to assign the correct pronunciation to a sequence of written symbols making up a word (or word decoding), but the joint product of decoding and deep linguistic comprehension [10], [11]. Effective linguistic comprehension relies on language skills such as semantic and syntactic awareness. Both decoding and linguistic comprehension are necessary for reading comprehension, and neither is by itself sufficient [11]. However, current protocols for reading assessment measure decoding (reading accuracy and speed) and reading comprehension separately [12]–[14]. This does not allow evaluation of reading efficiency [15], defined as the ability to fully understand connected texts by minimising reading time, a cognitive ability that lies at the roots of students' academic achievement [16], [17]. Accordingly, we intend to develop a "Reading Efficiency Model" (REM), which combines decoding accuracy and automaticity (fluency) with reading comprehension. This will be measured by the so-called "Reading Efficiency Parameter" [15] through individual tablet-based test sessions that combine assessment of fluency and reading comprehension. Aspects of REM will be validated with ReadLet acquired data, and will be simulated with machine learning models.

In particular, Bayesian models of reading [18], [19] assume that lexical predictions drive attention in such a way that uncertainty about environmental task-relevant variables is dynamically reduced. This is done either by minimizing entropy, or by minimizing a combination of entropy and eye movement costs (i.e. saccade amplitude). We will use the Bayesian perspective to derive an ideal benchmark, and compare data of children reading performance against it, to discover analogies and differences. At the level of word decoding, we conjecture that in the first learning stages of reading, when letter-to-sound lexical representations are not fully developed and reliable, most input text contributes novel information, with few characters being skipped and lexical representations being frequently revised. When lexical representations get more deeply entrenched and dependable, novelties become rarer, more characters are skipped, reading gets more fluent and effortless, and lexical representations get revised only occasionally [20]. To test these hypotheses algorithmically, hierarchically arranged recurrent neural networks will be used to simulate effects of short-term and long-term memory interaction on different time scales [21]–[24], to replicate predictive reading effects on word, sentence and discourse levels.

III. The Architecture

ReadLet architecture requirements comply with the intended context of use of the proposed platform (Fig. 1). By distributing and mirroring data and processes over a cloud structure, the architecture is guaranteed to be fast and reliable. The user end-point is a native app for tablet devices. The app is responsible for the administration of the protocol and for the subsequent local recording of finger touch and speech data. Commercial tablet devices can be adopted if equipped with medium-high quality hardware, in terms of touchscreen sensitivity, audio and video acquisition quality, processor performance and storage capacity. To guarantee responsiveness also in off-line mode, the app has a local repository, automatically synchronised with the cloud central repository as the internet connection becomes available. The core of the architecture is a cloud server which exposes a set of functionalities, acting as an interface between the central repository and the users. As new data are stored in the repository, cloud processes are run to perform off-line text, audio, and video processing. Since all multi-modal data are

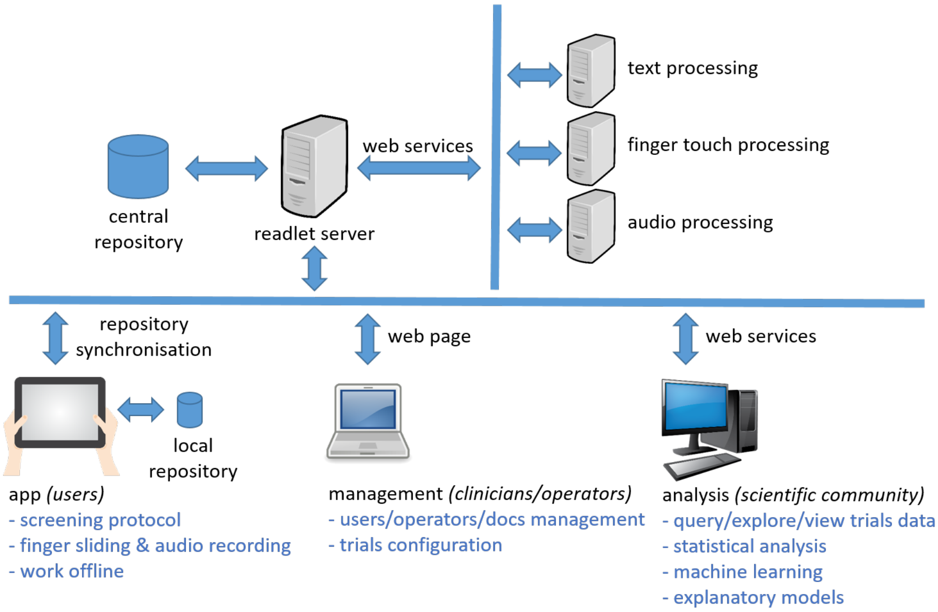

Figure 1. Outline of the ReadLet Functional Architecture

timestamped (i.e. aligned over time), processes can cooperate to make the analysis more robust. Once completed, analysis results are stored back to the central repository, being available for further post-processing. The management interface is a web-application accessed by clinicians and operators to manage the users' profile, to configure the screening sessions, and to manage the documents needed by the screening protocol (e.g written texts, questionnaires). Recorded data, as well as the result of the cloud off-line data processing, are available to the scientific community through a set of web services provided by the cloud server. This strategy permits the rapid prototyping of third-party applications for data visualisation, analysis and modeling.

The platform combines a number of modality-specific software modules, implemented as web services. They are shortly described in the ensuing sections. At the time of writing, only automated linguistic annotation, readability assessment, finger touch processing and statistical modelling are fully available and in the process of being tested.

A. *Text processing and readability assessment*

Increasingly sophisticated methods based on Natural Language Processing (NLP) techniques recently allowed the development of computational approaches to the automatic modelling and assessment of text complexity, leading to the estimation of text readability, and the development of advanced readability measures [25]. Unlike traditional metrics (e.g. Flesch–Kincaid or Gulpease tests), which rely on superficial text properties, new NLP-based methods take advantage of a wide range of multi-level linguistic features (e.g. lexical, syntactic, discourse-level) extracted from text and assumed to affect the process of reading comprehension: e.g. abstract or unfamiliar words, non-canonical sentences such as passive clauses, object relative clauses, 'chains' of embedded sentences etc. For our purposes, ReadLet texts are automatically enriched with multi-level linguistic information and be input to READ-IT [26], an automatic readability assessment tool based on a supervised machine learning approach: given a set of features and a training corpus, READ-IT can create a statistical readability model based on the feature statistics of the training corpus. To assign reliable readability scores to ReadLet texts, we anticipate preliminary training of READ-IT on a corpus of childhood texts classified per age brackets.

B. *Speech processing and decoding accuracy*

Speech processing technologies can recognise audio recordings of human speech by providing a translation of the acoustic signal into a text, and the temporal alignment of segmented acoustic units with the corresponding text units. Developing children's speech recognition systems ia a challenging task, due to lack of data resources and to the wide difference of the acoustic and linguistic characteristics of child speech from those of adult speech, not only at the frequency range level but also in the production modalities (e.g. disfluencies). In fact, the word error rate for children is normally higher than that for adults, even when using an acoustic model trained on child speech [27]. We intend to model child aloud reading, using the new CHILDIT2 corpus [28] to improve the recognition performance above an already good Phoneme-Error-Recognition baseline [29]. We anticipate that the speech module will be able to check if a specific read word is rendered correctly, and offer an overall accuracy score for text decoding.

C. *Finger touch processing*

The touch screen of high-medium quality commercial tablets captures the temporal sequence of touch events of a finger sliding across the screen with a sampling rate in the 60-120Hz range (corresponding to 12-24 touch events per syllable when reading at 5 syllables per second). When a finger slides across a text displayed on the screen with normal font size, time sequences of touch events can be aligned with letter bounding boxes fairly accurately, by compensating for vertical and horizontal drifts from the current line. Reliable evidence of the child's reading pace can then be derived from the "finger sliding" speed, with speed fluctuations across different text portions, as well as evidence of possible backwards and forwards shifts being accurately recorded. By anchoring finger sliding data on written text, we can associate sliding speed fluctuations with annotated linguistic structures, and with speed, rhythm and prosodic contours of the acoustic signal.

D. Statistical Analysis and Modelling

We expect fluency data to be analysed with established statistical linear models (linear mixed models and generalized additive models), to assess correlations and interactions among standard factors affecting reading performance. In particular, finger sliding data (e.g. per word sliding speed, frequency, average length and duration of sliding regressions) will be entered as dependent variables, and fitted with classical lexical predictors such as word frequency, number of word neighbours, probability distribution of sublexical constituents (e.g. bigrams, morphemes) etc. This will ensure comparability between multimodal reading data for common tasks and by subject groups, and validate statistical models and elicitation protocols cross-modally. Of late, accurate and fast reading of connected text by adults has been shown to have a strong predictive relation to reading comprehension, over and above fluency in reading isolated words [9], [30]. Preliminary results indicate that classical factors (such as word frequency) do not correlate with text reading fluency very well, and that linear analyses of reading speed (such as average word or sentence reading time) can provide only coarse-grained information about reading comprehension. Non-linear analyses of distribution tails and reading time fluctuations prove to fare much better. We will capitalise fully on time-aligned, multimodal reading data of Italian to investigate data interactions between decoding, fluency and text comprehension of early graders with non linear models.

IV. The Protocol

At the beginning of each reading session, the ReadLet interface prompts to fill in some required information about the reader and the task being administered: a reader identifier, age, grade level, sex, mother tongue, dominant hand, (corrected to) normal vision, language of reading, reading modality etc. A few text formatting parameters can also be set to customise font type, font size, inter-letter space, inter-line space etc. of the text being read (Fig. 2). By clicking a "Start" button, a short text of about two tablet "pages" is displayed full screen. The child is invited to read it, either aloud or silently, while sliding the finger of her/his dominant hand across the text as (s)he reads, to guide directional tracking. A new page is shown

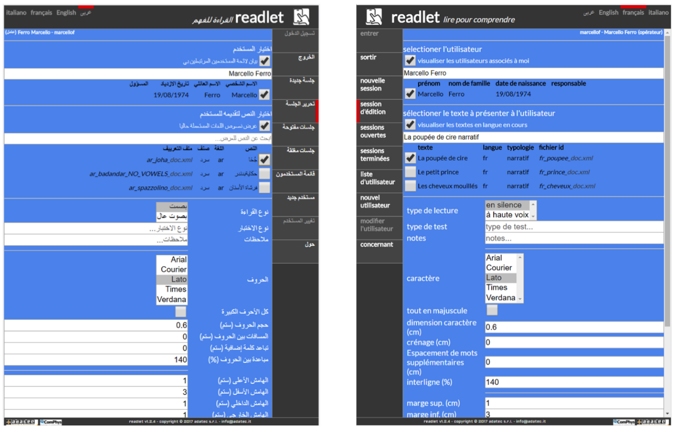

Figure 2. Screenshots of the ReadLet configuration interface for SMA (left) and French (right).

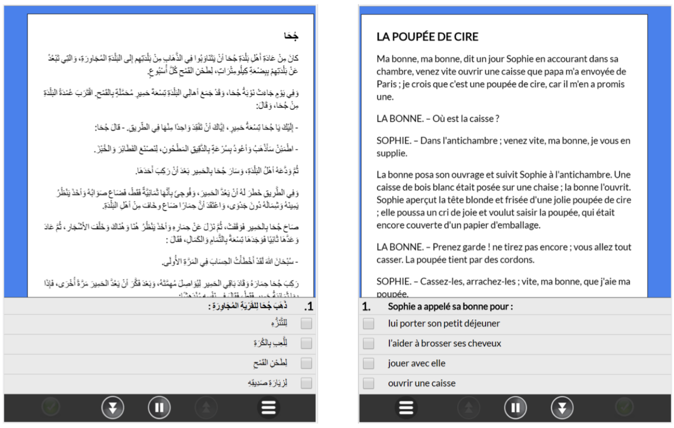

Figure 3. Screenshots of the ReadLet questionnaire interface for SMA (left) and French (right). The text in the background can be scrolled for consultation.

when (s)he clicks a "Continue" button at the end of the current page. When reading is completed, the child is prompted to answer a checkbox questionnaire. One question at a time is shown on the screen, to allow the child to go back to and flip through the text, to look for some relevant information (Fig. 3). When the final question is answered, a short message joyfully informs the child that the task was carried out successfully.

In the process, the tablet keeps track of time-aligned multimodal data: voice recording, finger sliding time, time of reading, time of question answering, and number of correct answers. Data are recorded, stored locally, sent to the ReadLet server through an internet connection, and processed remotely by a battery of cloud-based services, analysing data automatically to produce a detailed quantitative signature of each reading session. As both texts and questions are linguistically annotated and categorised, data on reading performance can be correlated with specific linguistic factors and levels of analysis. A server-based database aggregates anonymised data to make them available for specialists. Also individual's longitudinal profiles are stored, for them be queried and inspected upon authorised access.

V. Prototype Testing

Previous experience of administering a pen-and-paper version of the ReadLet protocol to children in the classroom turned out to require specialist assistance for performance assessment, timing and supervision, as well as hours of data post-processing. Moreover, children were reported to show moderate signs of performance anxiety. Preliminary testing of a prototype version of ReadLet technology with a population of about 200 pupils aged 8 to 11, both male and female, varying for socioeconomic status, language (Italian, French and Arabic) and geographical area (Italy, Switzerland and Morocco), showed that children are extremely responsive to using a tablet for reading, and very easy to engage in what they perceive as an enjoyable experience. A preliminary quantitative analysis of ReadLet data reveals a promising correlation with eye-tracking data elicited with more controlled lab-based protocols.

VI. Technological, Social and Economic Impact

In the long run, ReadLet intends to cover and integrate many language intervention issues, including diagnostic and corrective feedback, therapy, performance monitoring and intelligent decision management, to focus on a wide range of cognitive processes underlying both reading and comprehension. Nowadays, about 50-60% of the workload in childhood/adolescence Neuropsychiatry Units in Italy is devoted to screening children with suspected SLD. Clinical assessment of a single child takes about 6 working hours on average. Only a small percentage of suspected cases (about 15-20%), however, has an SLD diagnosis confirmed. A sophisticated tool for reading assessment able to assign accurate scoring profiles in ecological conditions would significantly reduce wait lists and screening overheads by selecting at-risk cases only, prevent provision of medical care for situations that do not need medical intervention, and improve on the overall quality of medical services, with expectedly lower costs.

With daily sustained usage, the ReadLet platform can also provide therapists with reading data of SLD diagnosed children, make room for more accurate knowledge of the levels of child reading skills, and help deliver the most appropriate treatment. ReadLet text annotation and formatting tools will also help select and deliver text stimuli with controlled and gradually increasing levels of linguistic difficulty, thus supporting more targeted potentiation. We expect this to improve response to treatment, reduce downtime between successive intervention steps, minimise repetition of overlearned tasks, and increase motivation.

Similarly, sustained use of ReadLet protocol in classrooms during normal school hours is likely to increase awareness of reading skills in both pupils and teachers, knowledge about specific factors causing poor reading performance and a more robust relationship between reading confidence and reading performance (this relationship is currently very weak in Italy compared with EU average). We expect both tools and protocols to enable teachers to provide adequate support to all students with reading difficulties, and to monitor and sustain steady literacy progress, regardless of whether children are officially diagnosed for SLD or not, with a view to promoting more inclusive education and sparser recourse to unnecessary provision of medical assistance. In addition, we expect project results to advance our theoretical understanding of text reading in both at-risk and non problematic conditions, as well as gain deeper insights into what occasionally makes reading difficult and inefficient. In particular, by monitoring both aloud and silent reading in the classroom, specialists will be in a better position to understand at what age and at what level of reading competence, shifting from aloud to silent reading results in better comprehension.

VII. Concluding remarks

We believe that technology cannot and should not supplant the role and professional judgement of teachers and therapists in helping children with reading and learning difficulties. Having said that, ReadLet protocols and tools can effectively support daily decisions and education/intervention management, and offer an example of effective introduction of adequate ICT tools into school curricula and daily teaching. From a broader perspective, today's society presents a clear demand for developing coordinated, interdisciplinary efforts in language sciences, implementing a new problem-oriented research life-cycle: i) language and behavioural models will be used in labs to design and implement better technology for language-assessment, addressing real-life issues, ii) outside labs, the new technology will collect larger and richer naturalistic evidence, and iii) the newly collected evidence, structured and classified by NLP tools, can find its way back to labs, for better lexical models to be developed. Such a coordinated effort will target four main objectives: a) sustain interdisciplinary research in lexical modelling; b) coordinate multimodal data creation; c) incentivise technological development for fundamental research, and d) deliver timely application of acquired knowledge and technologies matching real-life need.

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