Module of Contrastive Analysis for a Phonological Assessment Software in Development

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Abstract: The interest in software as tools to assist speech therapy has grown in recent years, with proposed features primarily focused on the analysis of children's speech. However, there is still a gap in tools to apply phonological assessments that are suitable to collect data. In this context, our research group is working on a digital platform called "e-Fono", which consists of a mobile application, a REST API, and a web service where the speech therapist has access to the assessments. However, despite the existence of robust tools for data analysis, predominantly used in academic contexts, no software was found with a module for phonological contrastive analysis in Brazilian Portuguese. In the contrastive analysis, the speech therapist compares and identifies the contrasts between the child's speech and that of an adult, providing a detailed report on which phonemes and in which positions of the words the child experiences greater difficulties. Through this process, currently carried out manually by the speech therapists in our group, the child's phonetic inventory is also obtained – a list of all phonemes the child can articulate. This paper proposes the development of a contrastive analysis module, which has been implemented in the e-Fono digital platform. In our implementation, the module was able to perform an automatic contrastive analysis by comparing the child's phonetic transcriptions with known correct transcriptions from our database. The results can be reviewed by the speech therapist, who can replace and submit information of this analysis in case of wrong or incomplete results. With these information on the platform, it will be possible to identify speech difficulties in children and guide the speech therapist toward a specific treatment for them. Finally, in this paper we also present screens from the implemented prototype, which may be available to the general public after validation and adjustments with specialists from our group.

1 INTRODUCTION

In the process of language acquisition, it is expected that a child will attempt to approximate their speech to that of an adult, by substituting or omitting sounds they are not yet capable of producing (Ceron et al., 2017). In speech therapy, these approximations are referred to as "phonological processes", and their application results in incorrect pronunciation. In the literature, such processes are already mapped, and a natural overcoming age limit is defined (Yavas and Lamprecht, 1988) – an expected age limit by which a child should naturally articulate a word correctly without substituting or omitting phonemes.

The integration of computational systems in speech therapy has assisted in the early identification of phonological processes (Franciscatto et al., 2021), the application of phonological assessments through software (Ceron et al., 2020), and the analysis of children's speech (Rose and Hedlund, 2021; Ramalho et al., 2022) for the identification and treatment of phonological deviations (Sotero and Pagliarin, 2018; Jesus et al., 2019; Uberti et al., 2020). Each assessment involves presenting a set of images to the child, who must pronounce the represented object (target word) in the image (Ceron et al., 2020). In this context, the *Contrastive Analysis* aims to compare the child's phonological system with an adult system (Storkel, 2022), identifying contrasts between

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both and detailing exactly which phonemes the child struggles to articulate and in which part of the word this difficulty occurs.

In the southern region of Brazil, where this work was developed, phonological assessments containing words familiar to the socio-economic context of individuals. This work is based on the phonological assessment software from the study by (Ceron et al., 2020).

Up until the writing of this article, no phonological assessment system containing a contrastive analysis module was found to support Brazilian Portuguese. Given the importance of this functionality for a comprehensive and detailed identification of phonological deviations, this work proposes an architecture for the operation of contrastive analysis in a virtual environment, utilizing technologies such as React and MongoDB, in addition to implementing functions in a REST API.

To validate the presented modeling, we implemented the prototype of the introduced module and demonstrated how the system behaves with real data. After implementing this module, it was possible to determine the indication of phonological deviation in the evaluated child according to the *PCC-R (Percent of Consonants Correct-Revised)* (Shriberg et al., 1997). This index is widely used in the field of pediatric speech therapy, associating the percentage of correct consonants in the assessment with an indication of phonological deviation present in the child's speech (Ceron et al., 2017; McCabe et al., 2023). Lastly, the child's phonetic inventory—the set of phonemes the child can correctly articulate—was also presented at the end of the assessment through the module introduced by this study.

The paper is organized as follows. In Section 2, the reader is introduced to the context in which this study was produced. In Section 3, the operation of Contrastive Analysis is presented, followed by its implementation in Section 4 where the screens developed in this study are presented. Finally, in Section 5, we conclude the work with our final considerations.

2 BACKGROUND AND CONTEXT

In (Franciscatto et al., 2021), a tool was proposed to predict phonological processes, aiming to assist speech therapists in identifying weaknesses in a child's speech. It is normal that mispronunciations occurs while the language acquisition process (Ceron et al., 2017) However, if the child do not overcome her speak difficulties, they can evolve into a more serious phonological disorder, persisting into adolescence and adulthood if not treated early. Hence, the importance of early identification.

The software introduced by (Ceron et al., 2020) presented a set of 84 target words for phonological assessment. The children were exposed to a set of images representing the word they should pronounce spontaneously, without reading or hearing the word beforehand. The mobile application discussed in (Franciscatto et al., 2021) is based on Brazilian Portuguese words and was developed to assist a team of speech therapy experts in collecting phonological assessment data.

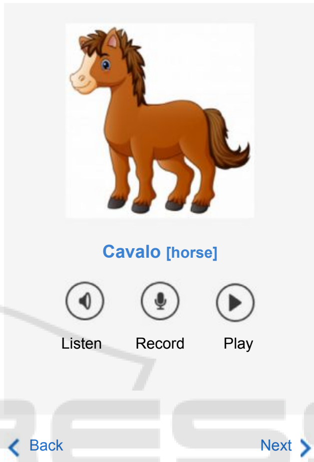

Figure 1: Target word that must be spoken by the subject. Adapted from (Franciscatto et al., 2021).

The software "Phon" (Rose and Hedlund, 2020) already has functionalities such as calculating the PCC-R, also implemented in our platform. Although suitable for clinical evaluation (Byun and Rose, 2016), it is primarily used for academic research (Rose and Stoel-Gammon, 2015). Additionally, it is an open-source software maintained and frequently updated, and it has plugins like AutoPATT by (Combiths et al., 2022). This plugin is capable of automatically generating the phonetic inventory, also generated in our implementation. One of the differences between our studies is the application of these functionalities in Brazilian Portuguese, and also the integration between a mobile application for data collection and a web service for analysis, allowing the workflow to be carried out by different professionals, regardless of their location.

2.1 e-Fono Platform

The e-Fono Platform is a prototype of a product developed by our research group, providing speech therapists with the capability to conduct phonological assessments online. It stores audio recordings and phonetic transcriptions in a database, as illustrated in Figure 2. All stored data have been the subject of previous studies (Franciscatto et al., 2019a; Franciscatto et al., 2019b; Franciscatto et al., 2021; Marques. et al., 2023). Currently, our database contains 132,031 phonetic transcriptions entered by a team of speech therapists from the Federal University of Santa Maria (Brazil). Additionally, the data is associated with over 1,200 phonological assessments conducted on 1,357 children aged 3–7 in the southern region of Brazil, encompassing approximately 130,000 audio samples.

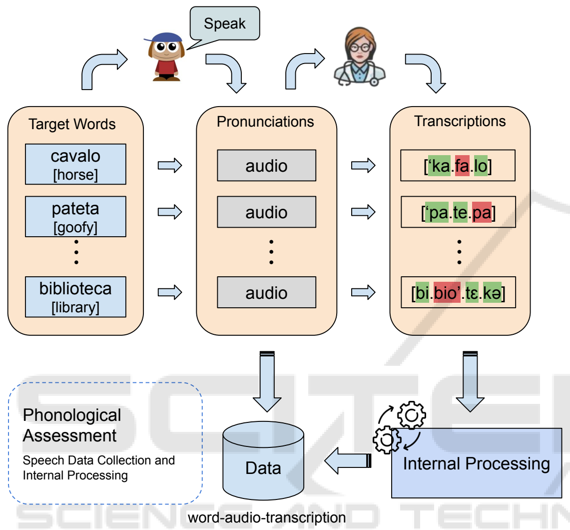

Figure 2: Model for implementing Digital Phonological Assessment.

Each phonological assessment comprises a set of target words that the child is expected to pronounce spontaneously. In a digital environment, the speech therapist records the child's speech in audios, which are stored on the platform. Following this initial collection, the professional enters the phonetic transcription of each word, including phoneme omissions and substitutions. All data undergo internal processing, involving the extraction of regions of interest and noise removal (Franciscatto et al., 2019a). It is at this stage that our module integrates into the platform, automatically analyzing the phonetic transcriptions from the assessment.

3 CONTRASTIVE ANALYSIS

The Contrastive Analysis is a process that compares the phonological system of the child with the standard adult system (Storkel, 2022). The Figure 3 presents

Table 1: Examples of Phonetic Transcriptions.

Palavra	**Transcrição Fonética**
Bi.blio.te.ca	bi.bli.o.'te.ka
	bi.o.'te.ka
	bi.bi.o.'te.ka
Ca.va.lo	ka.'va.lo
	ka.'va.lu
	ka'falu

this process in a simplified manner, where the speech therapist compares each phonetic syllable individually, noting differences in the child's pronunciation based on an acceptable outcome, indicated in dark green.

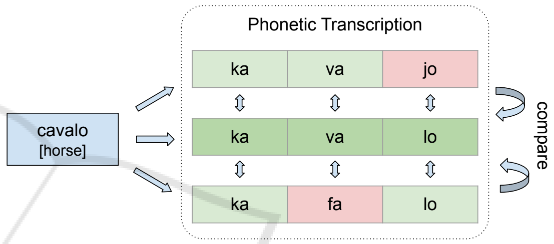

Figure 3: Comparison between a child's Phonetic Transcription and that of an adult (dark green).

In this analysis, concerning cases of phonological disorder and also considering the PCC-R index, only the consonantal phonemes are observed (Shriberg et al., 1997). This value is calculated according to Equation 1 and is associated with an indication of phonological deviation shown in Table 2.

$$\text{PCC-R} = \frac{PC}{TP} \times 100 \tag{1}$$

Table 2: Indication of speech disorder according with PCC-R value. (Shriberg et al., 1997).

PCC-R Value	Indication of Disorder
Less than 50%	High
Between 50% e 65%	Moderate-High
Between 65% e 85%	Low-Moderate
Greater than 85%	Low

So far, no freely available software with the functionality of contrastive analysis has been found in Brazilian Portuguese. It is up to the speech therapist to do manually this process with paper and pen, including counting correct productions and the total number of phoneme productions in an assessment. For this reason, the contrastive analysis module for the e-Fono software is the subject of this study, and its flowchart can be viewed in Figure 4.

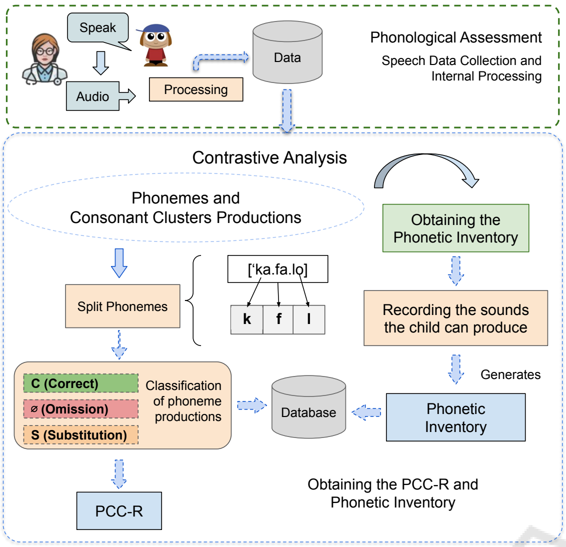

Figure 4: Contrastive Analysis Flowchart.

The implemented Contrastive Analysis separately analyzes the productions of phonemes and consonant clusters to obtain the phonetic inventory, i.e., the list of phonemes that the child can articulate. With the classification of each production, it is possible to calculate the PCC-R by tallying all correct productions in the assessment. This classification is automatically implemented by the module following the logic shown in Figure 3, comparing the transcriptions from the assessment with similar correct transcriptions in our database. This allows the identification of phonemes with correct productions, substitutions, and omissions. Next, we will see the details of each of these steps.

3.1 Phonemes and Consonant Clusters Productions

This step involves receiving the data from the phonological assessment, including the phonetic transcription of the word pronounced by the child. This allows the analysis of phonemes in different syllabic and word positions, classified as correct productions, substitutions, or omissions. In the case of an omission, the platform records the frequency with which it occurred for each phoneme. Occurrences of substitution of one phoneme for another are also recorded. The analysis details which phoneme was replaced in the child's pronunciation, the phoneme used in the substitution, and the frequency of this event. An example of this process is illustrated in Figure 5.

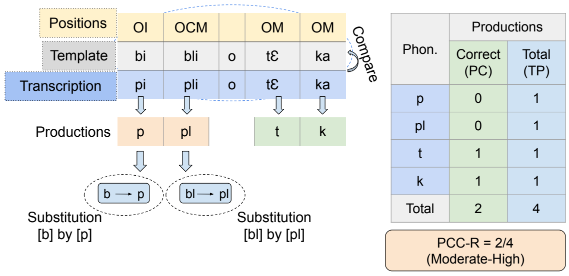

Figure 5: Example of Phoneme and Consonant Cluster Analysis and PCC-R calculation.

In the example, using the phonemes of the word "biblioteca" [*library* in English], from left to right: there was a substitution of the [b] phoneme with [p] in the Initial Onset (OI) and a substitution of the consonant cluster [bl] with [pl] in the Medial Complex Onset (OCM). Finally, in the last two Medial Onsets, there was a correct production of the [t] phoneme and the [k] phoneme.

At the end of this step, the necessary records are obtained to automatically generate the child's phonetic inventory, i.e., all the phonemes in certain positions of the word that the child can articulate at least twice (Stoel-gammon, 1985). It is sufficient to consider the number of correct productions for each phoneme and add it to the number of times that the phoneme was used to substitute other phonemes. This step will be discussed in more detail in the next section.

3.2 Phonetic Inventory

To determine the presence or absence of a sound in the phonetic inventory, a minimum of two occurrences of the segment can be considered, regardless of its position in the word (Stoel-gammon, 1985). In the example shown in Figure 6, even the phonemes that were articulated in an incorrect pronunciation (orange) are considered in the production count, as the

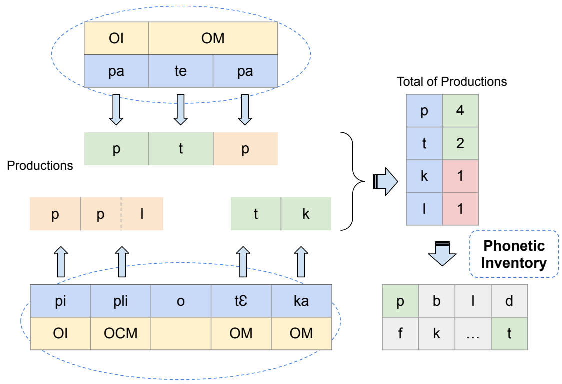

Figure 6: Example of the generation the Phonetic Inventory.

child was able to articulate them through the application of a phonological process. Also in the example, the phonemes [k] and [l] are not considered in the phonetic inventory, as they had fewer than two productions. In the table in the lower right corner, containing the phonetic inventory, only the phonemes with two or more productions were considered acquired by the child (green).

4 IMPLEMENTATION

A basic architecture of the e-Fono Platform is presented in Figure 7. It consists of a REST API that connects the mobile application used for phonological assessments and the web service for data analysis. In this model, the mobile application could be used by family members or early childhood educators to assess children's speech. It would be useful for a screening process where children with results below the expected level for their age would be referred to a speech therapist for professional follow-up, similar to the concept presented in the study by (Franciscatto et al., 2021).

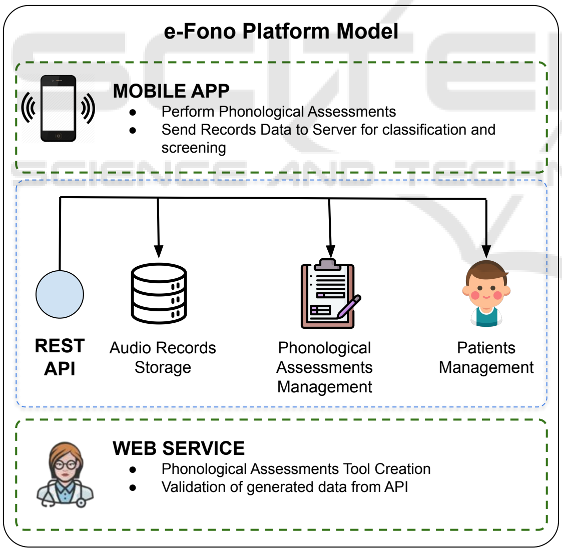

Figure 7: Presenting the Model of e-Fono Plataform with REST API.

The implementation of the present study occurred in the REST API and the web service since the contrastive analysis is a process that occurs *after* the phonological assessment. The main challenge was determining a way to recognize the positions (OI, OM, OCI, etc.) of each phoneme in the transcriptions, so that the therapist could have detailed information about which phonemes and in which positions the child faced the most difficulty.

To address this situation, the algorithm presented in Figure 8 compares the input transcription with a set of known transcriptions for the word, already containing the correct positions of the phonemes. In this step, the *Levenshtein distance* algorithm, previously used in works in the field of computational systems for speech therapy (Martinez-Quezada et al., 2022), was employed to identify which known case were most similar to the provided transcription.

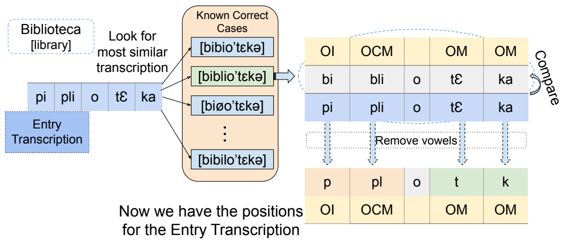

Figure 8: Algorithm for recognizing phoneme positions given an unknown transcription.

With the result provided by this algorithm, each phoneme can be analyzed separately, and it is sufficient to observe the differences between the correct transcription (gray) and the input transcription to obtain the contrastive analysis automatically. Thus, the classification of each phoneme in each word position is obtained, tallying productions as correct, omitted, or substituted.

For the automatic construction of the phonetic inventory and PCC-R, it is enough to consider the data from the entire assessment and count the number of correct productions for each phoneme. Figure 9 presents the obtention of the phonetic inventory and the indication of phonological deviation based on PCC-R, considering a minimum of two correct occurrences in each word position (Stoel-gammon, 1985).

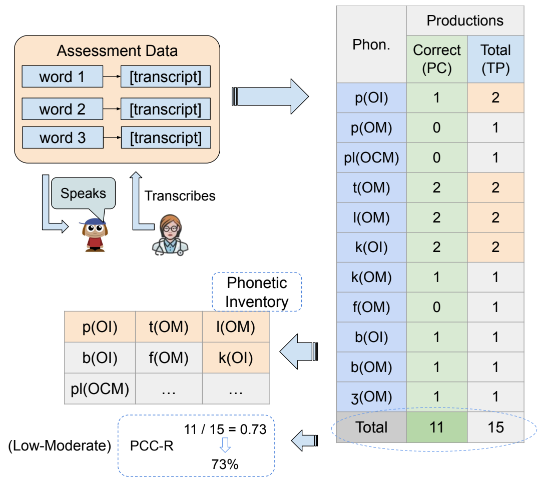

Figure 9: Method for obtaining the Phonetic Inventory and PCC-R.

Finally, since the data from the contrastive analysis are generated automatically by the proposed module, we implemented a mechanism in the records that distinguishes the information generated by the system from the data coming from user corrections or insertions. For this purpose, a variable "createdBySystem" stores all records generated by the module, so that they can be validated later by the speech therapist in the web service.

4.1 Prototype

The e-Fono Platform, currently in development, is a prototype of a tool to assist speech therapists in the screening process of patients with possible phonological disorders. With the implementation of the module proposed by this work, the platform gains functionalities for data analysis that occur after the screening performed by the phonological assessment.

The contrastive analysis module was implemented in the layers of the REST API and WEB SERVICE, using MongoDB for data storage and React on the web platform. Figure 10 shows how the Contrastive Analysis information is presented to the user on the web platform.

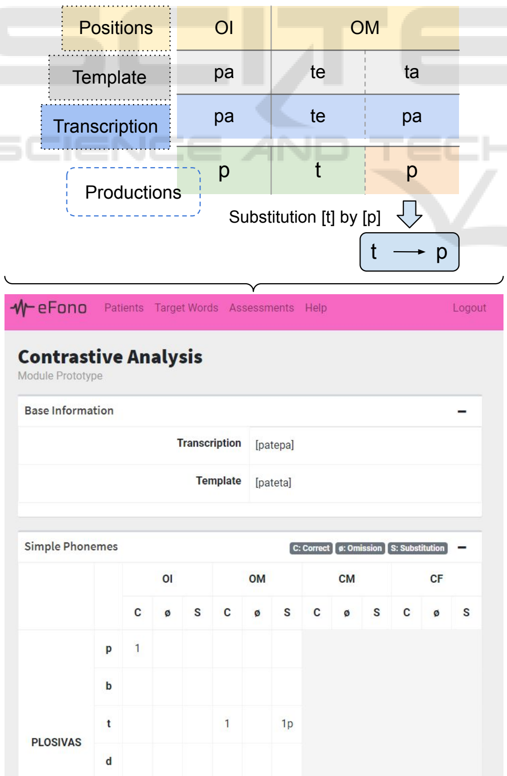

Figure 10: Screen of the Contrastive Analysis Module on the e-Fono Platform detailing the Production of Phonemes in a Transcription.

The visualization of the phonetic inventory is shown in Figure 11, where the speech therapist has access to all phonemes that the child produced in the assessments at least twice. However, in the current version, the module does not specify in which word position the phoneme can be considered acquired, according to the table in Figure 9. Therefore, the speech therapist has access to the child's phonetic inventory regardless of the word position, and this gap could be filled in future versions.

We implemented this prototype with the assistance of speech therapists from our group, and the graphical interface resembles the spreadsheets currently used in a manual process of contrastive analysis by paper and pencil. Compared to this method, our proposal tends to significantly reduce the time professionals spend from applying the assessment to diagnosis, given the automatic nature of data generation in our implementation. It is noteworthy that this tool has not yet been officially launched and its field validation should take place in the next months.

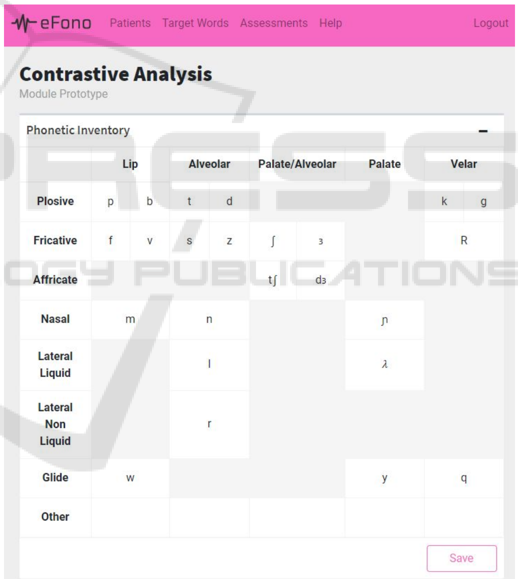

Figure 11: Contrastive Analysis Module screen showing the Phonetic Inventory of a fictional child.

Finally, the PCC-R is available on the main screen containing the patient's assessment data, as shown in Figure 12. This value is calculated automatically by the system and can be recalculated if the speech therapist identifies and corrects errors generated by the platform.

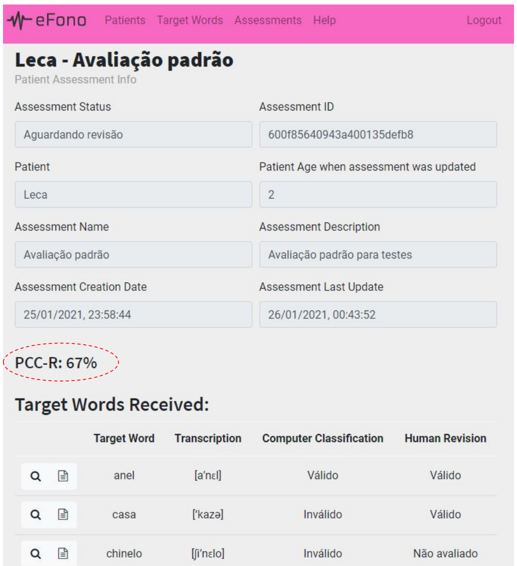

Figure 12: Screen showing the PCC-R value automatically calculated by the Contrastive Analysis Module.

5 CONCLUSIONS

In the Southern Brazil, where this study was developed, phonological assessments are used to identify potential phonological deviations in school-age children. Despite the increasing adoption of computational systems in speech therapy (Ceron et al., 2020; Rose and Hedlund, 2021; Ramalho et al., 2022), there is currently no literature on a phonological assessment system containing a contrastive analysis module in Brazilian Portuguese. This module aims to compare the child's phonological system with that of an adult (Storkel, 2022), identifying contrasts between them and detailing the difficulties present in the child's speech.

Through this analysis, the speech therapist not only obtains a detailed report on the phonemes and positions in which the child experiences difficulties, but also acquires the child's phonetic inventory. This refers to the list of all phonemes that the child can articulate according to the position in the word where they are observed. Additionally, it is possible to determine the *PCC-R (Percent of Consonants Correct-Revised)* value (Shriberg et al., 1997), widely used in speech therapy as an indicator of phonological disorder based on the percentage of correct consonants in the assessment.

Given the importance of this functionality, our study proposed the Contrastive Analysis Module in a digital platform called *e-Fono*, which is under development by our research group. In this platform, data generated in phonological assessments via a mobile application were automatically processed by the module, separating and identifying precisely which word positions and phonemes the child struggled with. It was also possible to automatically obtain the child's phonetic inventory and determine the PCC-R value using the phonological assessment data. As this value is associated with the level of phonological disorder in the child, a more targeted treatment could be applied, focusing on phonemes not yet acquired by the child, which can be observed in the platform.

The module was implemented in the *API REST* and *web service* layers of the e-Fono Platform. Through it, the speech therapist can have a more detailed understanding of the child's speech, isolating the phonemes that require special attention. The module was capable of generating the information of the contrastive analysis, phonetic inventory, and PCC-R automatically and displaying them in user interfaces for the speech therapist. We discussed the logic used in the implementation, and screens of the current prototype were presented in Section 4.1. Finally, it is worth noting that the system allows for a review by the specialist, enabling correction and insertion of new data. However, all corrected and user-inserted data are stored separately from the system-generated data, just to maintain control over the origin of the information.

For future work, the automatically generated information and those inserted by the speech therapist could be compared to identify gaps in the proposed logic and implement improvements and adaptations to the system. Also, with adjustments to the interface and a thorough review from our speech specialists, the platform could be made available to the general public in Brazil, and we are open to the possibility of contributions to larger projects. Given the continental size of a country like Brazil with its socio-economic limitations, the application of phonological assessment could, for example, be carried out by a teacher in a rural school and later accessed by a speech therapist in an urban center, democratizing access to phonological assessments.

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