DYSLEXIC CHILDREN'S READING PATTERN AS INPUT FOR ASR: DATA, ANALYSIS, AND PRONUNCIATION MODEL

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ABSTRACT

To realize an automatic speech recognition (ASR) model that is able to recognize the Bahasa Melayu reading difficulties of dyslexic children, the language corpora has to be generated beforehand. For this purpose, data collection is performed in two public schools involving ten dyslexic children aged between seven to fourteen years old. A total of 114 Bahasa Melayu words, representing 23 consonant-vowel patterns in the spelling system of the language, served as the stimuli. The patterns range from simple to somewhat complex formations of consonant-vowel pairs in words listed in a level one primary school syllabus. An analysis was performed aimed at identifying the most frequent errors made by these dyslexic children when reading aloud, and describing the emerging reading pattern of dyslexic children in general. This paper hence provides an overview of the entire process from data collection to analysis to modeling the pronunciations of words which will serve as the active lexicon for the ASR model. This paper also highlights the challenges of data collection involving dyslexic children when they are reading aloud, and other factors that contribute to the complex nature of the data collected.

Keywords: Automatic speech recognition, Pronunciation modeling, Reading pattern, Dyslexia, Children.

INTRODUCTION

The demand for ASR technology to help children read has increased significantly (Steidl, Stemmer, Hacker, Noth, & Nieman, 2003). ASR has been seen as an alternative way of teaching reading to children, especially those who suffer from a neurological and developmental condition called dyslexia. Dyslexia is a condition that impedes phonological awareness, which is strongly related to reading ability, especially in the phoneme-grapheme correspondence area. In addition to reading difficulties, dyslexia also causes problems in other skills such as writing, spelling, and motor skills, as well as problems with memory and cognition. However, various efforts have been made to overcome these obstacles and many conventional methods have been proposed to help dyslexis read. Methods such as phonological awareness training (Wilson, 2007), structured and multi-sensory approach (McIntyre & Pickering, 1995), and the Davis Dyslexia correction program http://www. dyslexia learning.com/) are some of the available methods used to treat dyslexics to overcome or reduce their reading difficulties.

However, recently computer-based applications are seen as having an added advantage in teaching dyslexic children read, as the computer itself is appealing to most children. This attribute in fact plays such an important role in the use of computers to teach reading to dyslexic children, especially when children can interact with the computer via animated, talking characters. Projects such as the Colorado Literacy Tutor – CoLiT http://www. colit. org/) is aimed at providing computer-aided reading instruction for children to enhance reading. The project is carried out with the collaboration of public schools (http://cslr. colorado.edu/ beginweb/ reading/ reading. html). Another example of such a project to improve reading amongst children is LISTEN's Reading Tutor (Banerjee, Beck, & Mostow, 2003). These projects use ASR as the key technology. ASR is used to track reading while the children are reading aloud and allow for interactions between the user and the application via speech (e.g. asking questions). Pronunciation accuracy is also provided as feedback. ASR technology has the potential to enhance reading ability for normal children, and as reported by previous studies (Hagen, Pellom, Vuuren, & Cole, 2004; Nix, Fairweather, & Adams, 1998; Raskind & Higgins, 1999; Williams, Nix, & Fairweather, 2000), it is also a good tool for helping those with dyslexia in reading.

Given the foregoing background of issues, this paper seeks to address the need for an ASR model that is able to help dyslexic children read in Bahasa Melayu , i.e., to help them read correctly and fluently in this language. For such a model to work, the language corpora has to be gathered and analyzed, and used to construct a pronunciation model to serve as the active lexicon for the ASR to train on. Thus, the scope of this paper is to highlight the data collection and analytical processes, and show how these processes have contributed to the pronunciation modeling of the ASR.

The next section briefly discusses dyslexia and how it affects reading ability. Then, methods to collect data and the careful analysis required are outlined.

Preliminary findings from the process is also discussed as it provides useful information on types of errors made by the children in the context of reading Bahasa Melayu. Teachers and reading facilitators will be able to use these findings as the basis for a more comprehensive, individual teaching of reading to dyslexics. The findings are also used as an important guide to the pronunciation modeling of the ASR.

DYSLEXIC CHILDREN AND READING CHALLENGES

Dyslexic children suffer from dyslexia, a condition that affects the ability to progressively learn to read, spell, and write due to deficits of a phonological origin. A solid body of research has concluded that the phonological-based deficits is the major contributor towards this condition (Frost, 2001; Lundberg, 1995; Shaywitz, 1996; Snowling, 2000; Wolf, 1999; Ziegler, 2006). Phonological deficits cause the brain to code or represent spoken attributes of words in a different way from normal people, and thus lead to reduced abilities in phonological awareness. According to Slaughter (2001), the brain recognizes language in a hierarchical order where the most upper level deals with semantics, syntax, and discourse, and the lowest level deals with phonemes. This lowest level is causing dyslexics to have problems with reading. They have difficulties in deconstructing words into phonemes that lead to problems in word recognition. Often while reading, they are concentrating on producing the correct pronunciation of words so much so that they unconsciously loose the semantics behind what is being read. Hence, comprehension is also a problem.

Reading for dyslexic children is therefore, an overwhelming task – they have to produce correct pronunciations of text so that it makes sense in order to enable comprehension. Reading is difficult since it requires phonological awareness ability to enable phoneme-grapheme correspondences (Snowling, 2000). Being phonologically aware is an essential decoding skill to enable word recognition which then leads to the meaning of that particular word (Slaughter, 2001; Shaywitz, 1996). Due to the lack of decoding skills, dyslexic children tend to make many mistakes when reading, which halt their interest in learning or attempting to read. At the sentence level, dyslexic children normally read with many pauses, substitutions, omissions, additions, transpositions, repetitions, and reversals in letters or numbers (Davis, n.d.). Sometimes they compensate their orthographic reading (letters) by using logographic reading (using visual cues) and guessing from the print physical features such as 'smaller' for 'yellow' because of the 'll' feature shared in both words (Snowling, 2000).

DATA COLLECTION METHOD

The first essential step towards a dyslexic children's reading-tuned ASR is to observe and record their reading over a period of time to obtain their reading error patterns as well as the audio files for later use. Later, a careful analysis is performed aiming at identifying the most frequent errors made by dyslexic children while reading aloud single, isolated Bahasa Melayu words.

The Stimulus

Before commencing the data collection process, suitable vocabulary to serve as stimulus is gathered and these comprise 114 words of all 23 syllable patterns (consonant (C) – vowel (V) pair), ranging from simple to complex spellings, which include prefixes and postfixes. Although rather complex, the words are all contained within the level one (standard one, two, and three) primary school syllabus developed by the Curriculum Development Division of the Ministry of Education, Malaysia, and which must be implemented in all schools across the nation. Each syllable pattern is represented by five words except one pattern with four words. The pattern corresponds to a CV+CV+CCVV syllable pattern that contains words such as *jerangau* and *meringai*. These words are rather complicated for the children as they are not so commonly used in the syllabus. The four words are included in the required vocabulary and presented as examples in *Buku Panduan Pelaksanaan Program Pemulihan Khas (Masalah Penguasaan 3M)* for level one. Table 1 presents an example word for each of the syllable patterns.

Table 1. The Syllable Patterns and Example Word for each Pattern

Syllable Pattern	Word	Syllable Pattern	Word
V+CV	*aku*	Dual vowel	*buas*
CV+CV	*baca*	CV+CV+CV	*menara*
CV+CV with digraph	*sunyi*	CV+CV+CCV	*pelangi*
CV+CV with diphthong	*ceria*	CV+CV+CVV	*senarai*
CVC	*dan*	CV+CV+CCVV	*perangai*
V+CVC	*ayat*	CVC+CV+CVC	*maklumat*
V+CVCC	*udang*	CV+CV+CVCC	*binatang*
CV+CVC / CVC+CV	*makan*	CV+CVC+CVCC	*penumpang*
CV+CVCC	*barang*	CVC+CV+CVCC	*pendatang*
CV+CVC / CVC+CV with digraph & diphthong	*sangat*	CVCC+CV+CVC	*panggilan*
CVC+CVC	*pandai*	CV+CVCC+CVC	*melanggar*
CVC+CVC with digraph	*kangkung*	-	-

The selection of words is based on discussions with special education teachers and reading facilitators who taught Bahasa Melayu to these children. It is important to expose these children to the varieties of syllable patterns so they can follow like the mainstream student population, the prescribed content of the syllabus. A noteworthy fact is that in public schools the Bahasa Melayu syllabus for both dyslexics and main stream students are the same. Thus, the dyslexic children must be able to read the range of words prescribed in the syllabus, not just the simple ones only.

The Participants

Data collection was carried out in two schools offering dyslexia classes to dyslexic children from standard one to six. A total of 10 dyslexic children, 8 males and 2 females, were recruited for the study. The selection for participation was based on a reading level which could identify a dyslexic child with problems in reading single, isolated words. The selection was made based on the recommendation from teachers who had taught the children and knew about their reading abilities. Other factors included similar exposure to Bahasa Melayu, and that the children were formally diagnosed by experts or through screening using an instrument provided by the Ministry of Education, Malaysia.

Observation and Recording Sessions

The purpose of the observation is to see patterns of reading errors surfacing during the recording sessions. The purpose is to ensure that only the most frequent patterns are to be modeled. The recording was done using a standard head mounted microphone to reduce the background noise as much as possible. Each recording session was done on an individual basis. The stimulus was a prompt, and response from the child was recorded in audio format (.wav file). The read speech was recorded at 16k per sample using a *SpeechViewer* tool from the CSLU Toolkit for speech recognition. If the recorded speech was found to be not sufficient for later use in speech recognition, i.e. the recorded speech does not contain all parts of the read word, the child would be asked to repeat the separate parts, and the word concerned and these would be recorded simultaneously.

Data Collection Issues

The main issue of collecting dyslexic children's speech when reading aloud is asking them to read. Due to their reading difficulties, psychologically, dyslexic children are usually very shy and worried when they have to read aloud. This pressure on them can contribute to their sense of low self-esteem and make them feel de-motivated. They try to avoid reading as much as possible because the task often frustrates them. This is because they cannot produce correct and smooth reading (Sagmiler, n.d.). Therefore, motivation is also decreased. The situation is worsened when they also suffer from the lack of concentration and interest towards any activity involving reading aloud.

Other issues include:

- Refusal to follow instructions – some dyslexic children did not give 100% commitment to the task at hand. Sometimes some of them refuse to participate in the reading recording session.
- High degree of talkativeness and playfulness – thus producing awkward and mock errors. Often when this happen, the participant is asked repeat his/her reading.
- Time consuming process – recording of manual reading is time consuming; this is because the stimulus was presented manually to the participant and the recording of the reading was done simultaneously.
- Availability of suitable rooms for recording – Recording sessions in the computer laboratory for example, could only be done during free periods when there was no other class conducted in the laboratory, and this schedule differed daily and weekly.

ANALYSIS AND FINDINGS

The data collection managed to obtain a total of 6384 utterances of read speech from the participants. From this data of six thousand plus utterances all the miscues or reading errors were identified and then grouped into matching error type categories. All 6384 utterances were carefully transcribed into corresponding spellings and the transcriptions were then tabled. Edit distance algorithm was performed on each and every transcript to measure the similarity between read words and target words. Edit distance represents the minimum number of operations needed to transform a string into another string, whereby operations included addition, deletion, and substitution of a character or more (Ristad & Yianilos, 1998). A difference was denoted by cost and given a value of '1'. In contrast, the cost was made equal to '0'. To determine the minimum value, the following matrix representation in Figure 1 illustrates the calculation involved.

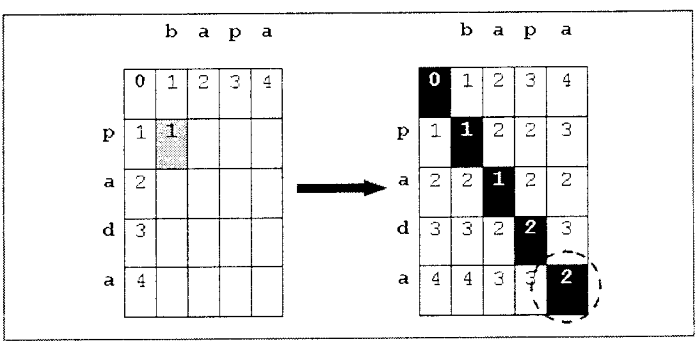

Fig. 1. Edit Distance Representation in Matrices

Since ‘b’ and ‘p’ were different, the cost was made equal to ‘1’. Then, three operations were performed as follows:

1. the value above the grey cell was added to ‘1’ giving a value of ‘2’ (1 + 1 = 2).
2. the value in the cell to the left of the grey cell was also added to ‘1’ giving it a value equal to ‘2’ (1 + 1 = 2).
3. Lastly, the value in the upper-left cell of the grey cell was added to the cost giving a value of ‘1’ (0 + 1 = 1).

These three values (2, 2, and 1) were then compared and the **minimum** was chosen and regarded as the value for the grey cell, as denoted in the matrix. The same operations were repeated for all of the cells until the last comparison of the last letters of both strings. The edit distance was given by the last value of the diagonal cell as denoted in the second matrix. Therefore, the edit distance of *bapa* and *pada* was equal to ‘1’.

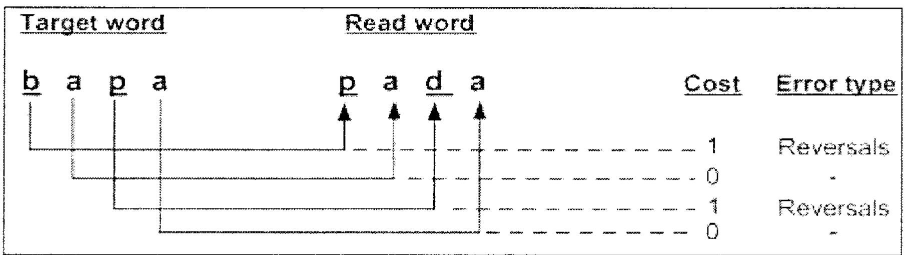

Fig. 2. Edit Distance Cost and Error Type Classification

The most important part was to perform a careful and thorough analysis on the transcripts in order to group them into suitable error type categories. Each transcript could contain zero or more errors. Figure 2 illustrates the comparison between the original word *bapa* and the read word *pada*. The two differences were reversals of ‘b’ to ‘p’ and ‘p’ to ‘d’. Hence, the cost was equal to ‘1’ for each of the differences and the error type was given by the ‘reversals’ category. The analysis was done according to the English phonological-based error types as recommended by the phonological-based theory of dyslexia (Sawyer, Wade, & Kim, 1999).

Errors which did not correspond to any of the categories in Sawyer et al.’s error types were classified accordingly into categories which were Bahasa Melayu-based. A few error types were introduced to occupy the errors made in the context of the effects of the spelling system of Bahasa Melayu when reading isolated words. Table 2 illustrates the findings. Errors that were Bahasa Melayu-based were as follows: ‘substitute vowel with consonants (vice versa)’, ‘omits syllable’, ‘adds vowel’, ‘syllable division confusion’, ‘adds syllable’, and ‘substitute with non-words’.

Table 2. Errors by Category and their Frequency of Occurrences in Dyslexic Children's Reading and Spelling of Isolated Bahasa Melayu Words

Category of Errors	n	%
Substitute vowel	1286	20.34
Omitted consonant *	786	12.43
Nasals (*m, n*)	770	12.17
Substitute consonant *	577	9.13
Omitted vowel	511	8.03
Substitute word	384	6.07
Added consonant	363	5.74
Substitute with non-words	272	4.3
Reversals	268	4.24
Incorrect sequence	224	3.54
Omitted syllable	167	2.64
Liquids (*l, r*)	156	2.47
Substitute vowel with consonant / consonant with vowel **	143	2.26
Substitute nasal for liquid	124	1.96
Added vowel	124	1.96
Syllable Division Confusion	94	1.49
Added syllable	74	1.17

* excludes *m, n, l ,r*

** *if: substitution of a vowel with a consonant (**excluding** m, n, l, r) or substitution of a consonant (**including** m, n, l, r) with a vowel*

It is noteworthy that these findings support the findings of Sawyer et al. (1999) that the most frequent error made is vowel substitution which is slightly more than 20%. The most frequent error pattern from the analysis is of the vowel substitution type, but with 'single error pattern' in the transcripts. In each transcript, error types can be zero (correct) or more. This means that in a word, several errors can occur resulting in the incorrect pronunciation of that particular word. Figure 3 demonstrates this notion as follows. The errors in this example are of 'substitute vowel' (SV), 'reversals' (Rev.), and 'add syllable' (AS) categories.

Target word	Transcript	Error types
barang	*baring*	**SV**
Kecundang	*Kecondong*	**SV, SV**
abang	*adangan*	**Rev., AS**

Fig. 3. Examples of Single Error Pattern and Double Error Patterns of the Type 'SV', 'SV, SV', and 'Rev., AS'

In this example, the three error types are obtained from the incorrect reading of the words *barang*, *kecundang*, and *abang* respectively. Referring to the above figure, the errors are: 1) single error type of 'SV'; 2) two double error types of 'SV, SV' and 'Rev., AS'. In fact, the combination of error types could vary from one to seven errors in a single word. However, this study only considered modeling words with single error for now.

PRONUNCIATION MODEL FOR ACTIVE LEXICON

Once the data analysis is completed, words were selected to be modeled for use in the ASR. The concern was the development of the pronunciation model for the active lexicon of the ASR. The pronunciation model was thus dependent on the lexical knowledge base , which was considered an important knowledge source for the ASR to train on and make generalizations on the speech (in this case, read speech) to be recognized. Other knowledge sources for ASR are acoustic knowledge, syntactic knowledge (grammar), semantic knowledge, and pragmatic knowledge (Rabiner & Juang, 1993).

Based on the most frequent error patterns, words were chosen which contained the errors. The selected words thus acted as an active lexicon for the ASR application. In addition, as suggested by Nix et al. (1998) and Williams et al. (2000) all the errors produced which corresponded to the selected pattern were also included in the active lexicon, be it words or non-words and were represented in a Worldbet representation. Since only the words with the four highest frequencies were considered, manual transcription was assumed to be sufficient. In this case, the words which were incorrectly pronounced and categorized as under the single pattern of 'substitute vowel', 'omit consonant', 'nasals', and 'substitute consonant' were then modeled.

The purpose of modeling only the most frequent errors was to enable the development of an ASR application that would be able to assist more dyslexic children. The pronunciation model was constructed using hand-coded transcriptions of the selected words citations into their corresponding Worldbet phones. For example, Figure 4 illustrates the Worldbet representations for *abang* (older brother), *ibu* (mother), and *bapa* (father) respectively.

Word	Worldbet
abang	A bc b A N
aku	A kh U
ibu	I: bc b U or I bc b u
baca	bc b A ts A
bapa	bc b A pc ph A

Fig. 4. Examples of Worldbet Representation of abang, aku, ibu, baca, and bapa

Using a context-dependent phoneme model, the pronunciation models of the words selected were constructed. The context-dependent phoneme model modeled each phoneme as either dependent on its preceding and/or succeeding context. Context-dependent modeling often manages to improve accuracy as demonstrated in Dupont, Ris, Couvreur, and Boite (2005), Tsakalidis, Prasad, and Natarajan (2009), Husniza and Zulikha (2009), to name a few.

For this purpose, each phoneme is defined to have one, two or three parts based on the coarticulation effects on each phoneme by its preceding and succeeding phonemes. Hence the three parts are as follows (Zulikha & Abdullah, 2007):

Part 1: phonemes that are independent, which means that they are not influenced by their preceding or succeeding phonemes.

Part 2: phonemes that depend on their preceding and succeeding phonemes (also referred to as the left and right contexts).

Part 3: phonemes that are divided into three parts, where the left context depends on the preceding phoneme, the middle context is independent, and the right context depends on the succeeding phoneme.

The context clusters are defined based on the Bahasa Melayu phonetic and phonological systems as described in Indirawati & Mardian (2006). Context clusters can be referred to as the broad categories context that the phonemes can be associated to. The context clusters defined are: $fnt for front vowels – a, e, and I; $mid for middle vowels – e; $bck for back vowels – u and o; $dip for diphthongs – ai, au, and ia; $dig for digraphs – ng and ny; $con for consonants (defined to be context-independent as they are least influenced by their neighbouring phonemes and always pronounced the same in Bahasa Melayu); $sem-vow for semi-vowels – w and y; $vib for vibration – r, and $bst_clo for burst closures. Figure 5 illustrates the context-dependent phoneme model for the word *aku*.

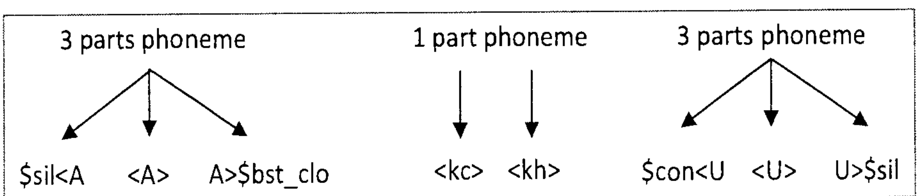

Fig. 5. The Context-Dependent Phoneme Model of the Word Aku

CONCLUSION

To enable the ASR model to support dyslexic children's reading in Bahasa Melayu, gathering suitable corpora and inducing reading errors are important pre-requisites. This is to allow for the development of an ASR-based application which is based on the most frequent dyslexic children's reading errors in the language. As explained in considerable details in the foregoing discussions, the most frequent error types to emerge from the analysis are 'substitute vowel', 'omitted consonants', 'nasals', and 'substitute consonants'. Words that fall within these errors are modeled before they can be used to train the model. The pronunciation models involve context-dependent phoneme models that model each phoneme with respect to the coarticulation effects of the surrounding phonemes. Modeling the pronunciation this way appears promising as it leads to the increased recognition accuracy of dyslexic children's read speech of selected vocabulary in Bahasa Melayu.

Noteworthy is the challenges that have been identified during the data collection process. To reduce the time spent in data collection process, effective approaches have to be identified and explored. This includes involving more than one researcher or observer in the study so that parallel individual sessions could be performed in one day. However, the suitability of the venue for recordings is also of significant concern. The Primary school environment is often noisy with children's classroom activities and thus, finding a quiet room is quite an issue. An automatic data collection process is of great significance too. Not only can it speed up the tedious process that a human performs, using a computer-based application, which is specifically built to prompt and record dyslexic children's reading simultaneously, can also increase the subjects' interest in participating in the study. This in turn will boost their motivation to read aloud, while at the same time raising their self-esteem and self confidence.

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