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Auditory Processing and Phonological Awareness among Biliterate Normally Progressing Readers and Dyslexic Readers

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ABSTRACT

Auditory processing deficits may underpin the development of phonological representations in children. The present study examined the relationship between auditory processing and phonological awareness among normally progressing and dyslexic readers. Fifteen normal readers and ten dyslexic readers acquiring literacy skills in both Hindi and English language were individually assessed on auditory processing tasks (tone and syllable discrimination and temporal order judgment), and phonological awareness tasks (phoneme and syllable deletion/substitution) to examine the relationship between auditory processing of speech and non-speech sounds and phonological awareness. Results indicate that it is the task and not the stimulus type (tones versus syllables) or task complexity (decreasing ISIs on TOJ task) that may result in difficulties in auditory processing. Auditory discrimination for speech sounds and syllable order judgment predicted the phonological skills among normally progressing readers as well as dyslexics. Auditory processing involving the speech sounds may affect the development of phonological awareness and may further affect reading acquisition.

Keywords: Dyslexia, Reading Acquisition, Auditory Perceptual Processing, Phonological Awareness, Hindi and English Language.

INTRODUCTION

Reading is the process of understanding speech written down in some sort of symbols. The goal is to gain access to meaning of the written speech. To acquire reading, children must learn the code that is used by their culture for representing speech as a series of visual symbols.

Learning to read is basically a process of matching distinctive visual symbols to units of sound. The first step in becoming literate is to learn the system of mapping between the symbols and their sounds. The process of learning and applying these mapping has been called *phonological recoding*. Phonological recoding has always been considered as very essential for successful reading acquisition (Ziegler & Goswami 2005). Phonological recoding is dependent on the phonological awareness of the child.

Phonological awareness is the ability to make explicit verbal reports of phoneme sized units and is involved on grapheme/phoneme correspondence (Stanovich 1988). Phonological awareness is the conscious awareness of or sensitivity to the sound structure of language. It includes the ability to detect, match, blend, segment, or otherwise manipulate the sounds in spoken language. Fitzpatrick (1997) has rightly said that phonological awareness is "the ability to listen inside a word." Children who have a well-developed phonological awareness do not find problem in understanding how sounds and letters operate in the printed word. This relationship has been found across all languages so far studied. It is now a well-established fact that the deficits in phonological processing play a critical role in reading impairment (e.g. Goswami & Bryant 1990; Vellutino, Fletcher, Snowling & Scanalon 2004). The "phonological core deficit" theory (Stanovich 1988) posits that dyslexics find it difficult to represent mentally the sound patterns of words in their language in a detailed and specific way.

The first step in gaining a phonological processing skill is to detect, or isolate, the component sound within a word. The most influential model of phonological awareness in relation to English language today has been Adams' (1990) five-stage developmental approach. The first level is described as having "an ear for the sounds of words," which is primarily measured through children's knowledge of nursery rhymes or ability to remember rhyming words more easily than non-rhyming words. The second level is the ability to successfully master oddity tasks, where the child can compare and contrast words on the dimensions of rhyme and alliteration. Third stage in this model is the ability to blend syllables or phonemes, as well as recognizing that syllables can be split. The fourth level is characterized by the actual ability to split words into phonemes on demand. Finally, the fifth level is phoneme manipulation, in which the reader can add or delete specified phonemes from target words and produce the new word (or non-word). Children who are bilingual from a preschool age may initially acquire literacy either in one or both of their two languages.

For children whose experience with literacy is in only one of the languages, it is probably the case that this experience is presented through the weaker of the two and not the language of the home.

There is a developing consensus that developmental dyslexia generally results from a deficit in the phonological processing of language. Learning to read an alphabetic language requires mastering grapheme to phoneme correspondences. Individuals with developmental dyslexia appear to have a weak representation of sounds of language and this in turn makes it difficult to relate those sounds to written letters. Deficits related to phonological processing have been studied with a developmental perspective in children with reading disability and have shown difficulties at each linguistic level, depending on the age at which they are tested. Goswami et al. (2002) proposed that as syllable-level information is primary in early language acquisition, a difficulty in perceiving aspects of speech rhythm could be impaired in developmental dyslexia. An early deficiency in extracting syllable level information from the speech stream would impair the development of the entire phonological system, necessarily including the representation of onset-rime level and phoneme-level information. Therefore, phonological processing would remain impaired even in consistent languages. In dyslexic children learning to read transparent orthographies, highly accurate performance in phonological awareness tasks is eventually achieved, but processing is always extremely slow. Phonological deficits in terms of slowing on phonological tasks observed in Hindi, though a language with transparent orthography; also indicates a general temporal processing deficit.

Phonological awareness is also considered part of metalinguistic abilities. Metalinguistic ability in the context of language refers to the ability of performing mental operations on the output of speech-perception mechanism (Tunmer & Rohl 1991). Durgunoglu, Nagy, & Hancin-Bhatt (1993) reported cross-language transfer of phonological awareness in Spanish-English bilingual children. Recognition of word and pseudoword in English was predicted by the levels of both Spanish phonological awareness and Spanish word recognition. Further, Cisero & Royer (1995) indicated that if phonological awareness is not restricted to language experiences, it would mean that phonological awareness can be transferred from a familiar language to an unfamiliar language. Cisero & Royer reported the evidence for cross-language transfer in English and Spanish. Chiang (2003) found that training Chinese children on tongue twisters in English had a bilateral effect not only on the perceptual skills in L2 (that is, English) but also in L1 (that is, Chinese).

A very important aspect related development of phonological awareness among normally progressing readers and dyslexic readers is the orthography a child is required to learn. Languages differ in the complexity of their orthographies and how they represent spoken language. It is possible to classify alphabetic orthographies along a continuum according to the transparency or regularity of their letter-sound (grapheme-phoneme) correspondences. English is an alphabetic orthography where each alphabet represents a sound. But in comparison to other orthographies English is a relatively non-transparent orthography, that is, there is not always a one to one mapping between alphabets and their sounds. In English, consonants and vowels exist independent of each other but in forming a word both play important roles (syllable is defined as "CVC"). In English we find several words that do not comply with the strict rule of grapheme to phoneme conversion. For instance, HAVE and GAVE are two words that have identical rimes (nucleus and coda) but they are pronounced differently. The presence of hundreds of irregular and exception words make English an opaque orthography and therefore, (theoretically) difficult to learn to read.

Contrary to English, Hindi is an alpha-syllabic orthography in which the degree of consistency in the sound and symbol mapping is high. The alpha-syllabic orthographies are a group of orthographies that represent sounds at the level of the syllable but have distinctive features to indicate sub-syllabic information (Bright, 1996). In Hindi the smallest unit of orthography is *akshara* which contains both the consonant and a vowel (therefore, known as alpha-syllabic orthography). In the *akshara* the consonant has a primary place with the following vowel represented as diacritics. An *akshara* with no vowel diacritics represents a consonant with an inherent vowel (schwa). Post-consonantal vowels are placed either to the left, right, top or bottom of the initial consonant as diacritics but when the vowel comes in the beginning of a word it is represented by its usual symbol. Irregular words are not found in this language.

Ingram (1963) believed that "difficulties in auditory discrimination or in the synthesis of spoken words are more important causes of reading retardation than visuo-spatial difficulties." Deficits among young dyslexics in discriminating between pairs of CV (consonant-vowel) syllables were reported by Hurford & Sanders (1990). Their work suggested that training children in making phonemic discrimination led to improvement in performance in this task but they did not assess whether an improvement in phonemic discrimination led to better reading. Earlier studies have revealed that the quality of a child's phonological representations is important for their subsequent progress in literacy. This relationship has been found across all languages so far studied, for both normal and dyslexic children. It is thus generally accepted that dyslexia is characterized by developmental weakness in establishing phonological representations of speech. The phonological core deficit theory (Stanovich 1988) argues that dyslexic children find it difficult to represent mentally the sound patterns of the words in their language in a detailed and specific way.

Although considerable studies support the hypothesis that the underlying core deficit of developmental dyslexia is a phonological processing deficit, the precise etiology of this deficit is still unknown. One hypothesis suggested that developmental dyslexia may be caused by a deficit in brain circuitry that processes rapidly changing auditory information (Miller, Delaney & Tallal 1995; Tallal 2004; Tallal & Gabb 2006). This "auditory temporal processing deficit hypothesis" suggests that processing of oral language can be impaired due to the inability to process the rapid spectro-temporal characteristics of phonemes and sounds. Dyslexics have difficulties in dealing with temporal patterns within the auditory modality. This in turn disrupts the essential components of language learning, beginning with the acquisition of adequate phonological representation that has been shown to be one of the key elements necessary for learning to read. Auditory processing deficits among dyslexics may be responsible for the phonological processing deficits (Eden, Stein, Wood & Wood 1995).

Banai and Ahisaar (2004) have found that poor performance in psychoacoustic tasks is characteristics of a specific, large, subpopulation of dyslexics with additional learning difficulties. These individuals suffer from particularly poor verbal working memory, the extent of which is correlated with the degree of their psychoacoustic and reading deficits. In this study they found that performance of dyslexics with additional learning difficulties was adequate on same/different type discrimination tasks with either pure tones or complex speech sounds (for example if the two tones are same or different). However, children with additional learning difficulties faced severe difficulties on comparison tasks (that is, comparison between high/low tones and long/short duration tones) and judging the ordinal position of the repeated stimulus, with exactly the same physical stimuli.

Nagarajan et al. (1999) conducted a study using magnetoencephalography to investigate the involvement of auditory cortex in response to brief and rapidly occurring successive stimuli in normal and poor readers. They found four interesting results: first, the response amplitude evoked by short-duration acoustic stimuli was stronger in the post stimulus time-range of 150-200 ms in dyslexic readers than in normal readers. Second, response amplitude to rapidly occurring successive and brief stimuli that were identical or that varied significantly in frequency were substantially weaker in dyslexic readers compared with normal readers, for inter stimulus interval (ISIs) of 100 or 200 ms, but not for an ISI of 500 ms. Third, this neurological deficit closely paralleled subjects' ability to distinguish between and to reconstruct the order of presentation of those stimulus sequences. Fourth, the average distributed response coherence evoked by rapidly successive stimuli was significantly weaker in the β- and γ- frequency ranges (20-60 Hz) in dyslexic readers compared with controls.

Auditory processing deficit may involve a sensory deficit or a higher order deficit involving attention. Individuals with reading difficulties have shown deficits in attentional focus, orienting and shift of attention. Rapid temporal processing of sounds has been found to be related to discrimination of phonological units. In addition, if reading across languages depends on a single phonological system the deficits in phonological awareness would be observed in all the languages that the individual knows irrespective of the nature of orthography of the known languages.

Deficit in phonological processing is a major cause for dyslexia. Speech perception is a perquisite for phonological processing. If dyslexics have difficulties in speech perception it would result in less precise phonological representations. The relationship between speech sound perception/discrimination and temporal processing of sounds may explain phonological processing related deficits among dyslexic readers. Dyslexics have poor representations of auditory stimuli. Hence they will have difficulty in discriminating between similar auditory stimuli irrespective of task complexity (manipulation with respect to ISIs in the temporal order judgment task). Perceptual selection of sounds may also interact with central auditory processing deficits and thus influence phonological processing in dyslexic readers. The current study examined the relationship between deficits in auditory processing (sound discrimination and temporal auditory processing) and phonological awareness in biliterate dyslexic readers.

METHOD

Participants

All the participants were Hindi-English biliterates studying in grade 1, 2 and 3 in a coeducation school with English being the medium of instruction. The dyslexic readers were taken from the data base already generated during earlier studies at the Centre of Behavioral and Cognitive Sciences (CBCS) conducted on school going children using the indigenously developed tests for identification of dyslexic readers (including tests of letter identification, word and nonword reading, irregular words (English only), reading comprehension, and spelling). Altogether there were 25 participants (11 males and 14 females; mean age = 8.18 ± 1.45): fifteen normally progressing readers and ten dyslexic readers. Brief screening tests for visual acuity, auditory comprehension, expressive speech and working memory span (digit span test) were performed on all the participants. Participants with normal or corrected to normal vision were taken for the study. Brief auditory test was conducted to rule out any sensory deficit in auditory modality.

Identification of normally progressing readers and dyslexic readers was based on multiple measures including teacher's report (problem checklist), reading and spelling tests (reading accuracy, speed, and nature of errors) in Hindi as well as English language. A battery of tests of reading skills in Hindi and English language was employed to identify children with reading difficulties (Kar & Chatterjee 2009). The tests were designed such that the test items were graded in terms of the difficulty level rather than grading for appropriate items. Grade appropriate curriculum was considered while selecting the passages for reading comprehension and dictation. Word reading and nonword reading tests in English were developed using the MRC psycholinguistic database taking the following criteria into consideration: age of acquisition, length of the words, and frequency/familiarity of words. Accuracy was the measure of performance for all the tests. Time taken in seconds to read the entire list of words was recorded for word reading and nonword reading tasks. For tasks such as listening and reading comprehension time taken to respond to each comprehension question was recorded using the digital voice recorder. Attempts were made to match the procedures adopted for developing the word and nonword reading tests as much as was possible particularly with respect to the number of words, syllabic length, nonwords developed by substitution of one phoneme of a meaningful word etc) since the two languages follow different orthographies. Complete equivalents were not possible with one language having an alphabetic script and another being an alphasyllabary.

Children who showed an accuracy of more than 80% on all of the reading tests were taken as normally progressing readers. Children who were reported with reading difficulties by the class teachers were subjected to a detailed assessment of intellectual functions, working memory, reading speed and accuracy (word and nonword reading), reading comprehension, phonological awareness, by examining the nature and frequency of errors. Children who scored two standard deviations below the mean on tests of word and nonword reading (accuracy), who were found to be average on the test of intellectual functions (Colored Progressive Matrices, Raven, Raven, & Court, 1998) were considered as dyslexic readers. All of the children identified as dyslexic readers showed poor performance on reading tests in both Hindi and English. Both normally progressing and dyslexic readers were matched with respect to chronological age and educational level.

MEASURES

Auditory discrimination task

This task was designed to investigate the auditory perception with respect to the discrimination of speech and non-speech sounds. Auditory discrimination task requires encoding of specific stimuli to be discriminated. It was hypothesized that dyslexics will have difficulties discriminating speech as well as nonspeech sounds and that the task (sound discrimination) rather than stimuli (tones vs syllables) would result in poor performance among dyslexic readers.

Stimuli and procedure

The auditory discrimination task consisted of two separate blocks. Each block consisted of 80 trials. In one block a pair of two pure tones one of 300 Hz and the other of 600 Hz of 75 ms duration at 90 dB level were presented in a series separated by an ISI (inter stimulus interval) of 300 ms. The tones were generated using the Goldwave sound editing software program. In the other block a pair of two syllables /ba/ and /pa/ of 75 ms duration (recorded in a male voice at 90 dB level using Goldwave sound editing software program) were presented in a series separated by an ISI of 350 ms. The participants were required to report whether the syllables (or tones) presented one after the other were same or different. Different keys were assigned for different responses: "Z" key when the same tones or the syllables repeated in the series and "/" key when the stimuli were different.

Temporal order judgment task

This task investigated the rapid sequential processing of auditory stimuli with speech and non-speech sounds in normally progressing readers and dyslexic readers. It was hypothesized that auditory temporal processing would be affected for both tones and syllables among dyslexic readers and that the task (temporal order judgment) rather than stimuli (tones vs syllables) would result in poor performance among dyslexic readers. We also hypothesized that same type of stimuli will result in greater difficulties with decreasing ISIs between the series of tones/syllables presented.

Stimuli and procedure

Temporal order judgment task consisted of two conditions one with pure tones and another with syllables. A set of two pure tones (300 Hz and 1000 Hz) were presented in rapid succession separated across two ISIs (inter-stimulus (tone)-interval) of 150 ms and 250ms. The task was to give the order of the tones by pressing "Z" key when the low tone (300 Hz) preceded the high tone (1000 Hz), otherwise "/" key. In the second condition, a set of two syllables (/ba/-/pa/) separated across two ISIs (inter syllable interval) of 350 ms and 450 ms were presented in a series. The task was to give the order of the syllables by pressing "Z" key when /ba/ preceded /pa/ and "/" key in the opposite order. Reaction time and accuracy were the measures of performance. There were separate blocks for each of the three ISI in each condition and each block consisted of 80 trials. The physical properties of both the stimuli (tones and syllables) were identical to the stimuli used in the auditory discrimination task.

Phonological awareness tasks

We aimed to investigate the phonological sensitivity in Hindi and English language of the both the normal and dyslexic biliterate readers. It was hypothesized that dyslexic readers will perform poor on phonological awareness tasks equally for both Hindi and English language and that difficulties with respect to phonological awareness will be related to difficulties in auditory processing. We also examined if auditory processing difficulties with tones versus syllables as these stimuli would differentially predict difficulties with phonological awareness.

Phoneme deletion task consisted of words in Hindi/English verbally presented one at a time. The task was to delete a given sound in the word at the initial, middle or terminal position and give the sound of remaining word. There were four practice trials followed by 20 test trials.

E.g.: English: /mid/ after deleting the sound of /n/ in /mind/
Hindi: /बाटी/ after deleting the /ल्/sound in /बाल्टी/

Phoneme substitution task consisted of words in Hindi/English verbally presented one at a time. The task was to substitute a given sound in the word by another sound and give the new word thus formed. There were four practice trials followed by 20 test trials.

E.g.: English: Replace the sound of /r/ by /h/ in /rope/: Response: /hope/
Hindi: Replace the sound of /म/ in the word /मटर/ by /प/: Response: /पटर/

Syllable deletion task would consist of bi-syllabic words verbally presented one at a time. The task would be to delete a given syllable at initial or terminal level. There will be four practice trials followed by 20 test trials.

E.g.:English: Syllable deletion (/Mar/ after deleting /ket/ in the word /Market/)
Hindi: Syllable deletion (/□□/ after deleting /□□□/ in /□□□□□/)

Syllable substitution

Syllable substitution task would consist of bi-syllabic words verbally presented one at a time. The task would be to substitute a particular syllable by a given syllable at initial or terminal level. There will be four practice trials followed by 20 test trials.

E.g.:English: Syllable substitution (substitute /Bas/ by /Mar/ in the word /Basket/)
Hindi: Syllable substitution (substitute /कोर/ with /खट/ in the word /चौकोर/)

Each participant was screened for visual and auditory acuity, working memory and attention span. The normal and dyslexic readers were identified with appropriate reading tests (word and nonword reading, reading comprehension, and spelling) (Kar & Chatterjee 2009). Participants were individually assessed in a quiet room. In order to examine auditory processing computer based auditory discrimination tasks and temporal order judgment tasks were used. All the participants were attending their regular academic curriculum during the study.

The phonological awareness tasks were manually administered and responses to each item on each task were recorded on a record sheet as well as the voice recorder. Auditory processing tasks were administered on a laptop computer using software called DirectRT. Speakers were used to present auditory stimuli. Headphones were not used to avoid any asymmetry effects. Accuracy and total response time on each task were recorded for the phonological awareness tasks but only the accuracy was analyzed. For auditory processing tasks both accuracy and reaction time were analyzed.

RESULTS

Information about linguistic environment was collected for each participant. Most (>80%) of the children's parents reported use of Hindi at home and use of English outside home particularly in school. Spoken language was Hindi for most of the participants across all grades. Proficiency in Hindi was rated higher for comprehension as well. The auditory processing of the normally progressing readers and dyslexic readers was investigated with auditory discrimination task and temporal order judgment task using tones and syllables as stimuli. Accuracy and reaction time were the measures of performance.

Data obtained on auditory discrimination task was analyzed using a 2 x 2 ANOVA (Group x Stimuli Type) to compare the performance of normal and dyslexic readers with respect to accuracy and RT for discrimination with tones and syllables.

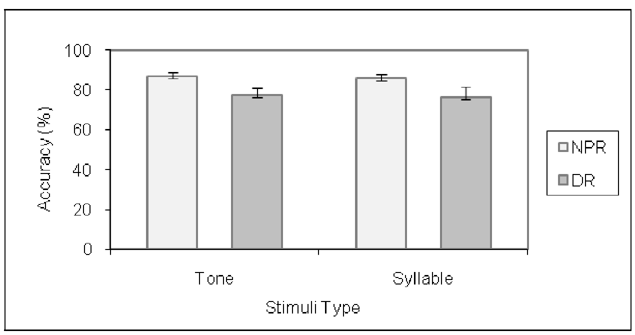

Fig. 1. *Mean-accuracy on auditory discrimination task (same/different discrimination) across groups*

For accuracy, the main effect of group of readers was found to be significant, F (1, 23) = 7.209, $p < 0.05$, but there was no significant main effect of stimulus type, F (1, 23) = 0.121, $p > 0.05$, and the interaction between group and stimulus type was also not significant, F (1, 23) = 0.004, $p > 0.05$. For reaction time, there was neither main effect of group, F (1, 23) = 3.339, $p > 0.05$, nor stimulus type, F (1, 23)

= 0.304, $p > 0.05$. Interaction effect between group and stimuli type was also not significant, F (1, 23) = 0.678, $p > 0.05$. Thus, the results indicate that dyslexic readers are impaired on auditory discrimination for both the types of stimuli.

The data obtained on temporal order judgment task were analyzed separately for tones and syllables across the two ISIs as follows:

Temporal order judgment (Tone): A 2 x 2 ANOVA (Group x ISI) was performed to compare the performance of normal and dyslexic readers on both accuracy and reaction time.

For accuracy, main effect of group was found to be significant, F (1, 23) = 6.879, $p < 0.05$, but main effect for ISIs was not significant, F (1, 23) = 1.895, $p > 0.05$, and the interaction between the group and ISI was also not significant, F (1, 23) = 0.012, $p > 0.05$, suggesting that ISI did not result in performance related differences between two groups. However, dyslexic readers were found to be poor with respect to temporal processing of tones.

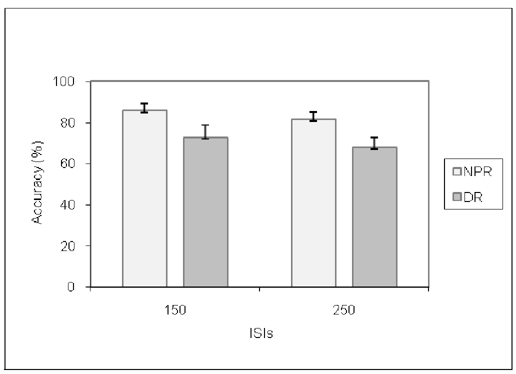

Fig. 2. *Mean-accuracy on temporal order judgment task (tone) across groups*

In case of reaction time, the main effect of group was not significant, F (1, 23) = 0.443, $p > 0.05$, nor ISIs, F (1, 23) = 3.001, $p > 0.05$. The interaction between group and ISIs was also not significant, F (1, 23) = 0.001, $p > 0.05$. Results indicate that dyslexic readers had difficulty in processing sounds but it did not improve even with longer ISIs as ISIs between tones did not affect their performance either in respect to accuracy or RT.

Temporal order judgment (syllable): Data obtained on the temporal order judgment (syllable) task were analyzed using a 2 x 2 ANOVA (Group x ISI) to compare the performance of two groups of readers. For accuracy, the main effect of group was significant, F (1, 23) = 10.789, $p < 0.01$, but the main effect for ISIs was not significant, F (1, 23) = 3.144, $p > 0.05$. The interaction effect between groups and ISIs was also not significant, F (1, 23) = 2.498, $p > 0.05$.

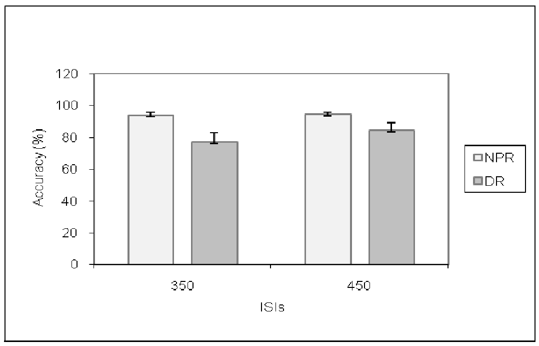

Fig. 3. *Mean-accuracy on temporal order judgment task (syllable) across groups*

In case of reaction time, the main effect of group was not significant, F (1, 23) = 2.960, $p > 0.05$, and the main effect for ISIs was also not significant, F (1, 23) = 0.169, $p > 0.05$. The interaction between groups and ISIs was also not significant, F (1, 23) = 0.524, $p > 0.05$. The results thus indicate that accuracy is a better measure than reaction time in discriminating normal and dyslexic readers on temporal order judgment tasks. The dyslexic readers were found to be impaired on temporal order judgment task irrespective of the stimuli (syllable or tone). The performance of the normal and dyslexic readers did not show significant differences across ISIs, thereby suggesting that deficit extended across all ISIs, both long and short.

In order to compare the performance of normal and dyslexic readers on phonological awareness tasks a 2 x 2 x 4 ANOVA was computed. There was significant main effect of group, $F(1, 23)$ = 51.707, $p < 0.01$, and phonological awareness tasks, $F(3, 69) = 45.028$, $p < 0.01$, but not of language, F (1, 23) = 0.087, $p > 0.05$. The interaction effect for group and phonological awareness tasks was found to be significant, $F(3, 69) = 19.552$, $p < 0.01$, also between language and phonological awareness, $F(3, 69) = 16.179$, $p < 0.05$, as well as the 3-way interaction among all the three factors was significant, $F(3, 69) = 3.102$, $p < 0.05$, but the interaction between the groups and language was not significant, $F(1, 23) = 0.027$, $p > 0.05$. Results indicate that dyslexic readers performed poor on phonological awareness tasks in both the languages thereby implying that phonological processing is similarly affected for Hindi and English. Post hoc comparisons using Tukey's post hoc test revealed that there was no significant difference in the performance of normal readers on phonological awareness tasks between the two languages, the dyslexic readers performed significantly better in English language $F= 8.330$, $p < 0.05$, than in Hindi language on the phoneme deletion task.

A 2 (group) x 2 (phoneme deletion and phoneme substituion task) ANOVA was performed to further compare the performance of normal and dyslexic readers on phoneme deletion and phoneme substitution tasks across the two languages. For phoneme deletion the main effect of group was significant, $F(1, 23) = 49.405$, $p < 0.01$, and the main effect of language was also significant, $F(1, 23) = 14.642$, $p < 0.01$. In the case of phoneme substitution, the main effect of group was significant, $F(1, 23) = 18.678$, $p < 0.01$, and the main effect for language was also found to be significant, $F(1, 23) = 10.914$, $p < 0.001$. However, the group x language interaction effect was not significant both for phoneme deletion and phoneme substitution.

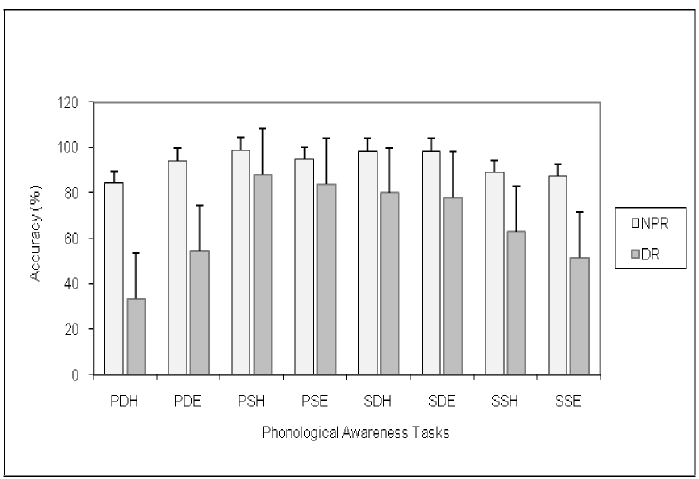

Fig. 4. *Mean-accuracy on phonological awareness tasks across groups*

Planned comparsons were performed for each phonological awareness task across the two languages and across the groups. The test revealed that there was significant difference between normal and dyslexic readers on phoneme deletion tasks, F (1, 23) = 20.164, $p < 0.01$, but not on phoneme substitution task, $F(1, 23) = 4.233$, $p > 0.05$, in Hindi. Normal readers performed significantly better on phoneme substitution task, $F(1, 23) = 5.688$, $p < 0.05$, as compared to phoneme deletion in Hindi. In Hindi, dyslexic readers' performance on phoneme substitution, $F(1, 23) = 21.619$, $p < 0.01$, was significantly better than their performance on phoneme deletion task. In English, there was no significant difference between different phonological awareness tasks for normal readers. Dyslexic readers performed significantly better on phoneme substitution task, $F(1, 23) = 11.702$, $p < 0.01$, in comparison to phoneme deletion in English. In the case of syllable deletion the main effect of group was found to be significant, F (1, 23) = 23.117, $p < 0.01$, but the main effect of language was not significant, $F(1, 23) = 0.175$, $p > 0.05$, and neither the interaction effect for group and language was significant, $F(1, 23) = 0.175$, $p > 0.05$. In syllable substitution task, main effect of group was significant, $F(1, 23) = 33.940$, $p < 0.01$, and main effect of language was also significant, $F(1, 23) = 2.473$, $p < 0.05$. The group x language interaction effect was not significant, $F(1, 23) = 2.676$, $p > 0.05$.

Planned comparsons using Tukey's post hoc test revealed that normal readers performed significantly better than dyslexic readers on both the syllable deletion task, $F(1, 23) = 7.140$, $p < 0.01$, (Hindi), $F(1, 23) = 7.934$, $p < 0.01$, (English) and syllable substitution tasks, F (1, 23) = 10.314, $p < 0.01$, (Hindi), $F(1, 23) = 14.213$, $p < 0.01$, (English) in both the languages. The performance on syllable deletion task in Hindi was not significantly different from that of syllable substitution among normal readers. However, dyslexic readers performed significantly better on on syllable deletion task as compared to the syllable substitution task, $F(1, 23) = 7.140$, $p < 0.01$. They performed better on syllable deletion task in both the languages. Dyslexic readers performed significantly better on syllable deletion task in English $F(1, 23) = 10.512$, $p < 0.01$, in comparison to syllable substitution task. In Hindi normal readers performed significantly better on syllable deletion task, $F(1, 23) = 5.423$, $p < 0.05$,but not on syllable substitution task, $F(1, 23) = 1.853$, $p > 0.05$ in comparison to phoneme deletion. Dyslexic readers performed significantly better on syllable deletion task, $F(1, 23) = 9.322$, $p < 0.01$, but not on syllable substitution task, $F(1, 23) = 1.190$, $p > 0.05$, in comparison to their perfornance on phoneme deletion task in English. In Hindi, dyslexic readers' performance on phoneme substitution,syllable deletion tasks $F(1, 23) = 18.446$, $p < 0.01$, and syllable substitution task $F(1, 23) = 11.702$, $p < 0.01$, was significantly better than their performance on phoneme deletion task.

Correlation analysis

Pearson's product moment correlation coefficients were computed between the auditory processing tasks and phonological awareness tasks to investigate if auditory perceptual processing is correlated with the development of phonological awareness which may affect learning to read. Performance on different phonological tasks was found to be significantly correlated with the performance on auditory discrimination and temporal order judgment. Results indicate that phoneme deletion and substitution (Hindi) were significantly positively correlated with all the auditory processing tasks. Phoneme deletion (English) was significantly correlated with only temporal order judgment with syllables. In sharp contrast to phoneme substitution (Hindi), phoneme substitution (English) was not correlated with any of the auditory processing tasks. Syllable deletion (Hindi) was significantly correlated with all the auditory processing tasks except temporal order judgment. In contrast, syllable deletion (English) was found to be significantly correlated with temporal order judgment (syllable) and auditory discrimination (tone). Syllable substitution in Hindi and English showed positive correlation with temporal order judgment (syllable) and auditory discrimination (tone).

Results suggest that phonological awareness is positively correlated with auditory processing. Performance on phonological tasks in Hindi showed stronger correlations with auditory processing as compared to English. Effortful and slow development of phonological representations even in a transparent orthography like Hindi seems to be related to auditory perceptual processing.

Regression analysis

Regression analysis was also performed in order to obtain the precise estimate of the relationship between phonological awareness and auditory perceptual processing (see Table 1 in Appendix A). Auditory discrimination and temporal order judgment were taken as independent variables and phonological awareness scores were taken as dependent variables. Auditory discrimination for speech sounds and syllable order judgment were found to be the best estimates for phonological awareness among normally progressing readers as well as dyslexics.

DISCUSSION

Development of phonological representations is important for the acquisition of reading skills across languages (Richardson et al. 2004). There is a causal relationship between phonological skills and reading acquisition. Children with reading difficulties have problem in establishing phonological representations of speech. Auditory perceptual difficulties affect the development of phonological representations. Auditory processes may underpin the development of phonological representations in children learning to read. Several studies have reported a phonological deficit as well as evidence for temporal processing deficits in dyslexia (Bradley & Bryant 1983). Speech perception is a prerequisite for all the phonological processing tasks (Schulte-Korne et al. 1998). Dyslexics have poor representations of auditory stimuli. They find it difficult to discriminate between acoustically similar sounds and in processing rapid sound sequences (Hari & Keisila 1996; Helenius, Uutela & Hari 1999). This could be due to the impaired magnocells in the medial geniculate nucleus of thalamus (Galaburda, Menrad & Rosen 1994).

The present study investigated the relationship between auditory perceptual processing and phonological awareness in biliterate normally progressing readers and dyslexic readers. Phonological processing in reading may be related to perception of transient acoustic signals. We examined auditory perceptual processing in terms of auditory discrimination and temporal order judgment with speech and nonspeech sounds. Phonological awareness was examined with tasks involving phoneme and syllable level manipulations. Results indicate that a) dyslexic readers were deficient on auditory discrimination and auditory temporal processing similarly for both speech and non-speech sounds as compared to normal readers; b) dyslexic readers performed poor on phonological awareness tasks such as phoneme deletion, syllable deletion and syllable substitution; d) auditory perceptual processing was found to be correlated with phonological awareness for both phoneme level and syllable level representations in Hindi and English; e) auditory discrimination and temporal order judgment with speech sounds served as the best predictors for phonological awareness.

Results revealed that the dyslexic readers performed poorly on auditory discrimination for both speech (syllable) and non-speech (tone) sounds. Dyslexic readers showed poor performance on temporal order judgment for tones as well as syllables. The data revealed that dyslexic readers showed greater impairment at shorter ISIs as compared to the normal readers for speech stimuli (syllable). The performance of dyslexic readers on temporal order judgment for tones as well as syllables was comparable across the different ISIs. Several earlier studies have shown that dyslexic readers are impaired on processing speech stimuli but not on non-speech stimuli (Paulesu et. al. 2001; Temple et. al. 2001). However, some studies have noted that difficulties in processing non-speech sounds are found in dyslexics and that they extend to stimuli presented at longer ISIs (Share et al. 2002). In the current study, dyslexics showed difficulties in temporal order judgement for both tones and syllables irrespective of ISI. Longer ISIs did not serve as an advantage for temporal order judgment of sequentially presented sounds (tones or syllables). These findings suggest that it may not be the speed of processing of sounds that is affected in dyslexic readers rather temporal processing of speech and non-speech sounds could be affected among dyslexic readers.

We found that dyslexic readers performed poorly not only in relation to speech stimuli (syllables) but also non-speech stimuli (tone). Our hypothesis that it is the task which results in poor performance and not the stimuli was confirmed as we did not find a difference between the two stimuli on both the auditory processing tasks. Hence dyslexics have difficulty with respect to sound discrimination and temporal processing regardless of the stimulus type. Such results have also been reported by Banai & Ahissar (2006). They argued that such results when coupled with recent findings from imaging studies (LoCasto et al. 2004) suggest that processing of both speech and non-speech stimuli shares some common processing that is affected among dyslexics. On the contrary, a study on Mismatch Negativity (MMN) in order to investigate the relationship between dyslexia and auditory processing reported that dyslexics may have a speech processing deficit at the sensory level and found attenuated MMN for speech but not for tone stimuli (Schulte-Korne et al. 1998). This could be because MMN examines an early preattentive process and phoneme perception may be more sensitive than tones as stimuli, to be picked up by the preattentive processes. Auditory processing difficulties may underlie phonological processing ability involved in reading.

According to the phonological deficit hypothesis of dyslexia (Snowling 2000) reading disability results from a specific deficit in phonological processing. Findings of our study do not support speech specific deficit as we found difficulties with speech as well as nonspeech sounds among dyslexics. Although, nonspeech processing may not be directly relevant to reading but it is part of the same underlying deficit in auditory processing contributing to the phonological processing deficit. The deficit in auditory processing was related to the task and not the stimulus type indicating a central auditory processing deficit. However, auditory processing for speech sounds emerged as the best predictor of phonological awareness. Some studies have reported that low level auditory processes also underpin the development of phonological representations in children (Richardson, Thomson, Scott & Goswami 2004) whereas some other studies including those with electrophysiological evidence have reported no differences with processing of tones on a temporal order judgment task among low, average and expert readers as compared to enlarged differences with respect to phonemes (Given, Chari & Ennis 2003; Schulte-Korne et al. 1998). Though we have found auditory processing difficulties with both speech and nonspeech sounds among dyslexic readers we also found that irrespective of reading achievement, auditory processing of speech sounds (syllables) best predicts the status of phonological awareness in children.

Auditory perceptual deficits in dyslexics have been reported to affect the development of phonological awareness and subsequent acquisition of reading skills. Neuroimaging studies have also reported common neural substrates such as left inferior frontal regions that are involved in phonological processing and are also sensitive to auditory processing (Poldrack et al. 2001). An early deficiency in extracting syllable level information from the speech stream could impair the entire phonological system including the representation of phoneme level information (Goswami et al. 2002). This would affect the development of phonological processing in a transparent orthography as well. Results of the present study also indicate deficits for both phoneme level and syllable level representations but they manifest differently in Hindi as compared to English language. Though we found a significant interaction between language and phonological awareness we did not find differences between the two groups with respect to language on phonological awareness tasks. Within group analysis showed that dyslexics performed poorly on phoneme deletion as compared to normal readers for both the languages. Overall performance on tasks with phoneme level manipulations was found to be more difficult than syllable level manipulations in both the languages. Phoneme deletion and syllable substitution were found to be more susceptible to impairment which suggests greater difficulty with respect to the ability to sequence and assemble phonemic units. It is to be noted that dyslexic readers showed deficits in auditory discrimination and temporal order judgment. Phoneme level manipulations in English were more strongly related to temporal processing of sounds whereas phoneme level manipulations in Hindi were significantly correlated with sound discrimination. Processing of transient acoustic events is fundamental to establish the phonological representations and greater phonological sensitivity may be required for English language being a deep orthography. Temporal information is critical for phoneme perception and phonemic awareness is necessary for reading. Auditory processing was found to be significantly correlated with phoneme substitution and phoneme deletion in Hindi, thereby, suggesting that manipulation of smaller phonemic units is difficult than manipulation of syllables in this language.

The phonological deficit theory (Snowling 2000) postulates that literacy problems originate from a cognitive deficit that is specific to the representation and processing of speech sounds. There is much evidence that phonological processing deficits are linked to difficulties in learning to read, that is, phonological awareness predicts later reading ability and the deficits in phonological awareness markedly differentiate between normally developing children and dyslexics. Tallal and Piercy (1973, 1974) have shown that dyslexics are deficient on both a temporal order judgment paradigm and same different discrimination paradigm compared to normal readers. Theoretically, it was argued that a rapid processing deficit could affect literacy because transient information is critical for phoneme perception, and phoneme awareness is necessary for reading.

Reading is a complex multifaceted activity that involves a dynamic interplay of multi-sensory and cognitive-linguistic processes, moderated by many unspecified environmental or higher-order cognitive influences (Boets et al. 2007). Comprehensive theories like the phonological theory, the auditory temporal processing theory or the visual magnocellular theory are nevertheless important and necessary to guide and stimulate scientific research, but it is an illusion to expect any one of them to explain the complexity of literacy development. One can also notice a broader conceptual change from a deterministic single cause model of developmental and learning disorders towards a probabilistic and multifactor model (Pennigton 2006). There is a lot of evidence to situate the core of the reading and spelling problems at the level of higher order phonological processing.

Recent studies have shown impaired perception of dynamic aspects in the auditory signal itself, like amplitude and frequency modulations (Menell, McAnally & Stein 1999; Talcott et al. 2000). The speech perception problem causes a cascade of effects, starting with disruption of normal development of phonological system and resulting in problems learning to read and spell (Talcott & Witton 2002). The results of the present study indicate that dyslexic readers perform poorly on all phonological awareness tasks and in both the languages. Thus deficit in phonological awareness among dyslexic readers may not be language specific rather it is language independent. Such results were also reported by many other studies (Cisero & Royer 1995; Durgunoglu et al. 1993; Chiang 2003) on Spanish English bilinguals, Chinese English bilinguals respectively. Cisero and Royer indicated that if there is transfer of phonological awareness skills from a familiar to an unfamiliar language, it would suggest a kind of "abstract cognitive ability" that develops which can facilitate language processing across a variety of languages. Similarly, Durgunoglu and colleagues reported that once a child is able to reflect on the components of a language, it is likely that this metalinguistic awareness could be applied to a second language as well. Such metalinguistic awareness need not be language specific. In addition neurophysiological evidence also suggests dysfunction along the auditory to motor stream implied in phonological processing and grapheme-to-phoneme mapping (Temple 2002). Hence, auditory processing with respect to discrimination and temporal sequencing may contribute towards the development of phonological representations and in turn influence the development of reading skills.

CONCLUSION

The current study demonstrates the relationship between auditory perceptual processing of speech and non-speech sounds and phonological awareness (phoneme and syllable level representations) among biliterate normally progressing readers and dyslexic readers. Task and not the stimulus type (tones versus syllables) or task complexity (decreasing ISIs on TOJ task) may result in difficulties with respect to auditory processing among dyslexic readers. However, auditory perceptual processing with syllables predicts phonological awareness better than the ability to process non-speech sounds. Both the languages (Hindi and English) were found to be equally affected as dyslexic readers showed difficulties with phoneme and syllable level manipulations in both the languages. However, phoneme level manipulations appeared to be more difficult and slower in Hindi and Syllable level manipulations were more difficult in English. Even though auditory perceptual processing of non-speech sounds as well as speech sounds is involved in the development of phonological representations yet it is primarily the auditory processing (discrimination or temporal processing) with respect to syllables, which best predicts the status of phonological awareness. The study has implications for literacy teaching at schools for young children as they start with their formal schooling. Emphasis should be given to help the children discriminate and process sounds to facilitate the development of phonological awareness, mapping sounds to words and reading skills. Intervention programs for dyslexic readers should also include a component of enhancement of auditory processing abilities which could precede the training in phonological skills.

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APPENDIX A

Table 1. Regression coefficients showing the relationship between auditory processing and phonological awareness

Dependent Variables	Independent Variables	Coefficients	Standard Error	t-statistic
PDHAC	SOJAC 1	.882	.394	4.796**
PDEAC	SOJAC1	.811	.425	3.405**
PSHAC	SOJAC2	.156	.517	2.273*
SDEAC	ADTNAC	-.326	.011	2.336*
	SOJAC1	1.131	.258	4.525**
SSEAC	SOJAC1	.925	.561	2.689**

Note: ** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; ADTNAC = Auditory discrimination (Tone) Accuracy; SOJAC1 = Temporal Order Judgment (Syllable, ISI=350) Accuracy; SOJAC2 = Temporal Order Judgment (Syllable, ISI=450) Accuracy; PDHAC = Phoneme Deletion (Hindi) Accuracy; PDEAC = Phoneme Deletion (English) Accuracy; PSHAC = Phoneme Substitution (Hindi) Accuracy; SDE AC= Syllable Deletion (English) Accuracy; SSEAC = Syllable Substitution (English) Accuracy.

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