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Random gap detection test and random gap detection test-expanded: Results in children with previous language delay in early childhood

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Abstract

Objectives: The children with difficulty in receiving sounds presented at rapid rates in speech sounds and language learning period, may have delay in speech sounds and language development due to hearing speech sounds not clearly. Auditory temporal processing (ATP) is the ability to perceive auditory signals of brief duration accurately when presented at rapid rates. ATP can be evaluated by the random gap detection test (RGDT), which detects a brief gap between two stimuli. In this study, we investigated performance of children with previous language delay (PLD), currently having disorders in more than one speech sounds, on random gap detection test (RGDT) and RGDT-expanded (RGDT-EXP) tests.

Methods: 12 children (8 male, 4 female) with previous language delay (PLD) and complaint of expressing speech sounds distorted, were included into the study. They had applied language training for at least one-year period in the past and in the current time, their language development is normal. They expressed one or more speech sounds as distorted. The control group consisted of 10 normal hearing children with normal phonological development and language matched for age; and who had not PLD (5 male, 5 female). Children language levels were evaluated by Preschool Language Scale-4 test; or Clinical evaluation of language fundamentals, fourth edition (CELF-4) according to child's age. Speech sounds development was assessed by Speech Sound Development Test (SSDT). They were applied RGDT and/if necessary, RGDT-EXP. Each child responded whether he/she heard one or two tones. Their responses were taken as verbally and/or hold up one finger or two fingers. In the second test, they were applied speech discrimination test in quiet environment and in noise. Gap detection thresholds (GDTs) were detected at 500–4000 Hz; and Composite GDTs (CGDTs) were found for the study and control groups. GDT/CGDT $>$ 20 ms was considered as abnormal for temporal processing disorder.

Results: In the study group with PLD, mean of the GDTs were all over the normal limits; and in control group, mean of GDTs were all in normal limits. The difference between the mean GDTs of the study group were significantly higher than the control groups at all frequencies of 500–4000 Hz. In PLD group, CGDT (103.53 $\pm$ 11.63 ms) was significantly higher than that of the control group, (10.35 $\pm$ 0.65 ms) ($p = 0.021$).

Conclusion: The children with PLD have difficulties in perception of speech sounds at a certain rate, even they have not language learning difficulties. Therefore, difficulty in distinguishing of speech sounds may cause especially receptive language development delay.

We believe that perception of the speech sounds and language in a certain speed; and temporally degraded speech programmes should be incorporated into the training programme and may help to prevent delays.

Keywords: Previous language delay (PLD); Random gap detection test (RGDT); Random gap detection test-expanded (RGDT-EXP); Speech perception; Auditory; Processing; Children

1. Introduction

Language is a system of symbols which represent meaning and can be used for thinking and communication. Social communication commences in the first year of life

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with reciprocal vocalisations and non-verbal social exchanges and incorporates pre-verbal speech. First words develop between 10 and 12 months. By the second year the child may have a spoken vocabulary of hundreds of words and by the age of 3 years he can ask and answer questions in sentences. By the age of 4 or 5 he can understand language games e.g. rhyming and double meaning. The command, 'watch your hand', when the child is cutting with scissors is correctly interpreted as, 'be careful', not a command to sit and look at the fingers. The 4–6-year-old can use adult grammar and syntax and is able to construct sentences [1].

A number of studies have been conducted to examine the relationship between perception and production of speech for children [2]. Auditory temporal processing plays an important role in development of speech perception [3,4]. Temporal processing refers to the processing of acoustic stimuli over time; such as a temporal asynchrony task: the temporal alignment of two stimuli differs and the listener's task can be to differentiate between the two stimuli [5,6]. Among the demands placed on the auditory system during everyday listening is the separation of speech from background noise. To detect a brief gap between two stimuli, a minimum time-gap is necessary [7].

Gap detection procedure is a non-verbal test. Some studies find that temporal processing ability predicts language outcome whereas other studies do not. This study examined the effects of stimulus properties, experimental task, and perceptual learning on listeners' gap detection performance. Gap detection thresholds were obtained from adults with normal hearing and language ability. They found thresholds which were highest for gaps defined by markers with disparate frequencies (1000 and 4000 Hz; i.e., between-channel gap detection), and with longer (300 ms) trailing markers. Their results suggest that gap detection thresholds reflect a variety of sensory and nonsensory factors. Understanding these underlying factors is critical for any evaluation of the relation between temporal processing and language outcome [8].

However, it is controversial whether or not deficits or delayed development in auditory temporal processing cause speech sound development delay or language delay. Therefore, the present study assessed the effects of previous language delay (PLD) and speech sounds disorders in the current time on auditory processing disorders of young children in terms of identifying lowest gap by RGDT and RGDT-EXP Tests. To date, we could not find any similar studies in the literature.

2. Materials and method

The study was assessed in Kırıkkale University Faculty of Medicine, ENT Department and Hacettepe University Faculty of Medicine, ENT Department, Audiology and Speech Pathology Division, Educational Audiology Unite. All steps of the study were planned and continued according to the principles outlined in the Declaration of Helsinki [9].

3. Subjects

In the present study, 12 children (8 male, 4 female) with previous language delay (PLD) and complaint of expressing speech sounds distorted referred to the ''Educational Audiology Unite'' of ''Audiology and Speech Pathology Division'' at ENT Department in Hacettepe University Faculty of Medicine, were included in the study. They were applied language training for one-year period in the past and in the current time, their language development was normal. They expressed one or more speech sounds as distorted. Their mean age was 6.16 ± 1.14 (ranged 5.00–9.00) years.

The control group consisted of 10 normal hearing children with normal phonological development and language matched for age; and who had not PLD, between ages of 6 and 13 years (5 male, 5 female). The control group was the same group, as used in our previous study [10]. Their mean age was 9.4 ± 2.71.

According to the hospital files, all of them underwent audiologic tests according to their ages, and those with normal levels bilaterally were included in the study. Additionally, the Denver II (General Development Test) [11] test was performed to evaluate the children's overall development, which were normal. Their medical histories revealed no maternal illnesses during pregnancy, any perinatal trauma, infection or asphyxia, no use of autotoxic drugs, no psychosocial history, and no family history of significant illnesses. They had normal gestational age at birth, birth weight and past health. In this study, RGDT and RGDT-EXP [12] were applied to 12 children with PLD and 10 children of the control group. In the first test, all children were applied to RGDT and RGDT-EXP. Each child responded whether he/she heard one or two tones. Their responses were taken as verbally and/or hold up one finger or two fingers. In the second test, they were applied speech discrimination test in quiet environment and in noise. Normal gap detection threshold was considered to be between 2 and 20 millisecond (ms). A gap detection threshold >20 ms was considered as abnormal for temporal processing disorder [12].

4. Instrumentation

4.1. Evaluation of language development

4.1.1. Preschool Language Scale-4 (receptive and expressive language test) [13]

In Children, aged between 5 years to 6 years and 11 months, language development levels were evaluated by Preschool Language Scale-4 (receptive and expressive

language test) [13]. The receptive and expressive language level of each child was assessed via Turkey Preschool Language Scale, Fourth Edition (TPLS-4) test. It consists of two subscales: Auditory Comprehension (AC) and Expressive Communication (EC). The AC subscale evaluates a child's ability to understand spoken language. Sixty-two AC tasks and 68 expressive communication tasks make up the total scale, and each may include one or more sub-items. Administration time varies, depending on the child's age and his/her cooperation during the test (mean: 20–45 min). Response scoring is as follows: passing an item required a score of ''1'' and not passing, a score of ''0.'' Scores of ''1'' are summed for each subscale to yield an AC and an EC raw score. This study used the age equivalents. A language development level equal to or above the expected for the specific chronologic age was accepted as ''normal'', and otherwise as ''delayed'' for all groups of I–V.

Each child's receptive and expressive language levels were evaluated by Preschool Language Scale-4 test.

4.1.2. Clinical evaluation of language fundamentals, fourth edition (CELF-4) [14,15]

In Children, aged over than 6 years 11 months, language development levels were evaluated by Clinical evaluation of language fundamentals, fourth edition (CELF-4) [14,15]. By this test, language development of the children was screened in the view of whether it was normal or not. The results were given as ''passed'' or ''failed''.

4.2. Speech Sound Development Test (SSDT) [16]

4.2.1. The structure of Turkish language

Turkish is composed of 21 consonants and 8 vowels. Native 21 consonant phonemes of standard Turkish, in their alphabetical order, are ''b, c, ç, d, f, g, ğ, h, j, k, l, m, n, p, r, s, ş, t, v, y, z''. Vowel phonemes of standard Turkish, in their alphabetical order, are ''a,e,ı,i,o,ö,u,ü'' [13,16]. According to the International Phonetic Alphabet (IPA), Turkish consonants show that 'ş' indicates/ʃ/, 'ç' indicates/tʃ/, 'c' indicates/→/, 'y' indicates/j/, 'ğ' indicates/ɣ/, and 'j' indicates/∞/[16,17]. According to the International Phonetic Alphabet (IPA), the vowels of Turkish language show that ''a'' indicates/a/, ''e'' indicates/e/, ''ı'' indicates/ɯ/, ''i'' indicates/i/, ''o'' indicates/o/, ''ö'' indicates/œ/, ''u'' indicates/u/, ''ü'' indicates/y/[16,17].

4.2.2. Speech Sound Development Test (SSDT) [16]

The SSDT was applied to children between the ages among 2- to 7-year-old. The development of 21 sounds was evaluated. The SSDT consists of 123 words used to test the 21-target consonants. The sounds, except for/b, c/, are placed in six positions within the words: [Consonant (C), Vowel (V)]; 1) One syllable word-initial (C̲VC), 2) Two syllable word-initial (C̲VCVC), 3) Two syllable word-within-word; together with one consonant (CVC̲C̲VC), 4) Two syllable word-within-word; between two vowels (CVC̲V), 5) Two syllable word-final (CVCVC̲), 6) One syllable word-final (CVC̲).

The speech-language pathologist, clinical audiologist, child development specialist, and kindergarten and primary school teachers were trained to ensure the consistency of the test's application. The test was applied through visits at the children's homes, kindergartens, and primary schools.

Each child was individually assessed. The interviewer and the child were seated side-by-side around a table in a quiet room. Direction was 'Say', such as 'Say top'. If a child failed to express a consonant in the repeated-word task correctly, he/she would be allowed for two or three extra attempts. The word expressed by the child was recorded 'as is'. If the sound being tested existed within the expression the child mimicked, it would be accepted as acquired by the child. Incorrect expression of the word would be ignored. For example, when testing the sound of 'p'; if he/she said 'bop' instead of 'top', the sound 'p' would be accepted as correctly expressed by the child. As a result, 1 point was given for correct expression of the testing sound in its own position within the word, and 0 otherwise. Articulation mistakes (omission, distortion, substitution, addition and/or incorrect sequencing of speech sounds) were ignored. The only thing that was taken into consideration was the correct expression of the testing sound.

The criteria for 'acquiring' and 'completing development' of speech sounds among 2- to 7-year-old children were as follows: the mean percentage of the expressed age-appropriate words in the six positions was determined. The percentages were between the ranges 0.25–0.74, 0.75–0.89, and 0.90–1.00. The age-appropriate words expressed by 75–89% of the children were accepted as 'acquired', whereas those expressed by 90% of the children were accepted as 'completed development'.

It was determined that children between 1 and 2 years of age acquired the sounds of/b, d∞,tʃ,d,g,ɣ,k,l,m,n,p,s,ʃ,t,j,z/, children at 3 years of age acquired the sounds of/h,f,v/, and children at 4 years of age acquired the sounds of/r,∞/. However, it was revealed that the development of all sounds was being completed when the children were 5 or 6 years old. Speech sounds acquisition times of Turkish children is given on Table 1 [16].

In the present study, each child's speech sounds development was assessed by SSDT [16]. There was delay/disorder in more than one sound.

4.3. Random gap detection test (RGDT) [12]

The RGTD is a test of temporal processing (auditory timing) ability. Disorders of auditory timing are related to disorders of auditory discrimination, reading and language. Stimulus pairs with 0–40 ms gaps are presented. Individual identifies when one or two tones are heard. Normal gap detection occurs at 20 ms or less.

The auditory gap detection threshold of tones and white noise (clicks) is obtained by having the subject identify

Table 1
Speech sounds acquisition times of Turkish children [16].

%75 acquisition of speech sounds Child's Age Level (years)					%90 completed speech sounds Child's Age Level (years)				
2	3	4	5	6	2	3	4	5	6
b							b		
d∞							d∞		
tʃ							tʃ		
d							d		
g							f		
ɣ[a]							g		
k							ɣ[a]		
l							h		
m							k		
n							l		
p							m		
s							n		
ʃ							p		
t							s		
j							ʃ		
z							t		
							j		
	h							v	
	f							r	
	v								z
		r							∞
		∞							

[a] The phoneme/ɣ/indicate/ğ/), usually referred to as *yumuşak g* ('soft g') [16].

when signal pairs are separated in time from 0 to 40 ms. The major improvement in the signal presentation during the RGDT is that the gap interval is randomly assigned, and therefore unpredictable to the subject. The test includes stimuli at four frequencies (500, 1000, 2000, and 4000 Hz) and white noise clicks of 50 ms duration. A practice session is presented with tone pairs at 1000 Hz.

In Random gap detection test example of inter-stimulus interval (gap), according to the order of presentation in ms is: 20-2-40-5-10-25-15-0-30 [12].

4.3.1. Description of the stimuli

Each stimulus is composed of a pair of tone pulses. Each pulse has duration of 17 ms, including a 1 ms rise-falltime. The silent interval between the two pulses varies from 50 to 300 ms. The test includes four frequencies: 500, 100, 2000, and 4000 Hz.

4.3.2. Scores reported

- Gap detection thresholds (GDTs) were reported for each frequency tested; 500, 100, 2000, and 4000 Hz. Identified Lowest Gap was detected for each of the frequencies 500–4000 Hz.
- The composite gap detection threshold (CGDT) was the average of results reported across the four test frequencies of 500–4000 Hz.

Normal GDT was considered to be between 2 and 20 millisecond (ms) [12].

When a subject failed the RGDT and gap detection threshold exceeding 40 ms, the RGDT-expanded was administered. Test results indicated that any subject with RGDT thresholds greater that 20 ms was likely to have temporal processing deficits that interfere with normal speech perception, and phoneme recognition [12]

4.3.3. The RGDT-expanded test (RGDT-EXP) [12]

RGDT-EXP was intended for individuals whose gap detection threshold exceeding 40 ms. This test began at time intervals longer than those measured by the standard RGDT, and included time intervals between 50 and 300 ms. The test was administered in the same manner as the standard RGDT. Individuals who required this test to establish a gap detection threshold have already demonstrated abnormal temporal processing abilities. The single purpose was to determine the time interval in which their gap detection thresholds existed.

4.4. Administration procedures

The stimuli presented through an audiometer, earphones connected directly to CD player. The signal was presented binaurally at the comfortable listening level according to child (55 dB between 65 dB). The test took approximately 10 min to administer, including instructions and practice. Interpretation was made by averaging the gap detection threshold for all tonal stimuli and comparing the results to normative data that was currently available for children over 5 years old.

4.5. Child's response

All of children had to respond verbally or hold up one finger or two fingers whether he/she heard one or two tones. In healthy children without hearing loss, normal value of gap detection threshold was <20 ms [12].

4.6. Statistical analysis

Statistical packet for SPSS (Version 9.0) was used for statistical evaluation. At each frequency (500–4000 Hz) of RGDT, the difference between GDTs; and CGDTs were analyzed by ''Mann–Whitney *U* Test''.

p value < 0.05 was considered as statistically significant.

5. Results

In the study group, language development levels were normal for their chronological age (Table 2); whereas, by Speech Sound Development Test (SSDT) [16], there was delay/disorder in more than one sounds compared to the normal development process and speech sounds acquisition times. SSDT results of the study group were demonstrated on Table 2.

Minimum detectable gap (Gap Detection Thresholds) with RGDT/RGDT-EXP Tests at 500–4000 Hz; and

Table 2
Language development levels; and speech sounds development test results of the study group.

Case No	Age	Language development levels		Speech sounds development test results[c]
		Receptive language	Expressive language	
Case 1[a] (Male)	5 years	60–65 months	60–65 months	/→/,/tʃ/,/s/,/ʃ/,/t/,/d/,/l/
Case 2[a] (Male)	6 years	72–77 months	60–65 months	/v/,/r/
Case 3[a] (Female)	5 years	66–71 months	60–65 months	/h/,/f/,/v/
Case 4[a] (Female)	5 years	66–71 months	66–71 months	/→/,/tʃ/,/ʃ/
Case 5[a] (Male)	6 years	72–77 months	72–77 months	/tʃ/,/ʃ/,/r/,/l/
Case 6[b] (Male)	9 years	CELF-screening:passed	CELF-screening:passed	/r/,/l/
Case 7[a] (Female)	6 years	78–83 months	72–77 months	/l/,/r/,/→/,/l/
Case 8[a] (Male)	6 years	72–77 months	72–77 months	/s/,/ʃ/,/∞/, tʃ/
Case 9[b] (Male)	7 years	CELF-screning:passed	CELF-screning:passed	/z/,/∞/,/v/
Case 10[b] (Female)	7 years	CELF-screening:passed	CELF-screening:passed	/z/,/∞/,/l/,/ʃ/
Case 11[a] (Male)	6 years	78–83 months	72–77 months	/k/,/g/,/tʃ/,/s/
Case 12[a] (Male)	6 years	72–77 months	72–77 months	/r/,/l/,/v/

[a] Language development levels were evaluated by Preschool Language Scale-4 test [13].
[b] Language development levels were evaluated by Clinical evaluation of language fundamentals, fourth edition (CELF-4) [14,15].
[c] The delayed/disordered sounds of the children in the study group.

Composite Gap Detection Thresholds for each child of the control and study (PLD) groups were shown on Table 3 [10]. In the study group, if the subjects failed the RGDT at any of the frequencies of 500–4000 Hz and gap detection threshold exceeding 40 ms; therefore, the RGDT-expanded was administered. In control group, all children performed the RGDT (See on Table 3) [10].

In the study group, some of the GDTs were over 50 ms at 500–4000 Hz; and CGDTs were over 50 ms for all children included into the study group with PLD, except child 5, 6, 8 and 12. In control group, except child 9 (GDTs were 25 ms at 2000 and 4000 Hz); and child 10 (GDT was 25 ms at 500 Hz); GDTs were all normal limits for 500–4000 Hz for all children included into the study as control group [10].

Table 3
Minimum detectable gap (Gap Detection Threshold), identified by RGDT/RGDT-EXP Tests at 500–4000 Hz for each child of the control and study groups [10].

	Age	Minimum detectable gap (GDT) results in each of the Frequencies (ms)				The composite gap detection threshold (ms)[b]
		500 Hz	1000 Hz	2000 Hz	4000 Hz	
	Control group (RGDT Results) [10]					
Child 1 (Male)	6 years	20.00	5.00	0.00	15.00	10.00 ± 9.12
Child 2 (Male)	12 years	0.00	15.00	15.00	15.00	11.25 ± 7.50
Child 3 (Female)	6 years	0.00	0.00	0.00	0.00	0.00 ± 0.00
Child 4 (Female)	11 years	0.00	5.00	15.00	2.00	5.50 ± 6.65
Child 5 (Female)	11 years	10.00	15.00	2.00	15.00	10.50 ± 6.13
Child 6 (Male)	12 years	10.00	5.00	10.00	5.00	7.50 ± 2.88
Child 7 (Male)	7 years	20.00	20.00	20.00	20.00	20.00 ± 0.00
Child 8 (Female)	13 years	0.00	0.00	0.00	0.00	0.00 ± 0.00
Child 9 (Female)	9 years	20.00	20.00	25.00	25.00	22.50 ± 2.88
Child 10 (Male)	7 years	25.00	15.00	10.00	15.00	16.25 ± 6.29
		Study group (RGDT and RGDT-EXP Test results)				The composite gap detection threshold (ms)[b]
Case 1 (Male)	5 years	40.00	300.00[a]	25.00	30.00	98.75 ± 134.11
Case 2 (Male)	6 years	40.00	50.00[a]	30.00	150.00[a]	67.50 ± 55.60
Case 3 (Female)	5 years	300.00[a]	300.00[a]	300.00[a]	300.00[a]	300.00 ± 0.00
Case 4 (Female)	5 years	200.00[a]	20.00	20.00	150.00[a]	97.50 ± 91.78
Case 5 (Male)	6 years	25.00	40.00	15.00	40.00	30.00 ± 12.24
Case 6 (Male)	9 years	15.00	20.00	15.00	15.00	16.25 ± 2.50
Case 7 (Female)	6 years	150.00[a]	300.00[a]	300.00[a]	300.00[a]	262.50 ± 75.00
Case 8 (Male)	6 years	15.00	25.00	50.00[a]	30.00	30.00 ± 14.71
Case 9 (Male)	7 years	40.00	40.00	250.00[a]	250.00[a]	145.00 ± 121.24
Case 10 (Female)	7 years	40.00	40.00	200.00[a]	200.00[a]	120.00 ± 92.37
Case 11 (Male)	6 years	150.00[a]	150.00[a]	50.00[a]	50.00[a]	100.00 ± 57.73
Case 12 (Male)	6 years	20.00	40.00	30.00	25.00	28.75 ± 8.53

[a] In the study group, subjects failed the RGDT at that frequency (500–4000 Hz) and gap detection threshold exceeded 40 ms. Therefore, the RGDT-expanded was administered.
[b] The composite gap detection threshold is the average of results reported across the four test frequencies (500–4000 kHz).

CGDTs were all in normal limits for the control group, except child 9 (CGDT were 22.50, slightly higher than normal limits).

Mean of Minimum detectable gap (GDT) at 500–4000 Hz with RGDT/RGDT-EXP Tests; and the composite gap detection thresholds in the study (PLD) and control groups were demonstrated on Table 4, Fig. 1 [10]. In the study group with PLD, mean of the GDTs were all over the normal limits; and in control group, mean of GDTs were all in normal limits. The difference between the mean GDTs of the study group were significantly higher than the control groups at all frequencies of 500 Hz ($p = 0.001$), 1000 Hz ($p = 0.000$), 2000 Hz ($p = 0.001$) and 4000 Hz ($p = 0.000$) by Mann–Whitney U test.

In PLD group, CGDT (103.53 ± 11.63 ms) was significantly higher than that of the control group, (10.35 ± 0.65 ms) ($p = 0.021$).

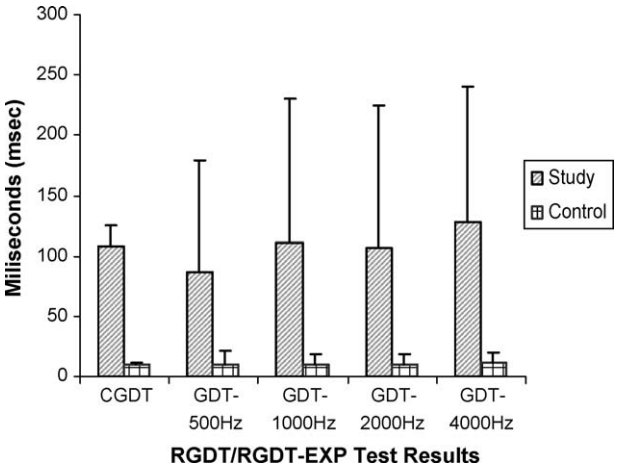

Fig. 1. Mean of minimum detectable gap (GDT) at 500–4000 Hz; and the composite gap detection thresholds (CGDTs) by RGDT/RGDT-EXP Tests in the study (PLD) and control groups [10]. Deep note: 500 Hz ($p = 0.001$), 1000 Hz ($p = 0.000$), 2000 Hz ($p = 0.001$), 4000 Hz ($p = 0.000$), GDT; and CGDT values ($p = 0.021$) of the study group were significantly higher than those of the control group by Mann–Whitney U Test.

6. Discussion

Language development is the process by which children come to understand and communicate language during early childhood. It reflects the growth and maturation of the brain. From birth up to the age of five, children develop language at a very rapid pace. After the age of five it becomes much more difficult for most children to learn language. In general girls develop language at a faster rate than boys. Receptive language usually develops faster than expressive language [18].

Temporal processing is very important for us to be able to understand speech in quiet and in background noise, degraded speech, since speech stimuli and other background sounds vary over time. It refers to the lower limits to the ability of the human auditory system to resolve time. Gap detection is a commonly used measure of Temporal processing [19]. One explanation for this is poor temporal processing, was difficulty in separating brief or rapidly presented sounds [20].Speech sound and language delay in Early Childhood (SSLDEC) can be characterized by poor speech understanding which is often associated with learning disabilities, speech disorders or language disorders. Clinical manifestations can be included difficulty in listening in the presence of background noise, difficulty in following oral instructions and difficulty in understanding unexpectedly introduced rapid or unclear speech. These performances were able to determine the Filtered Words (FW) subtest (temporally degraded speech) which enabled the examiner to assess a child's ability to understand distorted speech [21,22]. The Auditory Figure-Ground (AFG) [21,22] subtest enabled the examiner to assess a child's ability to understand speech in the presence of background noise. Random gap detection test (RGDT) [12] is a test of temporal processing (auditory timing) ability. It is important to determine which children might benefit from intervention and how treatment may alter their speech processing in everyday listening [12].

In our study, we found that the temporal processing (shown in 500–4000 Hz lowest gap detection) was delayed in children with PLD and current speech sound delay, compared to children with normal speech sound and language development levels. This finding shows that temporal processing delay had been present in these

Table 4
Mean of minimum detectable gap (GDT) at 500–4000 Hz; and the composite gap detection thresholds (CGDTs) by RGDT/RGDT-EXP Tests in the study and control groups [10].

Frequencies	Groups								p^*
	Study group				Control group [10]				
	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	
500 Hz	86.25	92.24	15.00	300.00	10.50	10.12	0.00	25.00	0.001
1000 Hz	110.41	119.28	20.00	300.00	10.00	7.81	0.00	20.00	0.000
2000 Hz	107.08	118.00	15.00	300.00	9.70	9.05	0.00	25.00	0.001
4000 Hz	128.33	111.44	15.00	300.00	11.20	8.81	0.00	25.00	0.000
CGDT	108.01	17.25	86.25	128.33	10.35	0.65	9.70	11.20	0.021

* p value shows the results of Mann–Whitney U test.

children at the speech sounds and language learning stages in childhood. When day grown, there was no language delay; and only one or more speech sounds delay. But probably the effects of previous language delay were going on until the current time. It may be said that temporal processing delay in language and speech sounds' learned early childhood, may cause language and speech sounds development delay in following years. This temporal processing delay especially occurs when signals comes in brief duration and presented at rapid rates.

Our results are similar to other studies in the literature. Auditory temporal processing and speech perception were measured for three children with phonological disorders and three age-matched children with typical development (TD). Results showed that temporal processing, especially in gap detection, was significantly worse for phonologically disordered children than typical developing children [23]. Some studies showed that there was a significant relationship between discrimination and production for some speech sounds, but no relationship for other speech sounds. Moreover, many recent studies have revealed the relationship between speech perception and phonological awareness for both children with typical development and children with speech or language disorders [24,25]. For example, Nittrouer [26] measured temporal processing, such as gap detection, and speech perception including discrimination of/d/vs./t/and/se/vs./ste/for schoolaged children with TD and children with language impairment.

In our study, these children were observed during training period, at least 1 year. According to our observation, these children had difficulty in perception of speech sounds due to temporal processing delay in early childhood, even though there was not any language learning difficulty. As a result, receptive language development delay was seen parallel to the speech sounds perception delay. Another important issue in our study was the effect of temporal processing delay in early childhood seen as continued to this day.

In our study, minimum detectable gaps (Gap Detection Thresholds) of the children with PLD in RGDT and RGDT-EXP were inconsistent in different frequencies of the children. For example, in Case 9 of the study group (See on Table 3), Gap detection thresholds were 40 ms at 500 Hz, and 250 ms at 4000 Hz. This discrepancy was also seen in children's daily lives. Their speech sounds were sometimes heard as clear; and sometimes are heard as distorted. These distortions were often not fixed; and variable.

This condition varied according to receive speech sounds in speech clearly or not. For example, some sounds were heard as distorted; and some sounds were heard as clear. As the sounds were processed in the way of how they were received by the children; these variations affect both development of speech sound and receptive language. Our results showed that this situation continued to this day. For example, phonemic discrimination problems, resulting in difficulty in learning new words and poor phonological awareness were observed. These findings and observations suggested timing deficits or delay in rapid auditory processing. Word recognition could be as fast as determined experimentally (_200 ms of cortical processing) [27].

Nittrouer's study [26] demonstrated that children with phonological disorder (PD) at preschool age have delayed development of auditory processing and then may develop their auditory perception to a typical level at their school age (8–10 years). In her study, there was no special difficulty for children with language impairment in recalling rapidly presented non-speech stimuli and in their phonetic decisions compared to their [children with typical developing (TD)] peers.

According to our opinion, in the RGDT and RGDT-EXP, sound stimuli are presented with a rapid speed. The main reason for the delay in speech sounds and language development is especially difficulty in receiving rapidly presented non-speech and speech stimuli because sound stimuli come to the ears rapidly in daily life. Nobody speaks slowly or gives pauses during the speech. Speech has a certain speed. Receiving daily speech, perception and discrimination immediately are essential for speech sounds and language development. Because speech sounds are distinguished and recognized in second differences. For example,/l and/r/sounds (ka<u>l</u>, ka<u>r</u>) have similar wavelengths. Child must recognize and distinguish the speech sound signal in seconds [28]. If he cannot recognize and distinguish, he would use/l/sound instead of/r/because of not hearing and understanding the sound clearly. Therefore, both development of speech sounds and understanding the speech, including these sounds are delayed.

Perception the speech sounds and language in a certain speed and temporally degraded speech programmes should be incorporated into the training programme, can prevent delays. Because heard sounds in ongoing speech are evaluated in 1 s and transferred to auditory pathways to be processed [29]. It was reported that maximum perception time of auditory signals is approximately 250 ms; and the first 100–250 ms is very critical to recognize the stimuli [30].

In conclusion, the children with PLD have difficulties in perception of speech sounds at a certain rate, even they have not language learning difficulties. Therefore, difficulty in distinguishing of speech sounds may cause especially receptive language development delay.

Conflict of interest

The authors declare that there is no conflict of interest.

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