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Original Article

Statistical Learning in Late Talkers and Normal Peers

Abstract

Background: Late talkers (LTs) are children under three with poor vocabularies and no developmental problems. Statistical learning (SL) is defined as processing or learning patterns of environmental stimuli, for example, spoken language, music, or motor, that will unfold in time. We hypothesize if some LTs outgrow as developmental language disorder, they might be identified using SL tasks at the onset. We aimed to find any correlation between language measures and SL outcomes in LTs and normal children (NC). **Materials and Methods:** Sixteen pairs of LTs and NCs were recruited using a convenient sampling method from day-care centers and speech therapy clinics of the Comprehensive Center for Child Development in Isfahan city, Iran. Visual sequences presented using Habit software version 2.2.4. Children's eye movements to visual sequences were monitored, and their reaction times and the number of anticipatory looks were analyzed offline. The language measures were determined in the free-play context. **Results:** Results indicated no significant correlation between SL and language measures and no difference observed in SL between the groups ($P = 0.73$). **Conclusions:** The results may refer to no overt correlation between SL and delayed overall linguistic measures along with inadequate samples, children's fatigue, or insufficiency of the visual task in presenting SL.

Keywords: *Developmental language disorder, language development, late talkers, specific language impairment, statistical learning, visual sequence learning*

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Introduction

Late talkers (LTs) are children under 3 years old with poor vocabulary in the absence of any developmental problems.[1-3] Most of these children move into the normal range of language skills by preschool;[2,4] however, about one-third of LTs continue with their weaknesses and may develop as developmental language disorder (DLD) (in this study, we considered DLD instead of specific language impairment).[1,5] DLD is a neurodevelopmental disorder with impairments in all aspects of language.[6] Although these children have difficulty acquiring and using language skills,[7] they have no developmental impairments.[6] Moreover, it is argued that children with DLD have deficits with the procedural memory system, which underpin the acquisition of language grammar.[6,8] A clinical marker in these children is learning difficulties in morphosyntactic and morphological rules.[9]

The main origin of difficulties in DLD has not been recognized, yet;[9,10] therefore, a variety of theories keeps emerging. Recent studies have suggested statistical learning (SL) deficits in children with DLD, meaning that the linguistic inputs are not captured and processed in a systematic and organized way within the child's linguistic processing system.[6,7,9,11]

SL is defined as the ability to process or learn patterns of environmental stimuli such as spoken language, music, or one's motor action, which unfolds in time and usually occur unconsciously.[12-14] It is assumed that early performance on SL tasks could be used for predicting language outcomes from a very young age.[15] SL is considered an important mechanism for the acquisition of spoken language in recent studies.[14] Moreover, studies on normal children (NC) have indicated that there is direct correlation between SL and language acquisition.[16] Visual sequence learning (VSL) (VSL is one of SL tasks, it is explained in detail in method section) in 6 months old as well as 8½ months old infants showed a relation between SL and

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vocabulary acquisition.[6,13,17] Moreover, studies indicated not only SL is directly related to the acquisition of syntax[18] but also they reported relations between individual differences in visual SL and syntax acquisition.[16] Although SL studies conducted on different clinical populations such as autism spectrum disorder (ASD),[6,19] children with hearing impairment[14,20] and dyslexia,[21] most of them have been focused on DLD. These studies have shown the poor performance of children with DLD on SL tasks. Furthermore, they found that children with DLDs' phonological and syntactic problems may be related to impaired SL; therefore, SL plays an essential role in learning rule-based skills, such as grammar (morphology and syntax) and phonology.[6,7,22] Therefore, one explanation for children with DLD's difficulties might be deficits in SL ability.[9]

Although children with DLD have a history of delay in speaking, there is no evidence that DLD might be detected in all LTs. Moreover, predicting whether LTs continue their delay is extremely difficult for professionals.[1,5] Despite the studies on SL deficits in DLD and the findings that document one-third of LTs show similar language profile as DLDs, there is no evidence on LT's SL abilities. Hence, this study investigated the SL ability of normal and LT toddlers with the VSL task. Then, language analysis was conducted using parent reports and language sample analysis to find out whether their general language measures, in essence, mean length of utterance (MLU), is correlated with SL ability.

This study aimed to find the SL outcomes of LTs compared with normally developing language peers and whether there is any correlation between word combination measures and VSL. It is hypothesized that children with DLD have late emergence of two-word combination that can be detected from early years of language development by measuring SL ability.

Materials and Methods

Participants

Sixteen pairs of monolingual Persian-speaking normal and late-talking children aged between 24 and 30 months, with no history of developmental disorder were recruited using a convenient sampling method. NC were recruited from two day-care centers, and LTs were recruited from the waiting list of children who were referred personally or by pediatricians to the speech therapy clinic of the Comprehensive Center for Child Development in Isfahan city, Iran. The first researcher selected these children to test them before receiving language intervention. All children had normal developmental profiles according to the Persian edition of the second version of ages and stages questionnaire (ASQ-2)[23,24] except for the LT children whose scores in communication subscale of ASQ-Π was < 1.5 standard deviation (SD) below the mean. Furthermore, children were categorized as having normally developed language if they had at least 51 words according to MacArthur-Bates Communicative Development Inventory (MCDI-Persian)[25] with >10 two-word combinations; otherwise, they were classified as being an LT. The children were excluded if they had no cooperation during the tasks or the parents decided to withdraw from the study. Children in both groups were matched based on sex, age, and birth rank. The participants' characteristics are shown in Table 1.

Procedure

The data collection included two parts of (1) conducting SL task and (2) parent-child free play context. They took time for half an hour totally and took place at the virtual education center of Isfahan University of Medical Sciences, Iran.

The waiting list and the registered children at the day-care centers were screened to find the children who met the optimal age of 24–30 months. The children's medical profiles were carefully screened to include children with no history of developmental concerns. Then, the researcher called and asked parents for attending the child language laboratory. Before starting, they were asked to sign the informed consent. All parents completed the ASQ-Π-Persian and MCDI-Persian before the experiments. Then, the parent and the child were guided to the experiment room, and all the parents' questions were answered.

Prior to the main study, a pilot study was conducted on four children to address technical errors. Based on the results of the pilot study, low light was used during part one and collar microphone was replaced by a CS-50 Stereo Microphone. Furthermore, the parents were allowed to show accompany with their children during play activity. In contrast, they were noticed not to point the monitors or not to influence where the child is looking while doing SL task. They were also provided with a list of facilitative questions to elicit more expressive language from their children during parent-child free play.

Visual sequence learning task

The VSL task was conducted in an acoustic and dimly lit room, about 30 m^2. The mother and child had 5-min time

Table 1: Descriptive statistics of language measures in the two groups of the study

Variables	Mean (SD)	
	TD (*n*=16, 8 girls)	LT (*n*=16, 5 girls)
Age	27.62 (1.58)	26.93 (2.08)
Linguistic measures		
MLUw	2.06 (0.73)	1.16 (0.16)
MLUm	2.89 (1.26)	1.21 (0.17)

TD=Typically developing, LT=Late talker, MLUw=Mean length of utterance in words, MLUm=Mean length of utterance in morpheme, SD=Standard deviation

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to get familiar with the environment. Then, the children were tested while seated on their parent's lap in front of three LG LED 19-inch monitors, one of which was at the center, and others were on either sidewall [Figure 1]. The angle between monitors was set approximately at 57°. The monitors were connected to an Asus personal computer (Core-i7 with 16G RAM and GPU graphic card, three HDMI inputs, one AVG, and one DBI inputs) by three HDMI cables in the control room. A Samsung LED 19-inch monitor was connected to this PC and separated control window from stimuli windows using Habit [Computer Program], 2.2.4. version, 2019.[26] All monitors had HDMI, AVG, and DBI inputs. A Logitech webcam was placed on top of the center monitor, captured a close-up of the child's face, and showed on a laptop's monitor at the control room. We used Bandicam [Computer Program], 4.2.1.1454 Version, 2019 to record experiment sessions; therefore, the examiner was able to monitor the child's reactions to each stimulus and control stimulus presentation using the Habit software run on a Windows 10 desktop computer.[26]

Visual stimuli were selected from Shafto *et al*. study stimuli, which were 12 two-dimensional images of colorful geometric shapes that were set out in the four-object set.[13] They were like short videos and looming in and out. Dynamic shapes made children maintain on images more adequately.[13] Furthermore, each stimulus was zoomed in and out up to five times during one presentation that lasted maximum of 10 s. Visual stimuli that we used in this study are shown in Figure 2.

This task composed of three phases of (1) pretest (3 trials), (2) learning phase or phase one (12 trials), and (3) test phase or phase two (12 trials). There were no two trials in a row in the same direction. Children get familiar with the task in the pretest phase with a sequence of the center, left, and right. A looming yellow duck was displayed on each monitor. This phase was not included in statistical analysis. The learning phase composed of a sequence (left, center, right), which repeated four times, L-C-R/L-C-R/L-C-R/L-C-R. The stimuli of this phase were different from the test phase. Left, center and right monitors showed star, crescent, and check, respectively. The test phase consisted of the sequence as the same as the learning phase (left, center, right) with another object set. Left, center, and right monitors displayed, triangle, ellipse, and flower, respectively.

These phases were executed without any pause and lasted <4 min to show how fast children followed the correct location of each stimulus. The examiner monitored the child's eyes and head movements to activate presenting the next stimulus by pressing a key. There was a fixed interval of 1100 msec. between the trials by showing a dark screen (for example, L: Flower, 1100, C: Ellipse, 1100, R: Triangle, etc.).

The children were told that "we are going to watch a TV program. Look at the monitors. It will start soon." The mothers were asked neither to point to any monitor nor to show gestures guiding the child. The examiner monitored the children's eye and head movements toward the stimuli from the control room. Children's eye movements were analyzed offline using video recordings at 30 frame/s and were manually coded frame by frame (left, center, and right looks) using VideoPad [Computer Program], 6.30 Version, 2018. Although eye movements were our first priority for coding, head movements were also used as complementary data for a child's preference. Codes included as follows: A fake look assigned when the child did not look, the onset of stimulus presentation, reactionary look, and anticipatory look (AL). Although AL (correct or incorrect) occurred before the onset of the trial, the correct looks after the onset of the trial were considered as reactionary looks, too. Reaction time (RT) in each trial was referred to the time between the onset of stimulus presentation and the first correct look toward the correct monitor by off-line checking of the recorded videos from

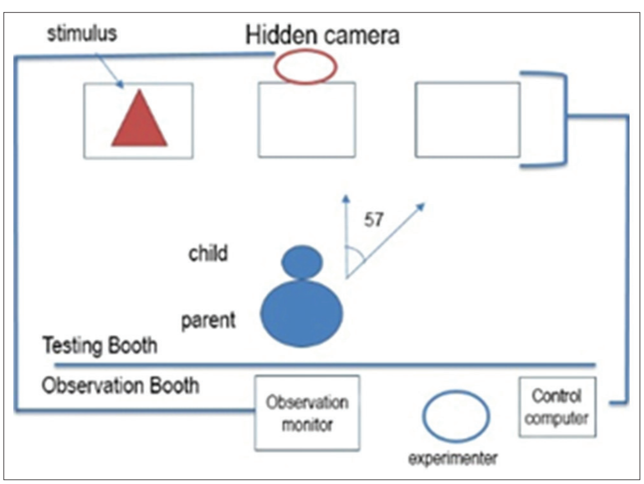

Figure 1: This figure displays the schematic image of the acoustic room used to run a visual sequence learning task. The experimenter monitored the child's eyes and control stimuli presentation

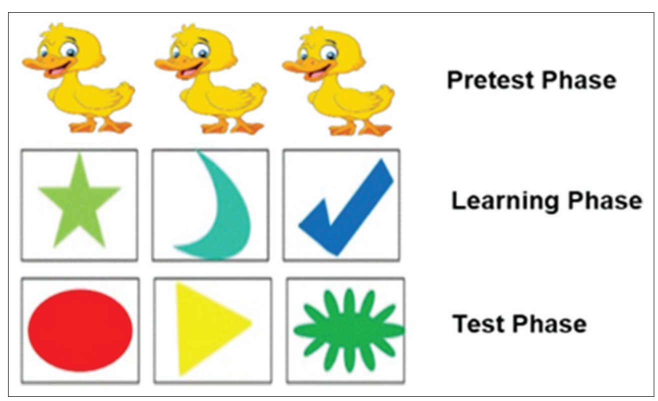

Figure 2: Stimuli used for each phase. Pretest phase; a yellow duck displayed in a different presentation pattern with two other phases (center, left, right), learning phase; star, crescent, and check; test phase; circle, triangle, and flower presented in the same pattern

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the sessions, frame by frame.[13] If the child attempted to anticipate the correct location, RT would be negative (in essence RT = Reactionary look time minus the onset of trial time). The median RT of 12 RTs of each phase was considered the main measure of the experiment to exclude the effect of outlier data.[13] Therefore, the participants had two median reaction times (mRT) for each phases of one and two. RT difference scores (in essence mRT P1_ mRT P2) were calculated to document whether the child learned the sequence, in essence of a drop. Consequently, a positive score documents that the child is a "learner." Moreover, the increasing number of correct ALs from phase one to phase two was considered as another measure of learning the sequence. Inter-rater reliability was calculated for 25% of data coding for ALs, reaction looks, and stimulus time, which showed agreements of 0.89, 1.00, and 0.99, respectively.

Parent-child free play and language sample analysis

The second part of the experiment included a 20-min parent-child free play to extract a natural language sample from the child. A furnished doll's house with four members of the doll family, two vehicles and a set of familiar animals (for example cat, dog, chicken, etc.) were used to elicit the language. We requested mothers to ask open-ended questions and follow the child's games to elicit more utterances. The sampling followed the conventions of the Persian Transcription Convention Protocol (PTCP)[27] using a CS-50 Stereo Microphone. The first 20 min of each sample were transcribed. Then, the main linguistic measures included the MLU in words and morphemes (MLUw, MLUm) were calculated by the Systematic Analysis of Language Transcripts software [Computer Program], SALT12 Research Version 2008. Correlation between children's VSL scores and their language sample measures was analyzed using the Spearmen test of correlation.

Results

The analysis examined whether the LTs and typically developed (TD) groups differed on the VSL task (which measured SL) and if there is any correlation between this task and linguistic measures.

Did the results show any sequence learning?

Children, who showed a descending pattern in RT scores from phase one to phase two or an increasing number of correct ALs were considered as a learner of sequence. Although the Mann–Whitney test showed no statistical significant difference between the two groups in terms of RT_{P1}-RT_{P2} ($P = 0.73$) and AL_{P1}-AL_{P2} ($P = 0.24$), the means and SDs of RT difference scores, indicated the maximum performance of LTs did not meet the minimum TD's performance.

Then, Wilcoxon test results showed RT score difference ($M = 3.75$, $P = 0.01$) and AL difference ($M = 5.78$, $P = 0.01$) were significant in TD and LT groups, respectively. Descriptive statistics of VSL measures are shown in Table 2.

Learner and nonlearner groups

According to the results, 11 children were classified as learners, which means that they showed decreased RT from phase one to phase two. Moreover, four children (TD = 3, LT = 1) showed an increasing trend in ALs. In fact, between the two groups, there were just two children who showed both learning criteria. Between groups analysis indicated significant ALs difference from phase one to phase two (t_{32}= −2.36, df = 25.51, $P = 0.02$, confidence interval [$CI_{95\%}$] = −2.68–−0.18) and RTs in phase two ($P = 0.01$, Mann–Whitney $Z = -2.50$) and RTs difference score ($P = 0.00$, Mann–Whitney $Z = -4.59$).

Within group analysis showed significant RTs difference in both learners ($P = 0.00$, Wilcoxon $Z = -2.94$) and nonlearners ($P = 0.00$, Wilcoxon $Z = -4.01$). Furthermore, paired *t*-test for ALs difference showed significant relation for nonlearners ($t_{21} = 3.85$, $P = 0.00$, df = 20, $CI_{95\%}$ =0.74–2.48).

Was there any correlation between visual sequence learning task performance and language measures?

We were interested in knowing whether there could be any relationship between VSL scores and linguistic measures in both groups. In the TD group, Spearman correlation did not display the statistically significant relationship between measures. In LT group, significant correlations were observed between RT in phase one and MLUw ($P = 0.004$, $r = -0.67$), MLUm ($P = 0.001$, $r = -0.74$). In both learner and nonlearner group, there was not a significant relation between MLUs and VSL scores.

Discussion

In this study, we aimed to start studying SL in Persian language and provide evidence from SL ability in late-talkers and relationships of SL with language skills. The preliminary results of the current study showed that there were no significant differences between LTs and typically developing children in the VSL task. However, there were some within-group differences and relationships between VSL scores and some morph-syntactic measures. In addition, comparing group learning performance suggested the best LTs' performance was lower than the least TDs' ones.

Learning the sequence

Congruent to Shafto *et al*. results,[13] children in this study did not learn the sequence as a group and had an upward trend in RT from phase one to phase two. However, contrary to that study, we did not have any children with no ALs in the phases; therefore, all the children were investigated in both RTs and ALs analysis. The within-group analysis

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Table 2: Descriptive statistics of visual sequence learning measures among two groups of the study

Measure	Median RT_{P1}		Median RT_{P2}		RT_{P1}-RT_{P2}		ALs in $_{P1}$		ALs in $_{P2}$		AL_{P1}-AL_{P2}	
	TD	LT	TD	LT	TD	LT	TD	LT	TD	LT	TD	LT
Mean (SD)	0.30 (0.16)	0.27 (0.12)	0.38 (0.17)	0.31 (0.14)	−0.08 (0.15)	−0.41 (0.17)	5.25 (2.29)	5.68 (2.62)	4.50 (1.96)	4.18 (2.42)	0.75 (1.84)	1.50 (1.89)
Range	0.69	0.40	0.69	0.50	0.52	0.83	8.00	9.00	6.00	8.00	6.00	7.00

n (TD=16, LT=16). VSL=Visual sequence learning, TD=Typically developing children, LT=Late talker, RT=Reaction time, ALs=Anticipatory looks, P1=Phase 1, P2=Phase 2, SD=Standard deviation

showed significant relation for RT difference score in TD and ALs difference in LT group, respectively.

Increasing RTs or decreasing ALs in phase two indicated nonlearning pattern; in fact, children did not learn the sequence. According to Shafto *et al*., one interpretation could be attributed to the children's fatigue.[13] Furthermore, some mothers commented that animated cartoon characters might help the children would have been more intrigued. According to children's natural language, not all inputs are interesting for them; therefore, using intrigued stimuli may have not enough reliability to present the children's individual differences although age-appropriate tasks are always recommended. On the other hand, language development in children does not necessarily include artificial reinforcement such as verbal or nonverbal reaction from the environment. The children receive positive reinforcement when they get what they want by using correct language in terms of semantics, morphology, and syntax. Therefore, it seems that the stimuli in SL tasks can be considered as the same as language components with no natural or artificial praises during the tasks.

Another interpretation refers to children's individual differences in processing and cognitive skills. The higher processing and cognitive skills, the better learning the sequences or language.[13] Although it is better to control these variables in future studies, it makes sample collection more difficult and time-consuming. Moreover, we do not know which LTs would outgrow as DLD, which is a result of the heterogeneity of this group of children. Therefore, the similar performance of both groups and the thing that most of them showed as nonlearners may lead to a condition, in which we see most of the TD children will outgrow as children with DLD similar to most of the children who were late talking. However, following children in a longitudinal study of at least 6 months would justify this hypothesis.

On the other hand, the low sensitivity of measurement tools might have affected the result. Actually, it refers to the sensitivity of both VSL in presenting SL abilities in children and tools for reporting or eliciting results. The higher sensitive tools such as eye-tracker reports, the more reliable the data. According to Arnon's study, in which they mentioned the reliability and stability of SL tasks for individual differences in children, children indicated learning as a group but all reliability measures were lower than norms. This finding increases concerns about using SL measures as reliable criteria or indicator of individual differences in children.[28]

Correlation between sequence learning and language measures

In the LT group, there was a significant relation between MLUs and RTs in phase one. However, neither nonlearners nor learners showed a significant relationship between language and VSL measures. In the study by Shafto *et al*., learner infants not only had better comprehension ability at the test time but also had a better gestural ability in the next 5 months. It supported a linear relationship between learning the sequence and vocabulary.[13]

SL studies suggested a relationship between SL ability and language development[13,16-18] and support domain-general accounts of language learning. Since, there was a relation between sequence learning, especially in a different modality (visual), and language development. Moreover, there are studies indicated SL deficits result in language problems.[6,13,22] However, SL studies on children with ASD showed the identical performance of these children with TD children.[6,19] It means that we cannot conclude that all developmental and language disorders have SL deficits.[29] Some other studies did not show SL deficits in children with DLD.[30,31] Jahangiri *et al*. mentioned the possibility of inadequate samples and insufficiency of the serial reaction time (SRT) task for interpreting their results. Gabriel *et al*. argued that children with DLD would learn the motor sequential information if the fine motor movement were kept at minimum. Moreover, a negative correlation between grammar knowledge and SRT measures were reported.

Conclusions

The current study provides primary evidence of SL ability in LTs and documented that these children did not illustrate SL deficit. Moreover, contrary to similar studies, this study did not support language measures and SL ability relationship. It may be because of small sample size, children heterogeneity, the sensitivity of measurement tools, and cognitive characteristics of children. Finally, it is indicated that we need more evidence about SL abilities with larger sample sizes and designing tasks with valid psychometric criteria. Future studies with more sensitive tools may help in faster identification of children at-risk of DLD.

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Recommendations

We suggested designing proper tasks for children, not only for representing SL abilities but also for considering children's attention limitation and their tiredness. For example, as we observed performance differences in each phase, the number and attractiveness of stimuli in phases may need to be considered.

For future studies, it is better to test children's attention in larger sample sizes. Furthermore, we could not match the groups in terms of caregivers' education due to time and fund limitations. It is suggested to consider this limitation in future studies. Follow-up studies and investigation of different aspects of language, especially rule-based ones may elicit valuable data. Within language variables, such as words and morphological items order should be considered for different languages.

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Conflicts of interest

There are no conflicts of interest.

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To,
The Editor

Covering Letter

Submission of Manuscript for publication

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in your journal.
On behalf of all the contributors I will act and guarantor and will correspond with the journal from this point onward.

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