Eye Tracking Based Assessment of Lexical Processing and Early Lexical Development in Very Preterm Children

Ståhlberg-Forsen, Eva Maria

2022-07

Ståhlberg-Forsen , E M , Latva , R , Leppänen , J , Lehtonen , L & Stolt , S 2022 , ' Eye Tracking Based Assessment of Lexical Processing and Early Lexical Development in Very Preterm Children ' , Early Human Development , vol. 170 , 105603 . https://doi.org/10.1016/j.earlhumdev.2022.10560

http://hdl.handle.net/10138/346094
https://doi.org/10.1016/j.earlhumdev.2022.105603

Early Human Development 170 (2022) 105603

Contents lists available at ScienceDirect

Early Human Development

journal homepage: www.elsevier.com/locate/earlhumdev

Eye tracking based assessment of lexical processing and early lexical development in very preterm children

Eva Ståhlberg-Forsén [a,*], Reija Latva [b,c], Jukka Leppänen [d], Liisa Lehtonen [d,e], Suvi Stolt [a]

[a] University of Helsinki, Helsinki, Finland
[b] Tampere University Hospital, Tampere, Finland
[c] Tampere University, Tampere, Finland
[d] University of Turku, Turku, Finland
[e] Turku University Hospital, Turku, Finland

ARTICLE INFO

Keywords:
Eye tracking
Lexical development
Lexical processing
Screening methods
Very preterm

ABSTRACT

Background: Associations between lexical processing and lexical development during the second year of life have been little studied in preterm children.
Aims: To evaluate associations between lexical processing at 18 months and lexical development between 12 and 18 months in very preterm children.
Study design: Correlational study.
Subjects: 25 Finnish-speaking children born <32 gestational weeks.
Outcome measures: Lexical processing (reaction time RT; correct looking time CLT) was measured with an eye tracking technology-based task at 18 months' corrected age. Lexical development was measured longitudinally at 12-, 15- and 18-months' corrected age using the following screening instruments: the short form version of the MacArthur Communicative Development Inventories and the Communication and Symbolic Behavior Scale: Infant-Toddler Checklist.
Results: The longer the RT of the child, the weaker expressive skills the child had at 12 and 15 months (correlations coefficient values −0.45 to −0.51). The more the child looked at the target image compared to the distractor (CLT), the stronger expressive skills the child had at 18 months (r = 0.45–0.52). A linear regression model with RT and gender as independent variables explained 33 % of the variance in lexical skills at 18 months. A model with CLT explained 40 % of expressive skills at 18 months.
Conclusions: Lexical processing at 18 months was associated with expressive lexical development in very preterm children. The results suggest eye tracking technology based methods may have utility in the assessment of early lexical growth in preterm children, although further research is needed to assess psychometric properties and predictive value of the method.

1. Introduction

Very preterm children, born <32 gestational weeks, are at risk of slower language processing [1], and slower lexical development [2,3] than full-term peers. Very preterm children, however, show considerable variability in language development and early identification of the children who need follow-up or support is challenging [4]. So far, studies evaluating very preterm children's lexical processing and associations between processing and lexical development during the first part of the second year of life have been scarce.

The development of speech perception starts prenatally [5] and it has been suggested that early speech perception is linked to later language abilities [6]. Auditory perceptual development proceeds from a general speech discrimination ability to a narrow ability to recognize the native phonological system, to segment auditory stimuli into words and, approximately by the end of the first year, to identify familiar words [7]. The speed and accuracy of lexical processing accelerates during the second year of life [8]. At this age, the lexicon also expands and the child can respond more rapidly to auditory stimuli [9]. In processing tasks, 18-month-old children can promptly look at the relevant image when

* Corresponding author at: Department of Psychology and Logopedics, Unit of Logopedics, Haartmaninkatu 3, PO Box 21, 00014 University of Helsinki, Finland.
E-mail addresses: eva.stahlberg-forsen@helsinki.fi (E. Ståhlberg-Forsén), reija.latva@pshp.fi (R. Latva), jukka.leppanen@utu.fi (J. Leppänen), liisa.lehtonen@utu.fi (L. Lehtonen), suvi.stolt@helsinki.fi (S. Stolt).

https://doi.org/10.1016/j.earlhumdev.2022.105603
Received 7 December 2021; Received in revised form 31 May 2022; Accepted 9 June 2022
Available online 13 June 2022

hearing only parts of the word [10]. Findings suggest that at least some preterm children have poorer or atypical performance in auditory perception [11], attention [12] and information processing [13,14] during the first year of life. Additionally, at preschool age they score lower than full-term controls in assignments for attention, processing speed and working memory [15]. Studies report slower language processing of preterm children at 18 months [1] and at 24 months [16], while other studies found no differences between preterm and full-term children's processing speed or accuracy at 18 months, when corrected age was applied [17].

The specific connection between early processing of linguistic items and lexical growth during the second year of life is not fully known [9]. In preterm children, language processing at 18 months predicts expressive lexicon at 30 months [1], receptive lexicon at 36 months [18] and language skills at 4.5 years [19]. However, information on the possible associations between early lexical processing and lexical development in very preterm children during the first part of the second year of life is currently lacking.

The looking-while-listening task, is a paradigm for investigating early processing [20]. In this paradigm, the child's eye movements are measured while the child watches images of different objects and hears speech that refers to one of them (e.g., "Where is the ball?"). The method may identify developing receptive skills that might not be noticed in everyday situations [9]. The method has been applied in studies utilizing eye tracking technology [21]. Primary variables include reaction time (RT), measured as the latency of first look at the referred target image, and proportion of correct looking time (CLT, accuracy), measured as the overall proportion of time looking at the target image out of the total looking time [9].

The time window used for analyzing RT and CLT in previous looking-while-listening tasks in young children has varied somewhat. Regarding RT, the time window has ranged from 200 to 2300 milliseconds (ms) from target word onset [22]. However, the upper cut off point in the looking-while-listening task has not been fully established and can vary from study to study [20]. CLT can be studied over a specific time window of interest [20], and in some studies on young infants, separate early (i.e. 300–1800 ms) and late (i.e. 1800–3300 ms) time windows have been used [23]. Furthermore, the time window for both reaction time and correct looking time has been extended in studies with different types of target words (e.g. longer time windows have been used with verbs or adjective-noun target phrases to permit the child time to combine the adjective with the noun [24]).

The first part of the second year is typically an active period in the child's lexical development, with individual variations in skill acquisition [25]. The receptive lexicon is developing rapidly [25,26] and the child starts using more complex gestures [27]. The word production is initially slow, with the first words emerging around 12 months, followed by accelerated word learning between 15 and 18 months [25,26]. Very preterm children have a smaller receptive lexicon at 12 and 15 months than full-term peers [3]. At 24 months, 20 % of very preterm children show delayed word production [2]. Early lexical skills are fundamental for later development of grammar and lexicon [28].

As there has been little research validating the tests of lexical processing as markers of early lexical acquisition in preterm children, and no studies exist in children acquiring Finnish, the main aim of this study was to investigate the associations between lexical processing at 18 months' corrected age (adjusted for degree of prematurity), and the lexical skills of very preterm children, acquiring Finnish, during the first part of the second year of life.

The research questions were:

1. Is there an association between lexical processing abilities (RT, CLT) of very preterm children measured at 18 months' corrected age, and receptive and/or expressive lexical development measured at 12-, 15- and 18-months' corrected age?
2. How much do lexical processing abilities (RT, CLT) at 18 months' corrected age explain of the variance in receptive/expressive lexical development at the same age when the effect of gender is taken into consideration?

2. Participants and methods

2.1. Participants

The present study is part of the APPLE (Auditory environment by Parents of Preterm infants; Language development and Eye movements) study, which investigates the impact of the language environment in the neonatal intensive care unit (NICU) on the development of very preterm children. Very preterm born (<32 weeks of gestation) children were recruited to the study from January 2017 to December 2020 in the NICU of Turku University Hospital, Finland. Infants with life-threatening conditions, major congenital anomalies, chromosome aberrations or syndromes were excluded. The Ethics Committee of the Hospital District of Southwest Finland has approved the study protocol. Informed consent was obtained from the participating families.

A total of 38 very preterm children, from primarily Finnish speaking families (≥70 % Finnish spoken at home), received parental consent to participate in the present study. Of those, the lexical processing data of 25 children (mean gestational age at birth = 28 weeks, SD = 2, min.–max. = 23–31; mean birth weight = 1222 g, SD = 431, min.–max. = 470–1860) could be collected at 18 months. The reasons for the lost data were: 6 children could not attend the assessment due to the COVID-19 epidemic, 2 children could not attend because of long distances to the hospital, 1 child could not be reached, 1 assessment could not be completed due to technical reasons and 2 children could not focus on the task. Furthermore, 1 child was excluded due to diagnosed cerebral palsy. Based on the medical background information of the children, obtained from the parents at 12 months' corrected age, no participant in the final sample of 25 children was reported to have major hearing, visual or developmental impairments. This information was missing for one child. Background characteristics of the children are presented in Table 1.

Table 1
Background characteristics of participants ($N = 25$). Numbers (n) and percentages (%) are presented. Percentages are calculated from the total number of participants.

Characteristics	n	%
Gender: male	12	48
Children developing as twins[a]	6	24
Small for gestational age (<−2 SD)	3	12
Bronchopulmonary Dysplasia at 36 weeks' corrected age[b]	9	36
Retinopathy of prematurity[c]	4	16
Intraventricular hemorrhage[d]	5	20
Need for hearing aids at 12 months	0	0
Maternal education[e]		
Basic	1	4
High school	6	24
Lower University	11	44
Higher University	6	24
Paternal education[f]		
Basic	1	4
High school	15	60
Lower University	3	12
Higher University	4	16

[a] 1 twin sibling diagnosed with cerebral palsy was excluded and 1 twin sibling from another family could not focus on the processing task.
[b] Mild: $n = 1$, moderate: $n = 5$, severe: $n = 3$.
[c] Stage 1: $n = 3$, stage 2: $n = 1$, stage 3–5: $n = 0$, data missing from 10 children.
[d] Grade I-II: $n = 5$, grade III-IV: $n = 0$.
[e] Data missing from 1 person.
[f] Data missing from 2 persons.

2.2. Methods

2.2.1. Eye tracking based lexical processing assessment

At 18 months' corrected age, the participants were invited to a lexical processing assessment, developed for this study based on the looking-while-listening procedure [8,9,17,20,29] and receptive lexical development of Finnish children [30]. In the processing task, the child's eye movements were measured with the Tobii X2-60 infrared eye tracker, which uses image sensors and processing algorithms to track the participant's point of gaze on a screen [31]. The target words were the Finnish words for 8 nouns (*silmä-eye, auto-car, kuppi-cup, kukka-flower, puu-tree, kuu-moon, avaimet-keys, leijona-lion*), 2 verbs (*hyppää-jump, nauraa-laugh*) and 1 adjective (*iso-big*). The words represent 3 levels of familiarity: easy words reported by the parents to be known by 80 %–99 % of 18-month-old typically developing Finnish children, moderately difficult words known by 60 %–80 % and difficult words known by <60 % [30]. A female native Finnish speaker presented the words in prerecorded phrases approximately 4 s long (“*Where is the car, where is it?*”), each word appearing three times as a target word and three times as a distracter. The visual stimuli were pairs of digital color images showing a target word-matching image and a non-matching distracter. The task was piloted with 4 children before the study phase.

During the assessments, which were administered in a hospital room, the child sat on the parent's lap in front of a computer screen watching a children's movie (distance approximately 60 cm from the screen). A read-out showing the child's distance from the screen (based on the eye tracking output) was used to detect the correct position. When the distance was correct, the assessment started with a 5-point eye tracker calibration. After the calibration, 2 practice trials and 5 test blocks were run. Before each trial, a small fixation stimulus (a cat animation) was presented in the screen center to standardize the gaze position at trial start. The trial started automatically when the child looked at the fixation stimulus or when a 1000 ms waiting period elapsed. The trial started with visible images, and after 2 s, the sound stimulus was presented. The images remained visible through the sound stimulus and approximately 1 s after. The test trials included 5 blocks, each block consisting of 6–7 trials. The images appeared in random order, but with the same target image only once in each block. Approximately 5 s long video clips were shown before the first trial, between the blocks and after the last trial, to maintain the child's interest and attention. The procedure lasted approximately 10 min.

2.2.2. Lexical development

Information on the very preterm children's lexical development was collected at 12 ($n = 22$), 15 ($n = 22$), and 18 months' corrected age ($n = 23$, and from all measure points: $n = 20$) using the following methods: the short form version of the MacArthur Communicative Development Inventories [32]; Finnish version (FinCDI-SF) [30] and the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist [33]; Finnish version (FinCSBS-ICT) [34]. Both methods are based on parental estimates of their child's language performance and have been validated and normed in Finnish [30,34].

The FinCDI-SF [30], an instrument for screening early lexicon, consists of an Infant form, for infants aged 9–18 months, and of a Toddler form, for children aged 18–24 months. The present study utilized the Infant form, a checklist of 89 words providing information on receptive and expressive lexical categories. The maximum score, for both categories, is 89 points (one word equals one point). The cut-off points of the Finnish norming group [30] for the 10th percentile values are, for the receptive lexicon: at 12 months 8 words, at 15 months 28 words and at 18 months 46 words, and these were used as cut-off points in the present study. The value for the expressive lexicon at 15 months is 1 word, and at 18 months 5 words. Values below these are defined as weak lexical skills [30]. At 12 months, a score of 0 expressive words is a typical performance.

The FinCSBS-ICT [34], a method for screening prelinguistic communication and language between 6 and 24 months. In the present study, the Symbolic (understanding of words, i.e. receptive words, and object use, max. 17 points) and the Speech (early vocalizations and word production, i.e. expressive words, max. 14 points) Composites of the method were used. The cut-off points (the 10th percentile values) of the Finnish norming sample [34], used in the present study, are 7, 10 and 13 points for the Symbolic Composite at 12, 15 and 18 months of age and 4, 6 and 9 points for the Speech Composite, respectively. Values below these indicate a risk of delayed communication or language development [34].

2.3. Data analysis

Two variables were derived from the lexical processing task, based on the primary measures used in previous research [9]: reaction time (RT) and correct looking time (CLT). RT was defined as the mean latency in ms from target word onset to the first look at the target image. According to the looking-while-listening procedure [20], trials where the gaze point was on the target image, upon target word presentation, were excluded from the analyses. The RT was measured within the 200–2800 ms time window from target word onset. The lower cut-off value was based on previous research [20]. The upper cut-off value was adjusted due to the phonetic characteristics of the Finnish language and to the target words used. In Finnish, diphthongs, long vowel sounds, and vowel-initial words are common, while consonant clusters are rare [35]. Thus, it is possible that Finnish words are also more challenging to auditorily discriminate than words with consonant clusters. In addition, Finnish words tend to be long [35], which may increase the time needed for word recognition. Moreover, the target words in the present task included 3 vowel initial words, 2 three-syllable-long words, 2 verbs and 1 adjective, which may require more time to process than the words used in previous tasks. Thus, the upper cut-off value was extended to ensure that the children had the time to auditorily discriminate and identify the target words.

CLT was defined as the mean proportion of time that the child was looking at the target image out of the total looking time, measured from both distracter and target initial trials. Two time windows were used for analysis of the CLT data (compare [23]). The early time window was measured from the same time window as for RT, and the late time window was measured 2800–6400 ms from target word onset. The different time windows were used to verify that all information derived from the whole task could be utilized.

RTs and CLTs were extracted from eye tracking data that had been filtered with a 117-ms median filter and in which the XY-coordinates from the two eyes had been merged by averaging (if both eyes returned a valid data point), or by using the data of one valid eye. Trials with missing gaze data for a continuous period lasting >250 ms were excluded. The preprocessing criteria were set a priori based on prior work [36], with the exception that the maximum length of missing gaze data was increased from 200 to 250 ms to reduce data attrition. The task included 33 trials. The mean number of successful RT trials was 7 (SD = 1, min. − max. = 1–15). RT data from 1 child was missing since the RT trials of that child did not yield valid data. The respective values for successful early time window CLT trials were 13 (SD = 2, min. − max. = 2–31) and for late time window trials 13 (SD = 8, min. − max. = 1–31). CLT late window data from 1 child was missing.

Spearman's correlation coefficient values were utilized to examine the associations between lexical processing at 18 months and lexical development at 12, 15 and 18 months. Based on correlation analyses, four linear regression models were used to explore how much of the variance in expressive development at 18 months could be explained by processing abilities when background factors were taken into consideration. The dependent variable in the first two models was FinCDI-SF expressive lexical skills. The independent variable in the first model was RT, and in the second model CLT. In the next two models Speech Composite skills were dependent variables, with RT and CLT

independent variables. Based on preliminary analyses, the values from the late time window, 2800–6400 ms from target word onset, were chosen as the CLT variable. Gender was an independent variable in all models. Gender was chosen as a background factor based on the preliminary analyses, which showed that of all the background factors (gender, gestational age, birth weight, maternal and paternal educational level), gender exhibited the strongest associations with the lexical measures used as dependent variables in the regression models.

Data analysis was conducted with SPSS version 27 (IBM Corp.) and *p*-values below 0.05 were considered statistically significant.

3. Results

3.1. Descriptive data

The mean RT in the lexical processing task was 1073.73 ms (SD = 335.96, min.–max. = 305.89–1728.28). Regarding the CLT, mean value for the early time window was 0.52 (SD = 0.12, min.–max. = 0.23–0.80) and for the late time window 0.47 (SD = 0.13, min.–max. = 0.24–0.74). The proportion of CLT by time bin during both time windows is presented in Fig. 1.

As displayed in Table 2, results from the methods FinCDI-SF and FinCSBS-ITC showed an increase of abilities from 12 months to 18 months, but a wide range of performance at all measure points. Based on the FinCDI-SF, the mean receptive value increased from 24 at 12 months to 56 at 18 months. The mean expressive value increased from 2 at 12 months to 24 at 18 months. At 18 months, weak FinCDI-SF receptive lexical skills were found in 26 % ($n = 6$), and weak expressive lexical skills in 22 % ($n = 5$) of the children. Based on the FinCSBS-ITC, the mean Symbolic Composite score increased from 9 points at 12 months to 14 points at 18 months, the respective Speech Composite values were 7 and 11. At 18 months, 23 % ($n = 3$) had weak symbolic skills and 18 % ($n = 3$) had weak speech skills (Table 2).

3.2. Associations between lexical processing and lexical development

Statistically significant, negative correlation coefficient values were found between RT and FinCSBS-ITC Speech Composite variables at 12 and 15 months (r-values −0.45 and −0.51) (Table 3). The correlation coefficient value between RT and FinCSBS-ITC Speech Composite skills at 18 months nearly reached significance level ($r = -0.43$). Thus, the slower the child looked to the target image after target word onset, the weaker were the lexical skills.

With respect to the CLT, investigated using the early time window, significant positive correlations to expressive lexical skills at 15 and 18 months were found when measured using the FinCDI-SF, and to skills at 12 months when measured with the FinCSBS-ITC Symbolic Composite (r-values varied between 0.43 and 0.58). The correlation coefficient value between CLT and FinCSBS-ITC Symbolic Composite skills at 18 months nearly reached significance level ($r = -0.42$). When the late time window was used, CLT correlated significantly with FinCDI-SF expressive and FinCSBS-ITC Speech Composite skills at 18 months, and FinCSBS-ITC Symbolic Composite skills at 12 months. The values indicated that the longer the child looked at the target image, the stronger the lexical values were.

3.3. Explaining value of lexical processing abilities

The results of the linear regression models with lexical processing and gender variables as predictors are presented in Table 4. Models 1–2 with FinCDI-SF expressive lexical skills as dependent variable were statistically significant. The models explained respectively 24 % and 40 % of the variation in expressive ability. In Model 2, CLT was a significant explanatory variable. Models 3–4 with FinCSBS-ITC Speech Composite values as dependent variables were also significant. As explanatory variables, RT and CLT nearly reached statistical significance. The models explained respectively 33 % and 26 % of the variance. Gender was a significant explanatory factor in all four models.

4. Discussion

The main aim of this study was to explore the associations between lexical processing, measured using an eye-tracking based assessment of RT and CLT, at 18 months, and lexical development of very preterm children during the first part of the second year of life. RT was associated with expressive skills at 12 and 15 months. CLT was linked to receptive skills at 12 and 15 months, and to expressive skills at 15 and 18 months. Regression models with processing variables and gender as independent variables explained a reasonable amount of variability in lexical development.

RT correlated with speech skills at 12 and 15 months, and the associations at 18 months were nearly significant. The associations are in line with previous studies that report connections between RT measured at 18 months and preterm children's concurrent and later expressive lexicon [1]. Further, full-term children's processing RT at 25 months has been linked to prior expressive lexicon, proposing connections between faster lexical growth during the second year of life and more efficient processing [9]. This study provides information on the association between RT and lexical development at an earlier developmental stage than in previous studies with preterm children. Research suggests that preterm children's early vocalization development is significantly associated with later language ability [37]. Findings from the present study may also suggest that very preterm children's vocalizations as well may be associated with lexical processing abilities. This can be concluded since the FinCSBS-ITC Speech Composite includes sound and syllable production. However, further research is necessary to verify this finding.

CLT was associated with expressive lexical skills at 15 and 18 months, which is comparable to previous findings describing the value of preterm children's processing accuracy at 18 months for concurrent language skills [17]. However, the present study describes links between

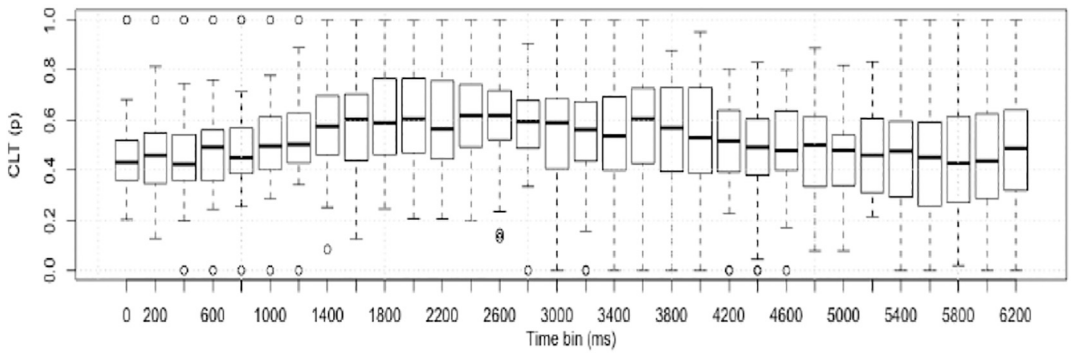

Fig. 1. Box plot describing the proportion of correct looking time (CLT) by time bin (ms) during the processing task.

Table 2
Descriptive statistics for language measures (Finnish short form version of the MacArthur Communicative Development Inventories -FinCDI-SF, and the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist -FinCSBS-ITC) at 12, 15 and 18 months. Mean (m), Median (MD), Minimum−Maximum (Min − Max) values and percentage of weak language skills (WLS%) are shown.

Method	12 months				15 months				18 months			
	M	MD	Min − Max	WLS %	M	MD	Min-Max	WLS %	M	MD	Min − Max	WLS%
FinCDI-SF												
Rec.	24	20	2–66	9	42	37	1–78	14	56	59	3–88	26
Expr.	2	1	0–12	–[a]	9	5	0–31	14	24	21	0–60	22
FinCBCS-ITC												
SyC	9	9	4–14	9	13	13	5–17	15	14	15	8–17	23
SpC	7	7	3–11	5	9	9	2–13	32	11	12	3–14	18

WLS: weak language skills, scoring below the 10th percentile of the normative population (Laakso et al., 2011; Stolt & Vehkavuori, 2018).
FinCDI-SF: Rec. = receptive lexical skills, Expr. = expressive lexical skills.
FinCBCS-ITC: SyC = Symbolic Composite (understanding of words, object use), SpC = Speech Composite (vocalizations, expressive words).
Note: data retrieved for different items varied between 19 and 21 cases.
[a] Weak expressive skills are not classified at this age point.

Table 3
Spearman's correlation coefficient values (r), and 95 % Confidence Intervals (CI) between reaction time (RT) and proportion of correct looking time (CLT) from the lexical processing assessment at 18 months and language items measured with the Finnish short form version of the MacArthur Communicative Development Inventories (FinCDI-SF) and the Finnish version of the Symbolic Behavior Scales. Developmental Profile. Infant-Toddler Checklist (FinCSBS-ITC). CLT values from the early time window (ET) and late time window (LT) are presented. Values from 12. 15- and 18-months' corrected age are displayed.

FinCDI-SF		12 months		15 months		18 months	
		Rec	Expr	Rec	Expr	Rec	Expr
RT[a]	r	−0.21	−0.15	−0.29	−0.29	−0.31	−0.29
	p	0.36	0.51	0.20	0.20	0.15	0.19
	CI	−0.60 − 0.26	−0.56 − 0.31	−0.65 − 0.17	−0.65 − 0.17	−0.66 − 0.14	−0.64 − 0.17
CLT ET	r	0.12	0.11	0.37	0.58**	0.34	0.46*
	p	0.61	0.62	0.09	0.00	0.11	0.03
	CI	−0.33 − 0.52	−0.34 − 0.52	−0.07 − 0.69	0.19 − 0.81	−0.09 − 0.67	0.05 − 0.74
CLT LT[a]	r	0.18	0.14	0.17	0.25	0.28	0.52*
	p	0.44	0.56	0.45	0.28	0.21	0.01
	CI	−0.29 − 0.58	−0.33 − 0.55	−0.29 − 0.57	0.22−0.62	−0.18 − 0.63	0.11 − 0.78

FinCSBS-ITC		12 months		15 months		18 months	
		SyC	SpC	SyC	SpC	SyC	SpC
RT[a]	r	−0.34	−0.51*	−0.26	−0.45*	−0.11	−0.43
	p	0.14	0.02	0.29	0.04	0.63	0.05
	CI	−0.68 − 0.12	−0.78 − 0.08	−0.65 − 0.24	−0.74—0.01	−0.53 − 0.35	−0.73 − 0.02
CLT ET	r	0.43*	0.26	0.42	0.19	0.42	0.37
	p	0.05	0.27	0.07	0.39	0.05	0.09
	CI	−0.00 − 0.73	−0.21 − 0.63	−0.05 − 0.73	−0.26 − 0.58	−0.02 − 0.72	−0.07 − 0.69
CLT LT[a]	r	0.52*	0.37	0.35	0.15	0.10	0.45*
	p	0.02	0.10	0.15	0.52	0.67	0.04
	CI	0.09 − 0.78	−0.10 − 0.71	−0.14 − 0.70	−0.31 − 0.56	−0.36 − 0.52	0.01 − 0.75

Rec. = receptive lexical skills, Expr. = expressive lexical skills.
SyC = Symbolic Composite (understanding of words, object use), SpC = Speech Composite (vocalizations, expressive words).
Note: data retrieved from language items varied between 19 and 23 cases.
* $p < 0.05$.
** $p < 0.01$.
[a] Data from one case was missing.

processing and specifically lexical development, compared with the more general language abilities presented in the previous study. Furthermore, in full-term children, CLT at 18 months has been shown to predict lexical development from 18 to 30 months [38]. The findings from the present study show the connection between CLT at 18 months and the prior expressive and symbolic skills of very preterm children. Accordingly, the current findings provide information on associations between processing skills and very early lexical and symbolic skills.

The linear regression analyses showed that CLT was more significant than RT for explaining the lexical skills of very preterm children at 18 months. In previous research exploring the RT and CLT of full-term children at 12 months, RT was most strongly connected with expressive skills [23]. In the present study, CLT explained a considerable amount of the variance (40 %) in FinCDI-SF expressive lexical development at 18 months, when gender was taken into consideration. The findings support research describing the relevance of assessing early processing skills in preterm children [1,17], and add new information on the significance of lexical processing abilities for explaining the lexical development of very preterm children.

The study provides novel information through the use of eye tracking technology in measuring early lexical processing of very preterm children. Of the variables explored by using the task, CLT was statistically more significant than RT for explaining lexical development. However, RT values were calculated from only distracter initial trials, and, thus,

Table 4
Linear regression models with lexical scores of the Finnish short form version of the Communicative Developmental Inventories (FINCDI-SF) and the Finnish version of the Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist (FinCSBS-ITC) measured at 18 months' corrected age as dependent variables. Reaction time measured in milliseconds (RT), proportion of correct looking time (CLT) from the late time window, 2800–6400 ms from target word onset, and gender were the independent variables. Standardized regression coefficient (β), confidence interval (CI), R square and adjusted R square (R^2, adj R^2), F-test (F) and statistical significance (p) are presented.

Explaining variables	β	95 % CI	R^2 (adj R^2)	F	p
Model 1: Dependent variable: FinCDI-SF expressive lexical skills					
RT	−0.02	−0.04 – 0.01			0.12
Gender	−17.08	−31.25 – 2.92			0.02*
Model			0.31 (0.24)	4.22	0.03*
Model 2: Dependent variable: FinCDI-SF expressive lexical skills					
CLT	65.20	17.73 – 112.67			0.01*
Gender	−17.55	−30.08 – −5.03			0.01*
Model			0.46 (0.40)	8.01	<0.01**
Model 3: Dependent variable: FinCSBS-ITC speech composite					
RT	−0.00	−0.01 – 0.00			0.05†
Gender	−3.23	−5.47 – −0.99			0.01*
Model			0.40 (0.33)	5.98	0.01*
Model 4: Dependent variable: FinCSBS-ITC speech composite					
CLT	7.74	−0.92 – 16.39			0.08†
Gender	−2.72	−5.04 – −0.40			0.02*
Model			0.33 (0.26)	4.43	0.03*

Symbolic Composite = understanding of words, object use.
Speech Composite = vocalizations, expressive words.
† $p < 0.10$.
* $p < 0.05$.
** $p < 0.01$.

were based on a smaller number of trials. In the analysis of the CLT data, an early and a late time window was utilized. The time windows provide detailed information on the temporal features of lexical processing during the looking-while-listening task. In previous research with full-term children at 12 months, the differences in processing between children with small and large vocabularies were evident mainly during the early time window [23]. In the present study, the associations between processing and lexical skills occurred during both time windows, which might be related to the characteristics of very preterm children's lexical processing, differences in the methods used, or language-specific issues.

In contrast to tasks used in prior studies [1,17], the target words in this study, in addition to nouns, also included verbs and adjectives. Verb acquisition is a more complex learning process than noun acquisition, and verb knowledge is a sign of a more mature lexicon at this early age, when compared to lexicon including only nouns and social-pragmatic words [39]. The inclusion of verbs might have contributed to the strength of the correlations at 18 months.

Compared with the norming groups of the screening methods used, a higher percentage of very preterm children exhibited weak receptive or expressive skills at 15 and 18 months, which is consistent with previous findings [2,3]. In this sample, the group with weak lexical skills increased from 12 to 18 months, which is consistent with the reported increasing gap in lexicon between full-term and preterm children during the second year of life [2,3]. Findings from the present study also show a large variability in lexical abilities across individuals, which is typical for developmental trajectories during the second year of life [25], and for the early language development of preterm children [4]. Notably, in the present study, the developmental data of a few individuals whose processing tasks could not be conducted successfully due to inattention or disability of the child were excluded from the total results. As these children exhibited weak lexical skills, the exclusion of this data might have affected our results.

Both screening methods in this study identified a higher percentage of weak receptive and expressive skills of the participants at 15 and 18 months, compared with the norming groups. However, the methods identified children with weak skills slightly differently. The differences between the methods in identifying weak expressive skills at 15 months are logical since the methods measure different aspects of early language development. The FinCDI-SF is a method for screening lexical skills, while the FinCSBS-ITC also evaluates prelinguistic development (vocalizations and object use). This may explain why FinCSBS-ITC identified a larger percentage of children with weak expressive skills at 15 months. According to the norming studies, the validity of the FinCDI-SF is particularly good from 18 months [30], the CSBS-ITC Symbolic Composite is most reliable from 12 to 18 months and the Speech Composite is most suitable from 15 months [34]. To our knowledge, of the screening methods utilized in the present study, only the short form version of the MacArthur Communicative Development Inventories (the adapted Italian version) has previously been used to measure preterm children's development during the second year of life [2]. Our findings provide knowledge on the use of these early screening methods when assessing the emerging lexical skills of very preterm children.

4.1. Strengths and limitations

The study presents novel information on the associations between lexical processing and both prior and concurrent receptive and expressive lexical development of very preterm children, which is the strength of the present study. Our study provides new information on assessing lexical processing using eye tracking technology and assessment of lexical skills during the second year of life. Furthermore, the study describes preterm children's early development by using two different screening methods. The associations were investigated comprehensively, through correlation and regression analyses.

A limitation of the study is the small sample size. The observed correlations in the present study suggest that the associations between lexical processing and lexical development are strong in the age period investigated. However, the confidence intervals for the correlation coefficients were wide given the small sample size in the analyses. Thus, future studies are necessary to verify the current findings in larger samples. The study did not utilize a control group of full-term children, but weak skills among the participants could be identified based on the results in the normed screening methods. Furthermore, all trials of the lexical processing task did not supply valid data, and in particular the RT values might be based only on a few successful trials. Finally, the current study was mainly descriptive. Further information on the causal relationship between lexical processing and emerging lexical skills in preterm children is needed (see [21]).

4.2. Clinical implications

The present study provides information on the associations between lexical processing skills and early lexical development in very preterm children. The findings have the potential to provide a base line for the use of an eye tracking-based lexical processing task in a clinical context. However, the lexical processing task used in the present study needs to be further developed and its psychometric properties and validity thoroughly examined before it can be fully assessed. European Standards of Care for Newborn Health recommend language follow-up assessments of preterm children by 2 years of age [40] and research emphasizes the importance of early language assessments of preterm

children [3]. The findings from the present study support the use of the screening instruments already available to identify weak early lexical skills in very preterm children as early as the beginning of the second year of life.

5. Conclusions

This study shows the connections between lexical processing and expressive lexical development in very preterm children during the first part of the second year of life. In the regression models, correct looking time together with a background factor explained a considerable amount of the expressive lexical skills of very preterm children. Moreover, the study utilized novel methods in assessing the early lexical processing and lexical development of very preterm children. However, further research on the use of the eye tracking based method for identifying very preterm children facing challenges in their early language development is needed.

CRediT authorship contribution statement

Eva Ståhlberg-Forsén: Conceptualization, Funding acquisition, Formal analysis, Data curation, Investigation, Methodology, Writing – original draft. **Reija Latva:** Conceptualization, Supervision, Writing – review & editing. **Jukka Leppänen:** Conceptualization, Formal analysis, Data curation, Methodology, Software, Writing – review & editing. **Liisa Lehtonen:** Project administration, Resources, Supervision, Writing – review & editing. **Suvi Stolt:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

References

[1] V.A. Marchman, M.D. Ashland, E.C. Loi, K.A. Adams, A. Fernald, H.M. Feldman, Predictors of early vocabulary growth in children born preterm and full term: a study of processing speed and medical complications, Child Neuropsychol. 25 (2019) 943–963, https://doi.org/10.1080/09297049.2019.1569608.

[2] A. Sansavini, A. Guarini, S. Savini, S. Broccoli, L. Justice, R. Alessandroni, et al., Longitudinal trajectories of gestural and linguistic abilities in very preterm infants in the second year of life, Neuropsychologia 49 (2011) 3677–3688, https://doi.org/10.1016/j.neuropsychologia.2011.09.023.

[3] S. Stolt, L. Haataja, H. Lapinleimu, L. Lehtonen, The early lexical development and its predictive value to language skills at 2 years in very-low-birth-weight children, J. Commun. Disord. 42 (2009) 107–123, https://doi.org/10.1016/j.jcomdis.2008.10.002.

[4] S. Stolt, A. Lind, J. Matomaki, L. Haataja, H. Lapinleimu, L. Lehtonen, Do the early development of gestures and receptive and expressive language predict language skills at 5;0 in prematurely born very-low-birth-weight children? J. Commun. Disord. 61 (2016) 16–28, https://doi.org/10.1016/j.jcomdis.2016.03.002.

[5] C. Moon, Prenatal experience with the maternal voice, in: M. Filippa, P. Kuhn, B. Westrup (Eds.), Early Vocal Contact and Preterm Infant Brain Development: Bridging the Gaps Between Research and Practice, Springer International Publishing AG, Strasbourg, 2017, pp. 25–37.

[6] T.K. Guttorm, P.H.T. Leppänen, A.-M. Poikkeus, K.M. Eklund, P. Lyytinen, H. Lyytinen, Brain event-related potentials (ERPs) measured at birth predict later language development in children with and without familial risk for dyslexia, Cortex 41 (2005) 291–303, https://doi.org/10.1016/s0010-9452(08)70267-3.

[7] S. Curtin, S.L. Archer, Speech perception, in: E.L. Bavin, L.R. Naigles (Eds.), The Cambridge Handbook of Child Language, Cambridge University Press, Cambridge, United Kingdom, 2015, pp. 137–158.

[8] A. Fernald, J.P. Pinto, D. Swingley, A. Weinberg, G.W. McRoberts, Rapid gains in speed of verbal processing by infants in the 2nd year, Psychol. Sci. 9 (1998) 228–231, https://doi.org/10.1111/1467-9280.00044.

[9] A. Fernald, A. Perfors, V.A. Marchman, Picking up speed in understanding: speech processing efficiency and vocabulary growth across the 2nd year, Dev. Psychol. 42 (2006) 98–116, https://doi.org/10.1037/0012-1649.42.1.98.

[10] A. Fernald, D. Swingley, J.P. Pinto, When half a word is enough: infants can recognize spoken words using partial phonetic information, Child Dev. 72 (2001) 1003–1015, https://doi.org/10.1111/1467-8624.00331.

[11] E. Jansson-Verkasalo, T. Ruusuvirta, M. Huotilainen, P. Alku, E. Kushnerenko, K. Suominen, et al., Atypical perceptual narrowing in prematurely born infants is associated with compromised language acquisition at 2 years of age, BMC Neurosci. 11 (2010) 88, https://doi.org/10.1186/1471-2202-11-88.

[12] H. Ryu, G. Han, J. Choi, H.K. Park, M.J. Kim, D.H. Ahn, et al., Object permanence and the development of attention capacity in preterm and term infants: an eye-tracking study, Ital. J. Pediatr. 43 (2017) 90, https://doi.org/10.1186/s13052-017-0408-2.

[13] S.A. Rose, J.F. Feldman, J.J. Jankowski, R. Van Rossem, Pathways from prematurity and infant abilities to later cognition, Child Dev. 76 (2005) 1172–1184, https://doi.org/10.1111/j.1467-8624.2005.00843.x.

[14] S. Ortiz-Mantilla, N. Choudhury, H. Leevers, A.A. Benasich, Understanding language and cognitive deficits in very low birth weight children, Dev. Psychobiol. 50 (2008) 107–126, https://doi.org/10.1002/dev.20278.

[15] E.S. Potharst, A.G. van Wassenaer-Leemhuis, B.A. Houtzager, D. Livesey, J.H. Kok, B.F. Last, et al., Perinatal risk factors for neurocognitive impairments in preschool children born very preterm, Dev. Med. Child Neurol. 55 (2013) 178–184, https://doi.org/10.1111/dmcn.12018.

[16] M. Ramon-Casas, L. Bosch, M. Iriondo, X. Krauel, Word recognition and phonological representation in very low birth weight preterms, Early Hum. Dev. 89 (2013) 55–63, https://doi.org/10.1016/j.earlhumdev.2012.07.019.

[17] E.C. Loi, V.A. Marchman, A. Fernald, H.M. Feldman, Using eye movements to assess language comprehension in toddlers born preterm and full term, J. Pediatr. 180 (2017) 124–129, https://doi.org/10.1016/j.jpeds.2016.10.004.

[18] V.A. Marchman, K.A. Adams, E.C. Loi, A. Fernald, H.M. Feldman, Early language processing efficiency predicts later receptive vocabulary outcomes in children born preterm, Child Neuropsychol. 22 (2016) 649–665, https://doi.org/10.1080/09297049.2015.1038987.

[19] V.A. Marchman, E.C. Loi, K.A. Adams, M. Ashland, A. Fernald, H.M. Feldman, Speed of language comprehension at 18 months old predicts school-relevant outcomes at 54 months old in children born preterm, J. Dev. Behav. Pediatr. 39 (2018) 246–253, https://doi.org/10.1097/dbp.0000000000000541.

[20] A. Fernald, R. Zangl, A.L. Portillo, V.A. Marchman, Looking while listening: Using eye movements to monitor spoken language, in: I.A. Sekerina, E.M. Fernandez, H. Clahsen (Eds.), Developmental psycholinqustics: On-line methods in children's language processing, John Benjamins, Philadelphia, 2008, pp. 97–135.

[21] S. Donnelly, E. Kidd, Individual differences in lexical processing efficiency and vocabulary in toddlers: a longitudinal investigation, J. Exp. Child Psychol. 192 (2020), 104781, https://doi.org/10.1016/j.jecp.2019.104781.

[22] J. Egger, C.F. Rowland, C. Bergmann, Improving the robustness of infant lexical processing speed measures, Behav. Res. Methods 52 (2020) 2188–2201, https://doi.org/10.3758/s13428-020-01385-5.

[23] J. Lany, M. Giglio, M. Oswald, Infants' lexical processing efficiency is related to vocabulary size by one year of age, Infancy 23 (2018) 342–366, https://doi.org/10.1111/infa.12228.

[24] A. Fernald, K. Thorpe, V.A. Marchman, Blue car, red car: developing efficiency in online interpretation of adjective-noun phrases, Cogn. Psychol. 60 (2010) 190–217, https://doi.org/10.1016/j.cogpsych.2009.12.002.

[25] S. Stolt, L. Haataja, H. Lapinleimu, L. Lehtonen, Early lexical development of finnish children: a longitudinal study, firstLanguage 28 (2008) 259–279, https://doi.org/10.1177/0142723708091051.

[26] P. Lyytinen, Varhaisen kommunikaation ja kielen kehityksen arviointimenetelmä, Jyväskylän yliopiston Lapsitutkimuskeskus ja Niilo Mäki instituutti, Jyväskylä, 1999.

[27] N.C. Capone, K.K. McGregor, Gesture Development: A Review for Clinical and Research Practices, Journal of Speech, Language & HearingResearch. 47 (2004) 173–186, https://doi.org/10.1044/1092-4388(2004/015).

[28] S. Stolt, Early lexicon and the development that precedes it and the development follws-a developmental view to early lexicon, in: A. Bar-On, D. Ravid (Eds.), Handbook of Communication Disorders, Walter de Gruyter Inc., Boston/Berlin, 2019, pp. 91–100.

[29] V. Marchman, A. Fernald, Variability in real-time spoken language processing in typically developing and late-talking toddlers, in: L. Rescorla, P. Dale (Eds.), Late Talkers, Paul H. Brooks Publishing Co., Baltimore, 2013.

[30] S. Stolt, S. Vehkavuori, Sanaseula., MacArthur-Bates Communicative Development Inventories, menetelmän suomalainen lyhyt versio (The Finnish short form version of the MacArthur-Bates Communicative Development Invetories), Jyväskylä: Niilo Mäki Instituutti (2018).

[31] A.B. Tobii Technology, User's Manual. Tobii X2-60 Eye Tracker, 2014. https://www.tobiipro.com/siteassets/tobii-pro/user-manuals/tobii-pro-x2-60-eye-tracker-user-manual.pdf/?v=1.0.3. (Accessed 14 October 2020).

[32] L. Fenson, S. Pethick, C. Renda, J.L. Cox, P.S. Dale, J.S. Reznick, Short-form versions of the MacArthur Communicative Development Inventories, Appl. Psycholinguist. 21 (2000) 95–116, https://doi.org/10.1017/S0142716400001053.

[33] A.M. Wetherby, L. Allen, J. Cleary, K. Kublin, H. Goldstein, Validity and reliability of the communication and symbolic behavior scales developmental profile with very young children, J. Speech Lang. Hear. Res. 45 (2002) 1202, https://doi.org/10.1044/1092-4388(2002/097).

[34] M.-L. Laakso, K.M. Eklund, A.-M. Poikkeus, Esikko-lapsen esikielellisen kommunikaation ja kielen ensikartoitus (The infant-toddler checklist of children's prelinqustic communication and language), Niilo Mäki Instituutti, Jyväskylä, 2011.

[35] F. Karlsson, Suomen kielen äänne- ja muotorakenne, Werner Söderström, Porvoo, 1983.

[36] J.M. Leppanen, L. Forssman, J. Kaatiala, S. Yrttiaho, S. Wass, Widely applicable MATLAB routines for automated analysis of saccadic reaction times, Behav. Res. Methods 47 (2015) 538–548, https://doi.org/10.3758/s13428-014-0473-z.

[37] S. Stolt, L. Lehtonen, L. Haataja, H. Lapinleimu, Development and predictive value of early vocalizations in very-low-birth-weight children: a longitudinal study, Clin. Linguist. Phon. 26 (2012) 414–427, https://doi.org/10.3109/02699206.2011.648365.

[38] A. Fernald, V.A. Marchman, Individual differences in lexical processing at 18 months predict vocabulary growth in typically developing and late-talking

toddlers, Child Dev. 83 (2012) 203–222, https://doi.org/10.1111/j.1467-8624.2011.01692.x.
[39] K. Hirsh-Pasek, R.Michnick Golinkoff, R.M. Golinkoff, Action Meets Word : How Children Learn Verbs, Oxford University Press, Incorporated, New York, 2006.
[40] European Foundation for the care of the newborn infant, European Standards of Care for Newborn Health. Final report, 2018. https://www.efcni.org/wp-content/uploads/2018/11/2018_11_16_ESCNH_Report_final.pdf. (Accessed 5 September 2021).