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Relation of infants' and mothers' pointing to infants' vocabulary measured directly and with parental reports

Sura Ertaş[1] | **Sümeyye Koşkulu-Sancar**[2] | **Ebru Ger**[3] | **Ulf Liszkowski**[4] | **Aylin C. Küntay**[1]

[1]Department of Psychology, Koç University, Istanbul, Turkey

[2]Department of Educational and Pedagogical Sciences, Utrecht University, Utrecht, Netherlands

[3]Department of Psychology, University of Bern, Bern, Switzerland

[4]Department of Developmental Psychology, University of Hamburg, Hamburg, Germany

Correspondence
Sura Ertaş, Koç University, Department of Psychology, Rumelifeneri, Rumeli Feneri Yolu, 34450 Istanbul, Turkey.
Email: sertas19@ku.edu.tr

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Abstract

Infants' and parents' pointing gestures predict infants' concurrent and prospective language development. Most studies have measured vocabulary size using parental reports. However, parents tend to underestimate or overestimate infants' vocabulary necessitating the use of direct measures alongside parent reports. The present study examined whether mothers' index-finger pointing, and infants' whole-hand and index-finger pointing at 14 months associate with infants' receptive and expressive vocabulary based on parental reports and directly measured lexical processing efficiency (LPE) concurrently at 14 months and prospectively at 18 months. We used the decorated room paradigm to measure pointing frequency, the Turkish communicative development inventory I to measure infants' receptive vocabulary, Turkish communicative development inventory II to measure their expressive vocabulary, and the Looking-While-Listening (LWL) task to measure LPE. At 14 months, 34 mother-infant dyads, and at 18 months, 30 dyads were included in the analyses. We found that only infants' index-finger pointing frequency at 14 months predicted their LPE (both reaction time and accuracy) prospectively at 18 months but not concurrently at 14 months. Neither maternal pointing nor

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infants' pointing predicted their receptive and expressive vocabulary based on indirect measurement. The results extend the evidence on the relation between index-finger pointing and language development to a more direct measure of vocabulary.

1 | INTRODUCTION

Before they speak, infants communicate through gestures. Pointing gestures are prominent means for infants to communicate with others referentially by indicating objects, events, or locations (Bates et al., 1979). There is ample evidence that pointing of both infants and parents predict infants' concurrent and prospective language development (Colonnesi et al., 2010; Iverson et al., 1999; Pan et al., 2005; Rowe & Goldin-Meadow, 2009). Particularly index-finger pointing, as opposed to whole-hand pointing, plays an important role in predicting language development (Lüke et al., 2017).

Previous research on the relation of pointing to language development mainly focused on vocabulary as a measure of infants' early language development, using parental reports such as checklists. However, there are inconsistent results on the relation between infants' pointing and their receptive vocabulary such that while some studies showed an association between infants' pointing gestures and receptive vocabulary skills (e.g., Goldin-Meadow, 2007; Salo et al., 2019), others did not find such a relation (e.g., Blake et al., 2003). In addition, a few studies demonstrated that parents might underestimate or overestimate infants' language comprehension and production, especially with regard to early vocabulary knowledge (Houston-Price et al., 2007; Reese & Read, 2000).

On the other hand, tools are available for a more direct assessment of infants' vocabulary skills, such as lexical processing efficiency (LPE), which represents how fast and accurately infants process and recognize known words (Fernald et al., 2006; Lany, 2017; Ronfard et al., 2021). The Looking-While-Listening paradigm (LWL; Fernald et al., 2008) provides a measure of LPE, which is related to later vocabulary growth (Fernald & Marchman, 2011; Marchman et al., 2015), and cognitive and social skills (Ronfard et al., 2021). To date, however, LPE has not been studied in relation to parents' and infants' point production, and not in relation to different pointing hand shapes. In addition, the relation between pointing and infants' early language skills has not been studied investigating vocabulary development with both direct and indirect measurements. In the current study, we investigated the association between mothers' and infants' pointing gestures and infants' concurrent and prospective vocabulary skills through a direct measure (LPE; LPE) and an indirect measure (parental checklist) and by considering different hand shapes.

1.1 | Role of infants' point production in vocabulary development

Around their first birthdays, infants frequently point to communicate with others. In addition, at this age, infants are able to understand others' attentional and intentional states (Carpenter et al., 2005; Liszkowski et al., 2004; Moll et al., 2006). Infants point to direct others' attention to specific objects and actively create joint attentional interactions, which provide optimal situations to learn language, for instance, by bringing about labeling and pointing by parents (Camaioni et al., 2004; Carpenter et al., 1998; Saxon et al., 2000). Several studies and a meta-analysis confirmed that infants' pointing is a predictor of their concurrent and prospective language development (Colonnesi et al., 2010;

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Goldin-Meadow, 2007; Salo et al., 2019). In a pioneering study, Bates et al. (1979) showed that the frequency of pointing gestures was related to language comprehension based on maternal reports at the end of the first year. Moreover, Salo et al. (2019) showed that infants who pointed more at 12 months had larger Vineland receptive language scores at 24 months, controlling for their 12-month language scores. In contrast, Blake et al. (2003) failed to find a concurrent or a prospective relationship between pointing frequency at 10 months and the Japanese version of the CDI at 10 or 12 months. Different findings in relation to infants' pointing and receptive language might result from (a) not differentiating between different hand shapes of infants' pointing and (b) measuring infants' receptive language skills via parental reports instead of direct assessments. Below we lay out the diverse communicative roles of different hand shapes of infants' pointing and the relation between maternal pointing and infant language. And then, we focus on the differences between parent-reported and directly measured vocabulary skills of infants.

1.2 | Role of infants' hand shape of pointing in vocabulary development

While adults commonly use the index-finger when pointing, and infants have been shown to point with the index-finger across a range of diverse cultures (Butterworth et al., 2002; Liszkowski et al., 2012), infants do not only point with the index-finger but also with the whole-hand during their first year of life (Franco & Butterworth, 1996; Ger et al., 2018; Liszkowski & Tomasello, 2011; Lüke et al., 2017). Infants' pointing with the whole hand (open palm) to communicate with others emerges at around 8–10 months (Boundy et al., 2016; Rüther & Liszkowski, 2023; Veena & Rajashekhar, 2013). The use of index-finger pointing, where only the index-finger is stretched while the remaining fingers are curled inwards, emerges later than whole-hand pointing, at around 10–12 months of age (Behne et al., 2011; Cameron-Faulkner et al., 2015; Ger et al., 2018; Rüther & Liszkowski, 2023).

There is some evidence suggesting that the hand shape matters for infants' comprehension and production of the pointing gesture. For instance, at 12 months, before pointing predominantly with the index finger, infants were cued only by the whole hand but not the index finger in a spatial cueing paradigm (Ger et al., 2021). In addition, in a study observing semi-natural interactions among infants and their caregivers, Liszkowski and Tomasello (2011) showed that 12-month-old infants, who used the index-finger, pointed more frequently than infants who used only the whole hand. Infants who pointed with the index-finger also comprehended the underlying referential intentions of pointing better in point following and informative point comprehension tasks compared to those who did not point with the index-finger. These results revealed that index-finger pointing is associated with being a more prolific pointer and grasping the referential communicative intentions of the gesture better. More crucially, the hand shape of pointing seems to matter for infants' language development. A study found that 12-month-old infants who pointed exclusively with the whole-hand but not with the index-finger had significantly lower language skills and a higher risk for language delay one year later based on parent-reported language measures (Lüke et al., 2017). To further our understanding regarding the special role of index-finger pointing in understanding referentiality and language development, it is important to investigate the relation between the hand shape of infants pointing and their early LPE, which reflects rapid encoding and interpreting speech. In the current study, we investigated whether infants' whole-hand and index-finger pointing were differentially associated with their vocabulary development using both direct and indirect measurements.

1.3 | Role of mothers' pointing in infants' language development

Infants not only produce gestures but also observe and respond to the gestures produced by their caregivers during their interactions. By the end of the first year, infants start to follow others' pointing

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to target objects both in front (Butterworth & Jarrett, 1991) and behind them (Deák, et al., 2000). Therefore, parents' pointing might provide opportunities to establish joint attention episodes with infants to learn vocabulary, such as labels for objects. Furthermore, when mothers direct the infant's attention to an object with a pointing gesture, infants' misunderstanding of the referent of a word is reduced (Zukow-Goldring, 1996), since pointing-speech combinations (e.g., saying "Look at the bird" + pointing at the bird) provide nonverbal support for infants in identifying the meaning of spoken words (Kobayashi et al., 2022).

Caregivers' pointing is also associated with infants' pointing (Liszkowski & Tomasello, 2011; Rowe, 2000; Rowe & Goldin-Meadow, 2009), and is a strong predictor of the emergence of infants' index-finger pointing (Liszkowski et al., 2012; Liszkowski & Tomasello, 2011; Rowe & Goldin-Meadow, 2009; Rüther & Liszkowski, 2023; Salomo & Liszkowski, 2012). Furthermore, caregivers' pointing predicts infants' concurrent and prospective vocabulary development. Iverson et al. (1999) found that at 16 months mothers' production of pointing gestures was significantly correlated with infants' vocabulary size. Another study conducted by Pan et al. (2005) found that 14-month-old infants whose mothers produced more pointing gestures showed faster vocabulary growth between 14 and 36 months. There are also intervention studies that support these empirical associations between maternal pointing, infant pointing, and infants' language development (Choi & Rowe, 2021; Matthews et al., 2012; Rowe & Leech, 2018). For instance, Rowe and Leech (2018) applied an intervention with a growth mindset component to mothers of 10-month-olds from diverse socioeconomic backgrounds about the important role of pointing in language development. Results demonstrated that mothers who received the intervention increased their pointing with their infants at 12 months. Also, the infants of mothers who received intervention pointed more and to a greater number of objects. Interestingly, the intervention also had an effect on a subset of the mothers who endorsed fixed mindsets (i.e., believing basic qualities are simply fixed traits) at the beginning of the intervention. Their infants showed greater vocabulary growth between 10 and 18 months. In sum, both correlational and experimental evidence suggest that mothers' pointing is an important predictor of infants' pointing and language development.

1.4 | Measuring infants' language skills

In most of the previous studies, measurements of infants' language skills were obtained indirectly through parental reports such as MacArthur-Bates Communicative Development Inventories (MB-CDIs; Fenson et al., 2006). However, research shows that assessment of infants' language skills based on parental reports versus more direct measures might yield inconsistent results. For example, Houston-Price et al. (2007) compared the parental reports on CDI and infants' preferential looks at the referents of target words. They found that infants correctly looked at the target pictures both for words that mothers reported to be comprehended by their infant and for words that mothers reported to be not yet comprehended. In addition, Reese and Read (2000) found that mothers from low SES backgrounds overestimated their children's vocabulary size compared with their performance on other standardized measures such as the Peabody Picture Vocabulary Test. A more recent study by Bennetts et al. (2016) used CDI as a parental report and Early Communication Indicator as a direct measurement based on observations of parent-child interactions for 6 min. They found a stronger consistency between parent-reported and directly measured child language for children who have poor or exceptional language skills, compared to children with average language skills. Taken together, these results suggest that parental reports may underestimate or overestimate infants' language skills. This may be especially true for the very young ages when infants are not yet producing words robustly. Findings

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also suggest that SES mediates both LPE (Fernald et al., 2012) and pointing frequency (Rowe & Goldin-Meadow, 2009), requiring investigating SES as an additional factor. While there is currently no empirical evidence, parents' overestimations and underestimations of their infants' language might also affect their gestural input to their infants. Since both parents' pointing input and report of their infants' vocabulary are likely to suffer from their estimation errors, the relationship between parental pointing and infant vocabulary might be represented better with a direct assessment of infant vocabulary at these early ages compared to indirect ones.

Alternative to the parent-reported language measures, the LWL paradigm provides a measure of another aspect of infants' vocabulary development, which is LPE. Infants' early LPE means how fast and accurately they process and recognize known words (Lany, 2017; Ronfard et al., 2021). Given that infants' LPE indicates language-specific cognitive skills for efficient encoding and comprehension of language, and it is associated with vocabulary growth (Fernald & Marchman, 2011; Peter et al., 2019), later receptive vocabulary (Marchman et al., 2015), and executive functions (Ronfard et al., 2021), it is important to understand the developmental antecedents of LPE. It is the first study to investigate whether infants' LPE relates to earlier nonlinguistic gestural communication. We also report whether maternal and infant pointing predict parental reports of vocabulary size in the same sample of infants.

1.5 | Current study

The present study investigates whether parents' and infants' early use of whole-hand and index-finger pointing at 14 months is associated with infants' concurrent and prospective vocabulary size and LPE at 14 and 18 months. Our specific research questions are whether infants' and mothers' use of pointing gestures at 14 months are i) concurrently related to infants' vocabulary size and LPE at 14 months, ii) prospectively related to the infant's vocabulary size and LPE at 18 months, and iii) whether the hand shape of infants' pointing gestures (i.e., whole-hand or index-finger pointing) are differentially associated with their vocabulary size and LPE. Based on the reviewed literature on pointing and language acquisition, we expected that the pointing frequency of mothers at 14 months would be related to infants' LPE and receptive and expressive vocabulary concurrently at 14, and prospectively at 18 months. We also hypothesized that, compared to whole-hand pointing, infants' index-finger pointing would be a better predictor of their concurrent and prospective vocabulary size and LPE. In addition, we explored whether SES would affect our measures or relations.

2 | METHOD

2.1 | Participants

Data were collected in the context of a larger longitudinal study investigating the communication, social, and cognitive development of Turkish-speaking infants and their mothers at 8 time points: each month between 8 and 14 months and at 18 months. For the current study, only the data from two time points at 14 and 18 months were used, because we collected our target measures of LPE only at those two time points. In the main longitudinal project, 57 caregiver-infant dyads participated. At 14 months, 44 dyads participated in the decorated room session, 34 of which also participated in the LWL session. At 18 months, 35 infants participated in the LWL session. We excluded 5 out of these 35 infants who attended the looking-while-listening session at 18 months because of a sound-related problem in the video recording. Thirty-four mother-infant (22 girls) dyads participated both in the

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decorated room and the LWL session at 14 months (M = 14.42, SD = 13.2 days) and 30 mother-infant (18 girls) dyads attended both the decorated room session at 14 months and the LWL session at 18 months (M = 18.53, SD = 13.8 days). Lastly, 24 infants (14 girls) participated in the LWL session both at 14 and 18 months. Thus, we included 34 participants to test concurrent relations, 30 participants to test prospective relations, and 24 participants to report correlations between LWL scores at 14 and 18 months in the corresponding analyses.

All infants were full-term, typically developing in monolingual households, and all participating caregivers were mothers. The mean age of the mothers was 31.5 (SD = 5.3) at their first visit when their infants were 8 months of age. The sample was aimed to be diverse in terms of maternal education: 16 percent of mothers completed primary education (5 years), 14% secondary education (8 years), 27% high school (∼11 years), 29% university (∼15 years), and 14% completed higher education (Master's or Ph.D. level, ∼17–22 years). We used maternal education as an indicator of SES since maternal education is the most robust SES component, especially for maternal measures such as quantity and quality of language input (Bornstein et al., 2003; Hoff et al., 2002). The study was conducted according to the guidelines of the Declaration of Helsinki, with written informed consent obtained from a parent for each child before the study. All procedures in this study were approved by the Committee on Human Research at Koç University (Project name: Influence of socioeconomic and immigration status on the cognitive origins of cultural learning - Protocol no: 2012.048. IRB3.18).

2.2 | Procedure

When the infants were 8 months old, demographic information (e.g., parents' education level, birthdate of children, siblings) and informed consent were obtained from the caregivers. At 14 months, mothers and infants participated in the decorated room and looking-while-listening sessions in the laboratory, and mothers filled out the Turkish communicative development inventory-I (TCDI-I). Decorated room sessions were recorded with four cameras in each corner of the room. At 18 months, infants completed the looking-while-listening task and mothers filled out the Turkish communicative development inventory-II (TCDI-II). At the end of each visit, parents were given a small gift for their participation.

2.3 | Measures

2.3.1 | Decorated room paradigm

To elicit and measure the pointing behavior of infants and their mothers, we used the decorated room paradigm (Liszkowski et al., 2012). In this paradigm, mother-infant dyads were invited into a room with 21 objects hung on the four walls (see Figure 1). Caregivers were instructed to carry their infants on their hips (to allow eye contact between the mother and infant) and walk around the room without touching the objects for 5 min.

Data coding was conducted using the ELAN software (Sloetjes & Wittenburg, 2008). We coded infants' and mothers' whole-hand and index-finger points separately. Maternal pointing was considered only as index-finger pointing, both because the conventional pointing type is with the index finger in the country where the study was conducted, and the frequency of the maternal whole-hand points was too low to be included in the analyses. Caregivers' and infants' pointing were coded according to the coding scheme of Liszkowski and Tomasello (2011). The coding of a pointing gesture started with

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FIGURE 1 Decorated room paradigm.

the initiation of extending the arm with the whole hand or the index finger toward an item or a location and ended roughly after retraction of the arm at least halfway. If there was a change of referents without retracting or bringing down the pointing arm, more than one point was coded for each change of referent.

The coding was done by four coders. First, the coders were trained on index-finger and whole-hand pointing classification over the sample video. Then each of the four coders coded 18 percent of randomly selected videos individually for calculating interrater reliability. Reliability analyses were conducted separately for mothers' index-finger pointing, infants' index-finger pointing, infants' whole-hand pointing, and infants' total pointing across four coders. Intraclass correlations were high among the four coders: Cronbach alphas ranged from 0.94 to 0.99.

2.3.2 | Looking-while-listening (LWL) task

Infants' real-time LPE was assessed at 14 and 18 months, using a version of the looking-while-listening procedure (Fernald et al., 2008). Infants sat on the caregivers' lap during all sessions, and caregivers were asked not to look at the screen. Infants were presented with two objects (one distractor and one target) on a screen while they heard the label of the target object in a sentence ending with a familiar target noun vocalized by a female native speaker across 32 trials. We made minor changes to the original vocabulary list to have target nouns of equal syllable length. The eight target nouns were highly familiar to children in this age range (*kedi-bebek*, *kitap-balon*, *köpek-balık*, *araba-telefon*; kitty–baby, book–balloon, doggie–fish, car–phone; respectively). Each stimulus sentence consisted

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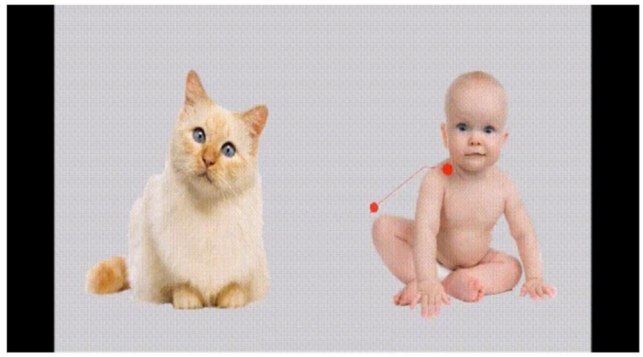


FIGURE 2 Example Screen of a Trial in the Looking-while-listening Task. Red points represent the infant's fixations on the screen.

of a carrier phrase with the target word in the final position, followed by an attention-getter (e.g., *Neredeymiş araba? Hadi bak bakalım./Bulabilir misin?* 'Where's the car? Look at that./Can you find it?'). The side of the target picture on the screen was counterbalanced across trials. On each trial, picture pairs were shown simultaneously for 2 s prior to speech onset, and they remained on the screen during the auditory stimulus and until 1 s after the speech offset. Between trials, the screen was blank for approximately 1 s. Each trial lasted around 7 s. While infants were watching the videos, their eye movements were recorded as a video during approximately 5 min by Tobii T120 Eye Tracker that has a 17 inches display and a resolution of 1280 × 1024 (width × height). To detect infants' eye movements on the screen (see Figure 2), we used the default fixation algorithm of Tobii Studio (Olsson, 2007). The default fixation filter uses the velocity threshold value representing the maximum pixel distance between two sequential data points for them to be considered part of a fixation. The velocity threshold value is 35 pixels. It means that if the distance between two sequential gaze data points is lower than 35 pixels, the two gaze data points are merged into a single fixation. Since the distance between the distracter and target pictures is 176 pixels in our task, the default fixation filter easily detects separate fixations on the distracter and target pictures. Therefore, we preferred the default fixation filter, which provides sufficiently precise data for our dependent variables of interest, namely the reaction time (RT) and accuracy.

The coding of the data was performed using the ELAN software (Sloetjes & Wittenburg, 2008). A recent study (Ronfard et al., 2021) demonstrated that children's word learning on a fast-mapping task, executive function, and pragmatic skills were associated with LPE measures obtained only from distractor-initial trials of the LWL task. According to their findings, the accuracy score from distractor-initial trials is a more sensitive measure of infants' LPE. Because, in the distractor-initial trials, infants need to follow verbal instructions, disengage from the distractor, and shift their gaze to the target (Fernald et al., 2008; Ronfard et al., 2021). Fernald, McRoberts, and Swingley (2001) suggested that this process reflects a more sophisticated measure of lexical competence. In contrast, in the target-initial trials, it is not clear whether infants continue to look at the target picture based on their general interest or the verbal instruction. Because of their diagnosticity, we focused only on distractor-initial trials (i.e., trials in which the infant's first fixation was on the distractor item). We included only those infants who provided data from at least two *distractor-initial trials*. We obtained two types of scores by calculating (i) *RT*, which was the average latency (in ms) to shift the gaze from the distractor picture to the target picture after target noun onset among the distractor-initial trials and, (ii) *accuracy*, which was the average proportion of looking time at the target picture relative to the total time they looked at both target and distractor pictures within the time window 300–1800 ms

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after the target word onset. Fernald et al. (2008) suggest that early and late shifts might not be in response to the stimulus sentence; therefore, the trials in which the child shifted to the correct picture either within the first 300 ms or later than 1800 ms from the target word onset were coded as invalid trials and were not included the infants' RT and accuracy scores. In addition, infants may look away from the screen or look at the area outside the target and distractor pictures at the beginning of the trial (within the first 300 ms time window, which is the onset of the target word). Since it cannot be detected whether these trials were distractor-initial or not, they were coded as invalid trials. Similarly, infants may shift their gaze away from the screen in the time window of 1500 ms, during which we coded RT and looking times for each trial, and then they may look back at the screen. In these trials, since it is not clear why infants looked back at the distractor or target picture, we code these trials as invalid as well. Consequently, at 14 months, the average number of valid distractor-initial trials was 10.85 and did not differ significantly across SES and sex t (34) = −1.005, p = 0.32; t (34) = −1.803, p = 0.08, respectively. At 18 months, the average number of valid distractor-initial trials was 6.84 and similarly did not differ significantly across SES and sex t (30) = 1.122, p = 0.27, t (30) = −0.386, p = 0.70, respectively.

2.3.3 | Turkish communication development inventory-I and II

TCDI-I and TCDI-II (Aksu-Koç et al., 2019) is the Turkish adaptation of the MacArthur-Bates CDI. TCDI-I is to be used for children aged 8–16 months to assess their receptive and expressive language and early communicative behavior. The vocabulary checklist consists of 418 items to measure both the expressive and receptive vocabulary of infants. At 14 months, mothers were asked to fill out TCDI-I and check whether their infants comprehend or produce the words listed to assess infants' receptive and expressive vocabulary. However, in this study, we only used the receptive vocabulary scores of TCDI-I since the variance for expressive vocabulary is less at this age range (Walle & Campos, 2014). TCDI-II can be used for children aged 16–36 months to assess their expressive language. The expressive vocabulary checklist involves 711 items. At 18 months, mothers were asked to fill out the TCDI-II and check the words their infants produce from the checklist to assess their infants' expressive vocabulary.

3 | RESULTS

The dependent variables were the accuracy and RT scores derived from the LWL task and TCDI-I receptive vocabulary scores at 14, and the accuracy, RT and TCDI-II expressive vocabulary scores at 18 months. The independent variables were the frequency of infants' whole-hand pointing, index-finger pointing, and mothers' index-finger pointing. The control variables were SES (i.e., years of maternal education) and infants' sex. In the following sections, we first present descriptive statistics for the dependent and independent variables. Then, we present the statistics examining the concurrent and prospective associations between mothers' index-finger pointing frequency, infants' whole-hand pointing, and index-finger pointing frequency, and their receptive and expressive vocabulary and LPE. Table 1 presents descriptive statistics for infants' and mothers' pointing, infants' receptive and expressive vocabulary, LWL-RT, and LWL-accuracy scores at 14 and 18 months.

We performed correlations as preliminary analyses (see Table 2). Negative correlations were observed between RT and accuracy scores at 14 and 18 months. There were positive correlations between infants' receptive vocabulary at 14 months and expressive vocabulary at 18 months. There

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TABLE 1 Descriptive statistics for infants' and mothers' pointing and infants' vocabulary and LWL scores.

Measure	*M*	*SD*	Min.	Max.
	14 Months			
Mothers' pointing frequency	15.98	13.67	0	52
Infants' whole-hand pointing frequency	8.42	6.82	1	27
Infants' index-finger pointing frequency	13.60	13.79	0	59
LWL—Accuracy (%)	0.53	0.11	0.23	0.81
LWL—RT (ms)	644.70	182.39	208.00	1156.33
Receptive vocabulary	188.5	102.68	37	417
	18 Months			
LWL—Accuracy (%)	0.58	0.14	0.24	0.87
LWL—RT (ms)	567.02	207.03	115.00	1135.50
Expressive vocabulary	88.5	83.63	8	387

TABLE 2 Correlations between maternal pointing, infant pointing, infants' vocabulary, and LWL scores.

Variables	1	2	3	4	5	6	7	8	9	10
1. Maternal years of education	1									
2. Mothers' pointing frequency at 14m	0.36*	1								
3. Infants' whole-hand pointing frequency at 14m	0.16	−0.08	1							
4. Infants' index finger pointing frequency at 14m	0.35*	0.28	−0.26	1						
5. LWL—Accuracy at 14 m (%)	−0.01	−0.29	−0.25	0.26	1					
6. LWL—RT at 14 m (ms)	0.05	0.25	0.17	−0.30	−0.93**	1				
7. LWL—Accuracy at 18 m (%)	0.07	0.20	−0.09	0.50**	−0.07	0.04	1			
8. LWL—RT at 18 m (ms)	0.11	−0.04	0.13	−0.52**	−0.19	0.23	−0.76**	1		
9. Receptive vocabulary at 14 m	−0.09	−0.13	−0.05	0.22	0.06	−0.06	0.04	−0.09	1	
10. Expressive vocabulary at 18 m	0.13	0.10	−0.19	0.38*	−0.03	0.02	−0.07	0.08	0.50***	1

*<0.05, **<0.01, ***<0.001.

were also positive correlations between SES (i.e., maternal years of education) and mothers' and infants' index-finger pointing frequency at 14 months. In addition, infants' index-finger pointing was positively correlated with their expressive vocabulary and accuracy scores and negatively correlated with their RT scores at 18 months. Next, we ran one way-MANOVA, as a preliminary analysis, to investigate whether there were any sex differences for the outcome variables. Results indicated that

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there were no sex differences in infants' receptive vocabulary, accuracy and RT scores at 14 months, and expressive vocabulary and RT scores at 18 months. We found a sex difference in infants' accuracy scores at 18 months F (5, 24) = 4.885, $p = 0.02$, Wilk's $\Lambda = 0.541$, partial $\eta^2 = 0.459$. Results showed that girls ($M = 0.62$, $SD = 0.11$) looked at the target picture longer than boys ($M = 0.50$, $SD = 0.14$). Thus, we included sex as a control variable in the relevant analyses.

3.1 | Concurrent relations between infants' and mothers' pointing and infants' receptive vocabulary (TCDI-I)

To test our first hypothesis that infants' and mothers' pointing frequency predicts infants' receptive vocabulary scores, we ran a hierarchical linear regression analysis. We entered SES (i.e., maternal years of education) as a control variable and mothers' index-finger pointing frequency at 14 months at the first step into the model. In the second step, we entered infants' whole-hand pointing frequency at 14 months. Lastly, we entered infants' index-finger pointing frequency at 14 months in the third step. The summary of these regression analyses can be seen in Table 3. For predicting infants' receptive vocabulary scores at 14 months, the models at steps 1, 2, and 3 were not significant in explaining any variance, and mothers' index-finger pointing frequency, infants' whole-hand, and infants' index-finger pointing were not significant predictors.

3.2 | Concurrent relations between infants' and mothers' pointing and infants' lexical processing efficiency

To test our second hypothesis that infants' and mothers' pointing frequency predict infants' LPE, we ran two hierarchical linear regression analyses predicting accuracy and RT, respectively. In both analyses, we entered the SES (i.e., maternal years of education) as a control variable and mothers' index-finger pointing frequency at 14 months at the first step into the model. In the second step, we entered infants' whole-hand pointing frequency at 14 months. Lastly, we entered infants' index-finger pointing frequency at 14 months in the third step. The following analyses were conducted with 34 participants. The summary of these regression analyses can be seen in Table 4. For predicting infants' accuracy scores at 14 months, the models at steps 1 and 2 were not significant in explaining any variance, and mothers' index-finger pointing frequency and infants' whole-hand pointing were not significant predictors. At step 3, only mothers' index finger pointing frequency emerged as a significant predictor for infants' accuracy scores at 14 months, but the model was not significant at this step. Similarly, for predicting infants' RT scores at 14 months, the models at steps 1 and 2 were not significant in explaining any variance, and mothers' index-finger pointing frequency and infants' whole-hand pointing were not significant predictors. At step 3, mothers' index finger pointing and infants' index finger pointing frequency emerged as significant predictors for infants' RT scores at 14 months, but the model was not significant at this step.

3.3 | Prospective relations between infants' and mothers' pointing and infants' expressive vocabulary (TCDI-II)

Similar to the concurrent analyses, we ran a hierarchical linear regression analysis to test whether infants' and mothers' pointing frequency predict infants' expressive vocabulary. We followed the

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TABLE 3 Infants' and mothers' pointing frequency predicting infants' receptive and expressive vocabulary size.

Outcome Variables	***Receptive Vocabulary at* 14 months**					***Expressive Vocabulary at* 18 months**				
Predictors	***β***	***p***	***R²***	**Δ*R²***	**F-change**	***β***	***p***	***R²***	**Δ*R²***	**F-change**
Step 1		0.544	0.056	−0.033	0.544		0.001***	0.547	0.476	0.001
Receptive vocabulary at 14 months	-	-	-	-	-	0.730	0.000***			
Maternal education years	−0.036	0.877				0.225	0.181			
Mothers' index finger pointing at 14 months	0.248	0.286				−0.145	0.39			
Step 2		0.401	0.134	0.004	0.197		0.003**	0.568	0.472	0.360
Receptive vocabulary at 14 months	-	-	-	-	-	0.687	0.000***			
Maternal education years	0.067	0.778				0.280	0.123			
Mothers' index finger pointing at 14 months	0.262	0.253				−0.126	0.363			
Infants' whole-hand pointing at 14 months	−0.298	0.197				−0.163	0.461			
Step 3		0.262	0.232	0.070	0.136		0.009**	0.570	0.443	0.819
Receptive vocabulary at 14 months	-	-	-	-	-	0.673	0.002**			
Maternal education years	0.021	0.929				0.275	0.142			
Mothers' index finger pointing at 14 months	0.216	0.332				−0.127	0.468			
Infants' whole-hand pointing at 14 months	−0.165	0.487				−0.151	0.430			
Infants' index finger pointing at 14 months	0.339	0.136				0.042	0.819			

*<0.05, **<0.01, ***<0.001.

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TABLE 4 Infants' and Mothers' Pointing Frequency Predicting Their LWL Scores at 14 months.

Outcome Variables	*LWL Accuracy*					*LWL RT*				
Predictors	***β***	***p***	R^2	ΔR^2	**F-change**	***β***	***p***	R^2	ΔR^2	**F-change**
Step 1		0.242	0.087	0.087	1.489		0.352	0.065	0.065	1.081
Maternal education years	0.074	0.688				−0.041	0.825			
Mothers' index finger pointing at 14 months	−0.313	0.097				0.267	0.160			
Step 2		0.142	0.164	0.086	1.955		0.371	0.098	0.032	1.082
Maternal education years	0.152	0.416				−0.092	0.634			
Mothers' index finger pointing at 14 months	−0.335	0.070				0.281	0.140			
Infants' whole-hand pointing at 14 months	−0.285	0.109				0.186	0.307			
Step 3		0.086	0.239	0.085	2.273		0.115	0.220	0.122	2.040
Maternal education years	0.054	0.774				0.032	0.868			
Mothers' index finger pointing at 14 months	−0.403	0.031*				0.367	0.050*			
Infants' whole-hand pointing at 14 months	−0.156	0.405				0.021	0.909			
Infants' index finger pointing at 14 months	0.323	0.101				−0.411	0.042*			

*<0.05, **<0.01, ***<0.001.

same steps as in the previous analyses but added infants' receptive vocabulary scores at 14 months as a control variable into the first step of the model since there was a significant correlation between infants' receptive and expressive vocabulary scores. The summary of these regression analyses can be seen in Table 3. For predicting infants' expressive vocabulary scores at 18 months, the models at steps 1, 2, and 3 were significant in explaining variance but mothers' index-finger pointing frequency, infants' whole-hand, and infants' index-finger pointing were not significant predictors for infants' expressive vocabulary scores.

3.4 | Prospective relations between infants' and mothers' pointing and infants' lexical processing efficiency

Similar to the concurrent analyses, we ran two hierarchical linear regression analyses on accuracy and RT to test our hypothesis that infants' and mothers' pointing frequency predict infants' LPE

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prospectively, and to see whether infants' index-finger pointing frequency is a better predictor than whole-hand pointing. We followed the same steps as in the previous analyses but added infants' sex as a control variable into the first step of the model for accuracy analysis since there was a significant correlation between infants' sex and accuracy scores. Since we have only 24 infants who participated in the LWL session both at 14 and 18 months, and there were no correlations between infants' LWL accuracy and RT scores at 14 and 18 months derived from these 24 infants, we did not add infants' LWL scores at 14 months as a control variable. Therefore, the following analyses were conducted with 30 participants. For predicting infants' accuracy scores at 18 months, the model at step 1 was significant, but mothers' index-finger frequency was not a significant predictor for infants' accuracy scores at 18 months. The model at step 2 was also significant for predicting infants' accuracy scores, but infants' whole-hand pointing frequency was not a significant predictor for infants' accuracy scores at 18 months. However, the model at step 3 was significant, and infants' index-finger pointing frequency emerged as a significant predictor for their accuracy scores at 18 months. For predicting infants' RT scores at 18 months, the models at step 1 and 2 were not significant in explaining any variance, respectively. However, the model at step 3 was significant, and infants' index-finger pointing frequency emerged again as a significant predictor for accuracy scores at 18 months. The summary of regression analyses for all models can be seen in Table 5.

As explained in the participants section, the remaining sample size used in the analyses of prospective relations was 30. We performed a post-hoc sensitivity analysis using the G*Power software package (Faul et al., 2007) to inspect whether the statistical power was sufficiently high to detect the effect sizes found in the present study. This analysis yielded a power of 0.70 ($R^2 = 0.433$) for accuracy and 0.74 ($R^2 = 0.419$) for RT, which approximate the conventional power level of 0.80 typically desired in psychological sciences. Considering the practical and methodological difficulties in infant research especially regarding longitudinal designs and technical equipment like eye-tracking, and in comparison to previous studies, these power values appear acceptable.

4 | DISCUSSION

Infants' pointing production (e.g., Colonnesi et al., 2010; Goldin-Meadow, 2007) and maternal pointing input (e.g., Iverson et al., 1999; Rowe, 2000; Salo et al., 2019) are critical indicators of infants' concurrent and prospective language development. Previous studies examined the relation between infants' and mothers' pointing and infants' language development by using indirect assessments of children's language such as Macarthur-Bates CDI (e.g., Iverson & Goldin-Meadow, 2005; Salo et al., 2019). However, mothers might overestimate or underestimate their infants' vocabulary (e.g., Houston-Price et al., 2007; Reese & Read, 2000). Studies using LPE as a more direct measure of vocabulary, on the other hand, focused on maternal verbal input and infants' vocabulary (e.g., Weisleder & Fernald, 2013), but not gestures. The current study investigated whether the maternal pointing gesture input and infants' early use of whole-hand and index-finger pointing at 14 months are associated differently with infants' concurrent and prospective vocabulary skills measured by direct and indirect measurements. The main finding is that infants' index-finger pointing, but not whole-hand pointing, at 14 months prospectively predicts their LPE at 18 months.

We expected that the pointing frequency of mothers at 14 months would be related to infants' concurrent and prospective parent-reported vocabulary size and LPE as a direct measure of vocabulary. Our results demonstrated that the frequency of mothers' pointing was neither concurrently nor prospectively associated with infants' vocabulary scores assessed with either direct or indirect measurements, along with no correlation between maternal pointing and infant pointing. This is

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TABLE 5 Infants' and Mothers' Pointing Frequency Predicting Their LWL Scores at 18 months.

Outcome Variables:	*LWL Accuracy*					*LWL RT*				
Predictors	***β***	***p***	R^2	ΔR^2	**F-change**	***β***	***p***	R^2	ΔR^2	**F-change**
Step 1		0.050*	0.256	0.256	0.050		0.363	0.072	0.072	1.053
Infants' sex	−0.475	0.11				-	-	-	-	-
Maternal education years	−0.159	0.402				0.286	0.163			
Mothers' index finger pointing at 14 months	0.264	0.162				−0.149	0.463			
Step 2		0.045*	0.313	0.057	0.162		0.557	0.075	0.003	0.706
Infants' sex	−0.656	0.005				-	-	-	-	-
Maternal education years	−0.295	0.164				0.269	0.214			
Mothers' index finger pointing at 14 months	0.315	0.097				−0.143	0.491			
Infants' whole-hand pointing at 14 months	0.309	0.162				0.056	0.776			
Step 3		0.013*	0.433	0.120	0.033		0.007**	0.419	0.344	4.512
Infants' sex	−0.504	0.023				-	-	-	-	-
Maternal education years	−0.339	0.090				0.442	0.019			
Mothers' index finger pointing at 14 months	0.296	0.094				−0.152	0.367			
Infants' whole-hand pointing at 14 months	0.332	0.108				−0.126	0.454			
Infants' index finger pointing at 14 months	0.390	0.033*				−0.624	0.000***			

*<0.05, **<0.01, ***<0.001.

inconsistent with previous findings which found significant concurrent relations between mothers' and infants' pointing frequency within the age range of 10–14 months (e.g., Liszkowski et al., 2012; Rowe, 2000; Rowe & Goldin-Meadow, 2009) and between mothers' pointing and infants' language skills (e.g., Pan et al., 2005; Rowe, 2000). One difference to previous studies is that while most studies used free-play sessions to observe the pointing use of mother-infant dyads, we used the decorated room paradigm, which was designed to elicit pointing. Liszkowski et al. (2012) did find a correlation using the decorated room paradigm, which is the same paradigm used in the current study, however across a wider age range entailing more variance in pointing. A recent study (Rüther, 2019) examined

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infants' and parents' gestures, including pointing, across settings of home visit, free play, and decorated room, suggesting that parents used more pointing gestures in the decorated room sessions than at home visits. Possibly, mothers' pointing patterns in the decorated room may not reflect their pointing patterns at home and not correlate with infants' pointing frequency and vocabulary skills assessed with direct and indirect measurements. For instance, a recent study using the decorated room paradigm demonstrated that parents' index-finger pointing at 12 months neither predicts infants' pointing at 12 or 18 months nor infants' vocabulary size at 24 months (Lüke et al., 2017). On the other hand, Rüther and Liszkowski (2023) did find predictive and concurrent correlation patterns between infant and parent pointing within the age range of 8–13 months using the decorated room, which suggests that coding and sample characteristics need to be further explored in future research.

Besides these methodological differences, in this relatively older age range, infants frequently use pointing gestures to indicate that they want to actively learn about an object (Begus et al., 2014; Lucca & Wilbourn, 2019). Hence, in infants' word learning, their own pointing may start to play a more prominent role than maternal pointing. That is, infants may point to objects for which they request information, rather than passively learning about objects that their mothers point to.

Moreover, a previous study demonstrated that there is an association between maternal verbal input and infants' LPE (Weisleder & Fernald, 2013) and vocabulary size (Fernald & Marchman, 2011). Since maternal pointing accompanied by verbal input may be more effective in affecting infants' vocabulary skills than pointing alone, we explored whether there was accompanying speech to mothers' pointing. Almost all, that is, 99% of the mothers' pointings were accompanied by vocalization and/or speech. Thus we could not test whether mothers' co-speech pointing gestures would be a better predictor than pointing gestures alone. Furthermore, it may also be important whether infants pay attention to the referent of maternal points. Therefore, we additionally attempted to examine infants' attention to the referent, which their mothers pointed at. However, in the current paradigm, the vast majority of points are situated within an already shared focus of attention, so that it was not possible to investigate this factor further.

Our second hypothesis was that infants' index-finger pointing would be a better predictor of their concurrent and prospective vocabulary skills than whole-hand pointing. In line with our hypothesis, we found that infants' index-finger pointing frequency at 14 months, but not their whole-hand pointing frequency, predicted their prospective LPE at 18 months. This finding corroborates the existing evidence that infants' index-finger pointing, but not other gestures, predicts their word comprehension at later ages (Lüke et al., 2016; Özçalışkan et al., 2015). Moreover, we present evidence from an earlier age window for the link between infants' index-finger pointing and LPE. These findings suggest that index-finger form in pointing may require certain underlying skills that exclusively contribute to language development (Leung & Rheingold, 1981). For one, we know that infants who already point with their index fingers comprehend pointing in terms of underlying referential intentions better compared to infants who only point with their whole hand (Liszkowski & Tomasello, 2011; Rüther & Liszkowski, 2020). This may mean that infants who point with the index finger are likely to point with a specific referential intention to communicate, and potentially with the expectation to receive verbal responses from caregivers that are relevant to the referent of their pointing. In turn, they may be more receptive to benefit from this input that comes as a response to their points. In addition, infants who frequently point with the index finger and thus understand referential intentions behind the pointing might also better understand referentiality of verbal input. In a similar vein, Ronfard et al. (2021) demonstrated that toddlers' LWL scores were associated with their pragmatic abilities, which include, for example, using language to obtain information and adapting conversations to other individuals. Researchers have suggested that pragmatic understanding promotes language learning, especially word learning (e.g., Tomasello, 2000). Accordingly, infants' understanding of referentiality may lead

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them to perform better in the LWL task, which taps into infants' understanding of referential intention and shifting their look toward the intended target of a word accordingly.

Alternatively, infants' whole-hand pointing may be perceived as a reaching or an imperative gesture by mothers. For this reason, mothers may approach or move away from that object (especially in the current decorated room context where touching is instructed to be avoided) rather than producing referential speech about that object. Indeed, a previous study showed that parents gave more prohibitive responses to their infants' whole-hand pointing than index-finger pointing in the decorated room paradigm (Ger et al., 2018). On the contrary, Lüke et al. (2017) demonstrated that caregivers' responses were similar to both the index-finger and whole-hand points of their 12-month-old infants. Furthermore, they also found that caregivers responded more often with a description when their 18-month-old infants pointed with a whole hand than with an index finger. But this behavior did not correlate with infants' later language development. This lack of a predictive effect of caregivers' descriptive response to whole-hand points on language suggests that the role of different hand shapes on language does not result from caregiver responses. It is possible that infants' index-finger pointing can enhance their lexicon by establishing a better connection between referent pointed at and verbal input, such as labels, than whole-hand pointing.

Our findings revealed that infants' index-finger pointing frequency at 14 months only predicted their prospective, but not concurrent LPE. For mothers to understand which object infants are pointing at, mothers should follow the path of pointing gestures to its target, so pointing gestures serve demonstrative pronouns' ("this" or "that") function (Goldin-Meadow & Alibali, 2013). Therefore, pointing gestures may signal to mothers that their infants would like to learn about the objects gestured at. Indeed, mothers respond to infants' gestures in ways that facilitate language learning, such as labeling, describing, or commenting on an object (Ger et al., 2018; Kishimoto et al., 2007; Masur, 1982; Olson & Masur, 2015). Thus, when infants point to an object, they are more likely to receive a label for the object from their mothers (Lüke et al., 2017). However, we know that especially in the early years of word learning, infants need many more instances of word-to-world labeling situations, such as pointing to an object and hearing its name, before it actually enters their lexicon (Iverson & Goldin-Meadow, 2005; Rowe et al., 2022). For instance, infants' fast mapping through their pointing seems to develop sometime between 12 and 18 months of age (Lucca & Wilbourn, 2016). Moreover, even though 24-month-old infants can fast-map a novel label to a novel object, they show very poor retention (Horst & Samuelson, 2008). Hence, at 14 months of age, infants may need more repeated and cross-situational exposure to object labels in response to their pointing before that label is actually learned and retained. This may explain why the current study found a predictive, but not concurrent, relation to LPE.

Our results showed a direct correlation between infant pointing at 14 months and expressive vocabulary at 18 months only. However, our regression models did not provide evidence for a relation between infant pointing and their expressive vocabulary size when controlling their receptive vocabulary. Contrary to our regression model in predicting infants' expressive vocabulary, Roemer and colleagues (2018) provided evidence for infant gesture and receptive vocabulary to predict later expressive vocabulary by showing that infants' receptive vocabulary at 14 months mediates the relation between gestures at 12 months and expressive vocabulary at 18 months in a different population, that is, younger siblings of children with autism spectrum disorder. But, they used CDI, a parental report, to measure infants' vocabulary skills and gestures. In addition, the gestures subset of CDI involves different gesture types such as conventional gestures (waving "bye-bye"), showing, reaching, along with pointing; therefore, their results do not provide specific evidence for the relation between pointing and vocabulary. Similarly, our study found no association between infants' pointing and receptive vocabulary at 14 months, according to both correlation and regression results. There is previous research both replicating (e.g., Goldin-Meadow, 2007) and not replicating this relation

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(e.g., Blake et al., 2003), suggesting the need for rigorous methodological analyses. As said above, parental reports may underestimate or overestimate infants' language skills. Parents' estimation errors may be especially true for infants in the targeted age group, who are very young and not producing speech robustly. In addition, parents of low SES backgrounds overestimate infants' vocabulary (Reese & Read, 2000). Mothers who participated in our study come from diverse SES backgrounds, and may have underestimated or overestimated their infants' vocabulary knowledge. Therefore, infants' parent-reported receptive and expressive vocabulary scores might not reflect their actual vocabulary skills, and this may be the reason that infants' vocabulary scores and pointing were not clearly associated.

Lexical processing efficiency represents how fast and accurately infants process and recognize known words (Lany, 2017; Ronfard et al., 2021). Research has investigated the predictive power of LPE. For example, mothers' verbal input is associated with infants' and toddlers' LPE (Weisleder & Fernald, 2013); infants' and toddlers' early LPE predicts their acquisition of new words, vocabulary growth, and vocabulary size (Fernald et al., 2006; Hurtado et al., 2008; Lany, 2017; Peter et al., 2019); and infants' LPE is related to linguistic, cognitive, and social skills, such as vocabulary knowledge, executive function, and pragmatic skills (Ronfard et al., 2021). However, less is known about the factors that may predict infants' early LPE skills. The current study provides new evidence for a relation between infants' index-finger pointing frequency and their later LPE skills. Infants produce pointing gestures not only to direct attention, but to receive comments (Kishimoto et al., 2007; Liszkowski et al., 2004) and engage in shared interactions (Leung & Rheingold, 1981; Liszkowski et al., 2012), which entails obtaining and learning new information, including word labels (Begus & Southgate, 2012; Kovács et al., 2014; for reviews, see Harris, 2019; Rowe et al., 2022). Since infants' index-finger pointing is underlain by referential intentions and associated with understanding the referential communicative intentions of the pointing gesture better (Liszkowski & Tomasello, 2011), when infants point with the index-finger, they may be more sensitive to the referential verbal labels they receive, or more ready to learn about the world generally (Lucca & Wilbourn, 2016).

One limitation of the current study may concern the paradigm we used to measure mothers' and infants' pointing frequency. We used a paradigm specifically designed to elicit pointing behavior. Therefore, the frequency of pointing produced by the mother-infant dyads during this paradigm might have been overestimated and may not fully reflect their everyday pointing usage (see Salomo & Liszkowski, 2012). Even though our data includes mothers who did not point at all during the 5-min session, we cannot ensure that the participants', especially mothers, pointing behaviors in our paradigm were nevertheless representative of their pointing in their natural contexts. Another limitation may concern the sample size, such that only 24 infants provided the LWL data both at 14 and 18 months. Due to the small sample size, we could not control their LPE scores at 14 months in the analyses for the prospective relation between maternal and infant pointing and infants' LPE scores.

In conclusion, the current study investigated the relation between maternal pointing, infants' whole-hand, and index-finger pointing and infants' vocabulary skills assessed with both a direct LPE measure and an indirect parental report measure since there are inconsistent results regarding infants' pointing and parent-reported receptive vocabulary. In addition, some past research demonstrated that mothers might make estimation errors regarding their infants' vocabulary skills. Our study demonstrated that neither maternal pointing nor infants' pointing predicted their receptive and expressive vocabulary based on parental reports. Similarly, mothers' pointing and infants' whole-hand pointing did not predict concurrent and prospective LPE. However, infants' index-finger pointing predicted their later LPE. Namely, while we found no relation between infants' index-finger pointing and parent-reported vocabulary size, consistent with some of the previous findings, we demonstrated such a relation with infants' LPE as a direct measure. Findings corroborated the evidence that the hand shape of pointing plays an important

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role in the relation between infants' pointing and their language skills (Liszkowski & Tomasello, 2011; Lüke et al., 2017; Rowe et al., 2022). Crucially, the results extended the evidential basis of a relation between index-finger pointing and language acquisition to a more direct measure of vocabulary.

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ORCID

Sura Ertaş https://orcid.org/0000-0001-5614-0625
Sümeyye Koşkulu-Sancar https://orcid.org/0000-0001-9221-2294
Ebru Ger https://orcid.org/0000-0002-6140-1807
Ulf Liszkowski https://orcid.org/0000-0003-4294-3632
Aylin C. Küntay https://orcid.org/0000-0001-9057-7556

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