Spatial Language Development in Preterm and Full-Term Infants: The Role of Object Exploration and Parents' Spatial Input

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Research Highlights

- Investigating the relation among object exploration, parents' spatial input, and spatial language development in preterm and full-term infants.
- Preterm and full-term groups were similar in object exploration. However, parents used more spatial input with full-term than preterm infants.
- Parents' spatial input co-occurred with 44% of the object exploration events, which was lower for preterm (*M*=36.1%) than full-term (*M*=52.1%) infants.
- The interaction between object exploration and parents' spatial input at Time 1 (M_{age}= 13.7 months) predicted spatial language at Time 2 (M_{age}= 26 months), regardless of the neonatal condition.
- Both preterm and full-term children who explored objects longer and received more spatial input at Time 1, knew more spatial words at Time 2.
- This interaction may lead to a cascading effect on spatial language development, regardless of neonatal condition.

Abstract

Infants learn object features and relations among objects by exploring them. Object exploration and parents' verbal input related to these spatial characteristics may lead to cascades for the development of spatial language. This longitudinal study examined whether infant object exploration and parents' spatial input at Time 1 (M_{age}=13.7 months) predicted spatial language of preterm (Mean gestational age=30 weeks) and full-term infants (Mean gestational age=38.9 weeks) at Time 2 (M_{age}= 26 months). The object exploration and parents' spatial input at Time 1 were coded from the semi-structured free play sessions, and infant spatial language was assessed via a parental report at Time 2. Our results showed no differences between preterm and full-term groups on object exploration. However, parents' spatial input differed based on neonatal condition, in which preterm infants received less input than full-term infants. Parents' spatial input co-occurred with 44% of the object exploration events, with a significant difference between groups (preterm: *M*=36.1% and full-term: *M*=52.1%). Importantly, the interaction between object exploration and parents' spatial input at Time 1 predicted children's spatial language knowledge at Time 2, regardless of children's neonatal status. Infants who explored objects for longer periods and received greater spatial input from their parents at Time 1 knew more spatial words at Time 2 than infants who explored objects less and received less input at Time 1. These findings suggest that early object exploration and parents' spatial input can together lead to a cascading effect on later spatial language development for both preterm and full-term infants.

Keywords: object exploration, spatial language, parental input, preterm infants

Spatial Language Development in Preterm and Full-Term Infants: The Role of Object Exploration and Parents' Spatial Input

The ability to understand and explain spatial concepts is one of the biggest challenges for children, especially in the early stages of their lives. Children's first receptive words usually include common nouns such as social words like *mommy*, *daddy or hi* or object words such as *ball* (Bergelson & Swingley, 2012; Casey et al., 2023; Tincoff & Jusczyk, 2012). The relational nature of spatial words makes them more difficult to learn than these words during infancy. However, infants as young as 2 years old already begin to learn relational words. Previous studies have mostly focused on preschool children or toddlers (Ferrara et al., 2011; Miller et al., 2017; Pruden & Levine, 2017), but the predictors behind spatial language development at younger ages have yet to be thoroughly studied. Moreover, the focus has been on typically developing children and less is known about atypical developmental trajectories.

Nearly 1 out of every 10 children born is preterm (i.e., born before 37 weeks of gestational age; Chawanpaiboon et al., 2019). Preterm infants often experience delays in both cognitive and motor development compared to their full-term peers (e.g., Caravale, 2005; Foster-Cohen et al., 2007; Sansavini et al., 2011). However, less is known about how these delays specifically affect spatial language development. While it is well-established that preterm infants tend to lag behind full-term infants in general language development, the unique pathways through which motor and cognitive delays might influence spatial language have not been thoroughly explored.

This longitudinal study aims to fill this gap by investigating two key factors that contribute to spatial language development in early years: child object exploration and parental spatial language input. We examine how these predictors, influenced by neonatal condition, affect spatial language development in both preterm and full-term infants. We also examine the real-time co-occurrence of child object exploration and parental spatial language input, and how the interaction between these factors at around 14 months (Time 1) predicts spatial language outcomes at around 26 months (Time 2). By focusing on the relationship among object exploration, parental input, and spatial language, this study aims to uncover the ways in which preterm and full-term infants' developmental trajectories may shape their spatial language and how the neonatal condition affects these trajectories.

Spatial language development

Spatial words encompass terms that relate to spatial concepts such as dimensions, shapes, features, patterns, locations, orientations, and deictics. These words describe actions in spatial areas with verbs (e.g., turning), features of objects with adjectives (e.g., like small or big), and relations between objects with prepositions (e.g., on, under). In their first year, infants can differentiate event components (Göksun et al., 2011), categorize containment, and support relations between two objects (Casasola, 2008, 2018). After detecting these spatial relations, infants map the labels onto them (Gentner & Boroditsky, 2001). This process is complex due to the relational nature of spatial words (Gentner, 2016). A part of this learning process happens when children have more cognitive resources to understand these relations (Turan et al., 2021). For example, to understand "left" or "right," children need to encode a viewpoint (based on either their body position or the position of the target entity), and they need to impose this viewpoint on spatial relations (Newcombe & Huttenlocher, 2000).

Children do start to learn some spatial words after their first year. The first spatial words that can be comprehended and produced by infants are "in," "on," and "under" in different languages such as English, Turkish, or Hebrew (Bowerman, 1996). Even with little exposure, in their second year, infants can learn to label objects related to spatial words such as shapes (e.g., Heibeck & Markman, 1987; Verdine et al., 2016). Children who learn English, Italian, or Turkish can comprehend the term "near" at around 2.5 years old and express it at 3 years old (Johnston, 1988). These studies showed the milestones for different spatial word groups for full-term infants. However, the acquisition of spatial language in children at risk of language developmental delays, such as preterm children, is understudied.

Preterm infants show delays in both receptive and expressive language development (e.g., Caravale, 2005; Foster-Cohen et al., 2007; Sansavini et al., 2011), as well as in gesture production (for a review, see Demir-Lira & Göksun, 2024). Studies on early spatial language development in preterm children are scarce and mostly blended with general language development analyses. A meta-analysis by Van Noort-van Der Spek and colleagues (2012) covered seven studies with preterm children. Results showed that between 3 and 12 years, preterm children are behind full-term children for complex language functions (i.e., the complete assessment of preposition knowledge, verb knowledge, grammar competence, and linguistic complexity), including spatial language. A recent study, however, found no difference in spatial language use in a puzzle-playing task between preterm and full-term preschoolers (Clingan-Siverly et al., 2021).

Early Predictors of Spatial Language: Object Exploration and Parents' Spatial Input

Language development, including spatial language, emerges through real-time social and physical interactions (Hollich et al., 2000). Vocabulary development at around 12 months is related to perceptual associations such as visual and manual engagement with objects and the naming of these objects by parents (Smith, 2013). Parental interaction shapes children's learning when they explore objects (Tamis-LeMonda et al., 2013). Parents canalize infants' exploration efforts to more effective learning processes. McQuillan and colleagues (2020) found that these engagements during object exploration increased learning opportunities for object features visually. Object exploration, such as holding or turning objects, provides informative moments for the visual system. Furthermore, visual representations based on object shapes are key factors in mapping processes for language development (Yu & Smith, 2012).

Object exploration

Object exploration is one of the primary ways children interact with and understand their environment during infancy (Masek et al., 2021). Manual actions can diverge from rhythmic movements, such as shaking, towards goal-directed movements, such as reaching and holding. Around six months, infants demonstrate more complex behaviors, such as turning and looking simultaneously (Lobo et al., 2015). Manual and visual exploration together provide a broad range of information about objects.

Object exploration promotes the development of spatial skills from a very early age (Möhring & Frick, 2013; Schröder et al., 2020; Slone et al., 2018). In addition to its relation to spatial skills, it plays a specific role in spatial language development. Object exploration provides the opportunity to learn and manipulate perceptual information about the spatial features of objects and the spatial relations among the objects (Samuelson, 2021). Object exploration is not only manipulating one object, but also allows a focus on relations. Infants can also "put" an object "on" a table or "throw" an object "in" a box.

Preterm infants start to explore objects later than typically developing children (Lobo et al., 2015). The frequency of object exploration for preterm children is less than for full-term peers at around 6 months (Lobo et al., 2015; Zuccarini et al., 2016). However, the results are mixed after 6 months. Some studies showed that preterm infants closed the gap at 9 months for object exploration (e.g., Zuccarini et al., 2017) whereas others found delays for preterm infants' object exploration at 9 months (e.g., Babik et al., 2017; Ruff et al., 1984).

For preterm infants, only a few studies have examined the connection between object exploration and cognitive skills. For example, Ruff and colleagues (1984) investigated the relationship between early object exploration and later cognitive development with typical and atypical preterm (i.e., preterm infants with unilateral or bilateral neurological damage) and full-term infants. Object exploration at 9 months predicted preterm children's cognitive skills (eye-hand coordination, imitation and comprehension, and social/active vocabulary) at 24 months. Zuccarini and colleagues (2017) also found that object exploration of extremely preterm infants at 6 and 9 months predicted language and cognitive skills measured with the General Development Quotient at 24 months. Object exploration may not be the direct source of spatial language development, but it may be effective in the relation between parents' spatial input and spatial language development. Identifying the predictors of spatial language development such as object exploration and parents' spatial input is important to understand the supportive factors for preterm children's spatial language development.

Previous studies that involve object exploration (i.e., fine motor toys such as blocks or cups) and spatial exploration (i.e., gross motor toys such as tunnels or hoops) showed the roles of object exploration in spatial language development (Oudgenoeg-Paz et al., 2015, 2016). For example, Oudgenoeg-Paz and colleagues (2015) found that spatial exploration at 20 months mediated the relation between sitting onset and spatial language at 36 months. In a further study, exploration at 20 months mediated the relationship between walking onset and spatial language at 43 months (Oudgenoeg-Paz et al., 2016). Unlike these previous studies that focused on the link among gross motor skills, such as walking, spatial exploration, and spatial language, our study investigates the relationship among early object exploration, parents' spatial input, and subsequent spatial language development in full-term and preterm groups.

Parents' spatial input

Parental input, both the quantity and quality is critical for language development in infants (Anderson et al., 2021). The role of parental input is not unidirectional and can be moderated by children's dynamically changing developmental status (Göksun et al., 2025). Object exploration may co-occur with parents' spatial input, and the interaction between them promotes spatial language development in preterm and full-term infants.

Spatial language development unfolds with the support of parents' spatial input during social interactions. Parents' spatial input contains words that describe objects' sizes, shapes, features, and orientations, deictics such as here or there, and location words such as prepositions or amount words (Cannon et al., 2007; Kısa et al., 2019). Pruden and colleagues (2011) found that parents' spatial input from 14 months to 46 months predicted children's spatial skills at 54 months, and children's spatial word knowledge mediated this link. Parental talk about space between 2 and 4 years predicted spatial language development of girls at around four years (Levine et al., 2012). Kısa and colleagues (2019) found that parents' spatial input increased by age between 16 and 20 months. These studies indicate that parents' spatial input in early childhood boosts spatial language development, and its effect increases with age.

A few earlier studies showed that preterm and full-term infants hear similar amounts of overall parental input (Adams et al., 2018; Salerni et al., 2007; but see Özdemir et al., 2024) that are independent of birth status or health history. In the first two years of life, preterm and full-term infants also receive similar types of specific input, such as talking about causal relations (Özdemir et al., 2024) or using sound symbolic words such as *woof woof* (Esmer et al., 2024). Talking about objects, actions, relations, and concepts enriches learning opportunities for language and cognitive skills of preterm infants from low SES families. Clingan-Siverly and colleagues (2021) found no difference in speech and gesture-based language between 3- to 5-year-old preterm and full-term children. Furthermore, regardless of neonatal condition, parents' spatial input in both modalities was related to children's mental transformation scores through children's use of spatial language.

Parents' spatial input plays a critical role in the spatial language development in infants, including preterm infants, but this relation might be changed depend on the other interactions between the child and the environment, such as exploration (Göksun et al., 2025). Spending more time on object exploration might moderate the relation between parents' spatial input at Time 1 and spatial language development at Time 2 for both full-term and preterm infants. However, preterm infants might be affected by this interaction between object exploration and parents' spatial input more than full-term infants due to possible delays in object exploration and parents' spatial input. The exploration provides both manual (touch and manipulation) and visual (looking and observing) experiences, and these experiences, when followed by timely and relevant parental input, are crucial for the learning process (Smith, 2013). Thus, the co-occurrences between their own actions and their parents' input might be another factor for the development of spatial language.

The current study

This study investigates the relations among infants' object exploration, parents' spatial input at Time 1, and children's spatial language at Time 2 in preterm and full-term groups. Time 1 included infants between 10 and 18 months, and Time 2 included the same infants tested after a year from their first testing. Infants reliably comprehend and produce spatial words after 24 months (Bowerman, 1996). For example, the proportion of children who can produce "big" at 26 months is approximately 75% among English learners and 50% among Turkish learners (Frank et al., 2017). However, previous studies (e.g., Pruden et al., 2011) usually focused on preschool-aged children. Investigating spatial word development at two years of age (i.e., Time 2, M_{age} = 26 months) is essential to understanding the early markers and cumulative experience behind spatial language development.

We investigated infants at Time 1 (M_{age}= 13.7 months) for object exploration because infants show object exploration behaviors primarily with fine motor toys during this time. Importantly, object exploration behaviors change after the first year of life. Infants start to engage in gross motor toys and spatial (or locomotor) exploration after the first year, which changes the exploration of the spatial area, and spatial features of objects (e.g., Hoch et al., 2020; Oudgenoeg-Paz et al., 2015, 2016). Thus, focusing on this early period uniquely enables us to examine the role of early object exploration. Our first time point is particularly conducive to studying parental input, as children's oral language skills are still limited between 10 and 18 months of age. We have three main questions: (1) Do preterm and full-term infants differ in their object exploration and spatial input they receive from their parents at Time 1? (2) Does object exploration co-occur with parents' spatial input in real-time for both groups at Time 1? (3) Does the interaction between object exploration and parents' spatial input at Time 1 predict the spatial language of infants at Time 2?

For the first question, we expect that preterm and full-term groups will differ in object exploration and the amount of parental spatial input they receive. Based on the previous research (Lobo et al., 2015; Ruff et al., 1984), we expect that at Time 1, preterm infants will significantly explore objects less than full-term infants. Although a previous study (Clingan-Siverly et al., 2021) found no difference between preterm and full-term preschoolers in receiving parental spatial input, we still do not know whether younger preterm children hear fewer spatial words from their parents than full-term infants in the first two years.

For the second question, we hypothesize that object exploration co-occurs with parents' real-time spatial input. Previous studies showed that infants' actions and parental input support language development with co-occurrences in real time (McQuillan et al., 2020;

West et al., 2022). However, the real-time co-occurrences of object exploration and parents' spatial input have yet to be studied. The object exploration events of the infants may be preceded or followed by parents' spatial input. We expect preterm infants to have significantly fewer co-occurrences than full-term infants because preterm infants have delays in object exploration and may receive less spatial input. Less engagement with objects (due to weaknesses in motor development, (e.g., Benassi et al., 2016; Caravale, 2005; Kobaş et al., 2023) may decrease the real-time co-occurrences between parents' spatial input and object exploration. We also expect the duration of object exploration events that co-occur with parents' spatial input to be significantly longer than object exploration events that do not co-occur with spatial language input because co-occurrences promote longer object exploration with joint engagement (McQuillan et al., 2020). The co-occurrences indicate the temporal overlaps between parents' spatial input and object exploration events. However, previous studies showed that the total amount of parents' spatial input is the predictor for spatial language development (e.g., Pruden et al., 2011), and object exploration duration (e.g., Zuccarini et al., 2017) is the predictor for language development. Therefore, we aim to investigate these in our third question.

For the third question, we hypothesize that the interaction between the total duration of object exploration (with or without spatial input) and the total amount of parents' spatial input (with or without object exploration) will predict infants' spatial language at Time 2. We expect that the effect of parents' spatial input on spatial language depends on object exploration. For example, infants who hear more spatial input from their parents may have better spatial language knowledge if they explore objects for longer times.

Method

Participants

This paper is part of a longitudinal study investigating preterm and full-term infants' cognitive and language skills.[1]. This study focuses on two time points (Time 1 and 2). Seventy-eight infants (34 girls, 44 boys, *M*age = 13.7 months, *SD* =1.40, range = 10-18 months) participated at Time 1. At this time point, there were 42 preterm infants (i.e., born before 37 weeks, *M*age=13.2 months) and 36 full-term infants (*M*age = 14.2 months). All infants were monolingual Turkish learners. Data was collected from Istanbul, Turkey. At Time 2, there were 48 infants (20 girls, 28 boys, *M*age = 26 months, *SD* =1.21, range = 24-29 months). Twenty-one preterm infants (*M*age = 25.8 months), and 27 full-term infants (*M*age = 26.2 months) participated at this time point. Infants were observed at one-year intervals. For example, an infant who started to join the study at 14 months at Time 1 was observed again at 26 months for Time 2. During data collection at Time 2, the Covid-19 pandemic started, and we could not reach out to all families from Time 1 (all demographic information is presented in Table 1)[2]. We used corrected ages for the preterm infants. Based on cranial ultrasound, 16 preterm children (for Time 1, *M*age=13.7 months, SD=1.68; for Time 2, *M*age=26.3 months, SD=1.17) were reported as having minor medical complications and stayed in intensive care. None of these infants have retinopathy due to prematurity or cerebral palsy. All of these infants could attend and participate in sessions. The subset of preterm infants with medical complications was not different from other preterm infants for maternal education, object exploration, parents' spatial input, word comprehension at Time 1, and

[1] The larger dataset collected during this longitudinal study on term and preterm-born infants' cognitive development was used for various other publications. However, the specific data and research questions reported here differed from previous work published from the longitudinal study (Author, 2024; Author, 2022; Author, 2023; Author, 2024). The only overlap was TCDI-1 data used in the earlier studies. Even though other studies used play sessions, these studies focused on different types of parental input (causal and sound symbolic input).

[2] We compared dropout participants and non-dropout participants in terms of demographic characteristics. For age, birth weight, gestational age, and maternal education, there were no significant differences between dropout participants and non-dropout participants, all *p*s>.05.

spatial language at Time 2 (all *p*s>.05). Thus, we merged the two groups for the rest of the analyses.

Parents of infants gave informed consent, and XX University's Institutional Review Board approved the study (Project name: A longitudinal study of examining preterm and full-term children's early language and cognitive development-Protocol no: 2018.118.IRB3.083).

Table 1. Demographic information of children born full-term and preterm

	Preterm		Full-Term		X^2 or t	*p*	d
Time 1	Mean or %	SD	Mean or %	SD			
% Girl	41		47		0.36	*0.55*	-
GA (weeks)	30	3.17	39	1.40	-15.5	*<.001****	-3.51
Birth Weight (g)	1506	533	3297	400	-16.6	*<.001****	*-3.76*
Maternal Education (years)	15	2.01	16	2.06	-2.44	*0.017***	-0.56
Time 2							
% Girl	33		48		1.07	*0.30*	-
GA (weeks)	29	3.15	39	1.44	-14.3	*<.001****	-4.16
Birth Weight (g)	1369	482	3329	440	-14.7	*<.001****	-4.27
Maternal Education (years)	15	1.83	16	1.96	-1.54	*0.131*	-0.45

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

Measures

Time 1 Measures

TCDI-1. Parents completed Turkish Communication Development Inventory-1 (TCDI-1) to assess their infants' language development between 8-16 months. As the Turkish adaptation of MacArthur-Bates CDI, the focus of TCDI-1 is receptive language, expressive language, and early communicative behaviors (Aksu-Koç et al., 2019). TCDI questionnaires were used to administer to both full-term and preterm infants (e.g., Aktan-Erciyes & Göksun, 2019; Kısa et al., 2019; Kobaş et al., 2021, 2023; Özkan et al., 2022).

Vocabulary Checklist, the first part of TCDI-1, consists of 418 items. Parents are expected to assess word comprehension and word production in this checklist. Aksu-Koç and colleagues (2019) found high internal consistency (*Cronbach's α* =.99) for the word comprehension subscale of TCDI-1. This study used the spatial words in the word comprehension subscale as a control variable of early language development. From the word comprehension scale, we defined 20 spatial words (4 verbs, four adjectives, 2 question words, and 10 prepositions). We decided to use these words based on the "System for Analyzing Children’s Language about Space” coding schema (Cannon et al., 2007) and the Turkish adaptation of that schema (Kısa et al., 2019).

Free Play Session. Infants and their caregivers played with toys (1 abacus, 4 cubes, 1 ball, 2 plush toys, and 1 book) together in play sessions for 10 minutes. These sessions were good for obtaining semi-naturalistic observations of infants’ and caregivers’ behaviors. The play sessions measured object exploration and parents’ spatial input. In this session, infants and parents were first welcomed into a silent room with toys and a carpet. Toys were placed on a play carpet where the caregiver and the child sit. Children could easily reach out to the toys without any particular gross movement. The instruction of the experimenter was, “Here, we want you to play with your child as you play at home.” These play sessions were recorded with a camera placed in the corner of the room. We coded object exploration and parents’ spatial input from these sessions at Time 1. We coded the first five minutes of play sessions following previous studies (e.g., Oudgenoeg-Paz et al., 2015).

Time 2 Measures

TCDI-2. Parents were asked to fill out Turkish Communication Development Inventory 2 (TCDI-2). TCDI-2, the Turkish adaptation of MacArthur-Bates CDI, has been administered to examine infants' communicative and language skills (Aksu-Koç et al., 2019). TCDI-2 can be used for infants between 16 and 36 months of age. TCDI-2 includes two parts. The first part is the Words, including 711 items. The items in the Words part are used to measure the expressive language of infants (Aksu-Koç et al., 2019). The internal consistency for the word subscale of TCDI-2 was very high (*Cronbach's α* =.99). For this study, we defined spatial words at 2 years. Then, we summed these words from TCDI-2 to measure spatial language. The total number of spatial words in this subscale is 38. TCDI-2 questionnaires were used to administer to both full-term and preterm infants (Aktan-Erciyes & Göksun, 2019; Kısa et al., 2019; Kobaş et al., 2021, 2023; Yumus & Turan, 2022).

Procedure

Infants were tested at XX University laboratory or Metin Sabancı Healthcare Center. The duration of free play sessions was 10 minutes. These sessions were the last part of a series of studies that took approximately 75 minutes. TCDIs were completed by parents during their participation or via the Internet within a week of testing. Infants received a book as a gift, and parents were compensated for transportation expenses.

Coding

Object Exploration. Object exploration behaviors of infants were coded from play session videos at Time 1, using ELAN software (Lausberg & Sloetjes, 2009). Coders were trained before to agree on at least 80% of the behaviors.

We measured object exploration episodes' duration and frequency (i.e., how often they performed these behaviors). Since there was a high correlation between the frequency and duration of object exploration (r=0.46, p<.001), we used the duration of object exploration in our analyses, following previous studies (e.g., Jarvis et al., 2020). Infants' intentional engagement with objects was coded as object exploration. Following Jarvis and colleagues (2020) these behaviors were classified into 4 subcategories: holding, inspective actions, rhythmic actions, and mouthing. *Holding* is any engagement that includes grasping with a whole hand (i.e., palmar grasp) or fingers (i.e., pincer grasp). *Inspective actions* include turning, fingering, and transferring behaviors. Turning is manipulating objects' spatial orientation to examine or place them better. Transferring is changing an object between hands, and fingering is gentle finger movements on the surface of objects. *Rhythmic actions* include shaking and banging. Shaking is moving the object from forward to backward or other directions repeatedly. Banging is throwing or hitting objects at another one or a place like a wall or floor. *Mouthing* brings objects into the mouth to lick, bite, or hold them.

The intraclass correlation (ICC) analyses showed a high degree of reliability between the two coders for the total duration of object exploration (ICC was .98 with a 95% confidence interval from .960 to .996, $p<.001$).

Parents' Spatial Input. Similar to object exploration, parents' spatial input was coded from the first five minutes of play sessions for this study. The coding schema has been adapted from Cannon et al. (2007). We followed the Turkish version of the coding schema used by Kısa et al. (2019). Blind assistants transcribed all talk in play sessions. The transcriptions were then coded for spatial words or phrases of parents. Spatial words can be categorized under two categories based on their reflection of relations among environmental characteristics (for navigation) or object-related spatial features (for object recognition and usage; Newcombe et al., 2013). We coded words related to size, shape, feature, deictics, amount, location, direction, and orientation of the objects, such as "big" (büyük in Turkish), "square" (kare in Turkish), "front side" (ön yüzü in Turkish), "turning" (çevirmek in Turkish), "here" (burada in Turkish), and "on" (üstünde in Turkish). We coded only the total number of spatial feature words (token) because the token of parental input indicates parents' contribution to language development better than type at around 2 years of age (Anderson et al., 2021). Because we did not have specific predictions regarding subtypes of spatial words used and consistent with the prior studies (e.g., Kısa et al., 2019; Pruden & Levine, 2017), we summed all the spatial words parents used.

The intraclass correlation (ICC) analyses indicated a high degree of reliability between the two coders for the total spatial input of parents (ICC was .97 with a 95% confidence interval from .550 to .992, p<.001).

Co-occurrences between object exploration and parents' spatial input. We calculated co-occurrences between object exploration and parents' spatial input based on a 6-second window surrounding the object exploration event (Bornstein et al., 2008, 2020). If a child receives the spatial input within 3 seconds preceding the object exploration event, within the 3 seconds following the event, or during the event, we count this object exploration event as a co-occurrence. We used the R programming language (R Core Team, 2020) to calculate co-occurrences using the start and end times of each object exploration event and the times when parents provided any spatial input.

Analysis Plan

For our first question, we conducted ANCOVA models to test whether preterm and full-term infants differed in object exploration duration and parents' spatial input. We also examined differences between these two groups in other variables such as children's spatial language knowledge or subcategories of object exploration at Time 1. In these models, the age at Time 1 was the control variable, the related variable was the dependent variable, and the neonatal condition was the independent variable. Correlations between these variables were also assessed.

In addition to individual-level data, we analyzed real-time object exploration events to evaluate differences in neonatal condition for object exploration and spatial input, as well as differences in subcategories of object exploration and the toys provided to infants. A chi-square test of independence was used to examine the relationship between neonatal condition and frequencies of exploration subcategories. We also ran a linear mixed-effects model to analyze the relationship between object exploration durations and subcategories. This model included object exploration duration as the outcome variable, the interaction between neonatal condition (0 = preterm, 1 = full-term) and subcategories, and infants' age (continuous) as fixed effects, with a random intercept for subject.

To investigate whether parental spatial language input varied by the specific object infants manipulated, we ran a binomial mixed-effects model. This model included co-occurrences as the outcome variable, the interaction between neonatal condition, toy type, and infants' age as fixed effects, and a random intercept for each subject. Additionally, we assessed whether object exploration durations differed by toy type, using a separate linear mixed-effects model with similar parameters.

For our second question, we used a linear mixed-effects model to determine whether object exploration events co-occurring with parents' spatial input lasted longer than object exploration events without co-occurrence. The model included the interaction between neonatal condition, co-occurrences, and infants' age as fixed effects, and one random intercept for the subject.

For our third question, we conducted hierarchical linear regression analyses to understand the predictors of child spatial language at Time 2. In Step 1, the model included neonatal condition, infants' age, and spatial word knowledge at Time 1. In step 2, the duration of object exploration and parents' spatial input at Time 1, and in step 3, the interaction term between object exploration and parents' spatial input, calculated as the cross-product of mean-centered terms, were introduced.

We used R and Jamovi stats software to run and check the ANOVA, linear regression models, chi-square test and descriptive statistics (R Core Team, 2020; The Jamovi project, 2020). We used chisq.posthoc.test package to run post-hoc chi-square analyses (Beasley & Schumacker, 1995). We fit mixed effect models using the lmer and glmer functions in the lm4 package (Bates et al., 2015) in R version 4.1.1. We derived p values using the lmerTest package (Kuznetsova et al., 2017), estimated marginal means using the emmeans package (Lenth et al., 2018), and created the figures and calculated the descriptive statistics using tidyverse (Wickham et al., 2019) and interactions (Long, 2024) packages. We omitted the missing data from the final analyses. Since there was no systematic dropout, we treated the missing data as entirely random.

Results

Descriptive statistic and differences between preterm and full-term infants at Time 1

Our first question was whether preterm and full-term infants differed in their object exploration and the spatial input they received from their parents at Time 1. To address this question, we presented descriptive information and age-adjusted comparisons of the key variables for each group in Table 2. Preterm infants were not different from full-term infants for object exploration (see Figure 1a for details). Parents' spatial input significantly differed between full-term and preterm infants, controlling for age at Time 1, $F(1,65) = 5.77$, $p =.019$, partial $\eta 2=.08$ (see Figure 1b for details), where parents of preterm infants provided less input than parents of full-term infants. There were no differences between the two groups for child spatial language knowledge at Time 1.

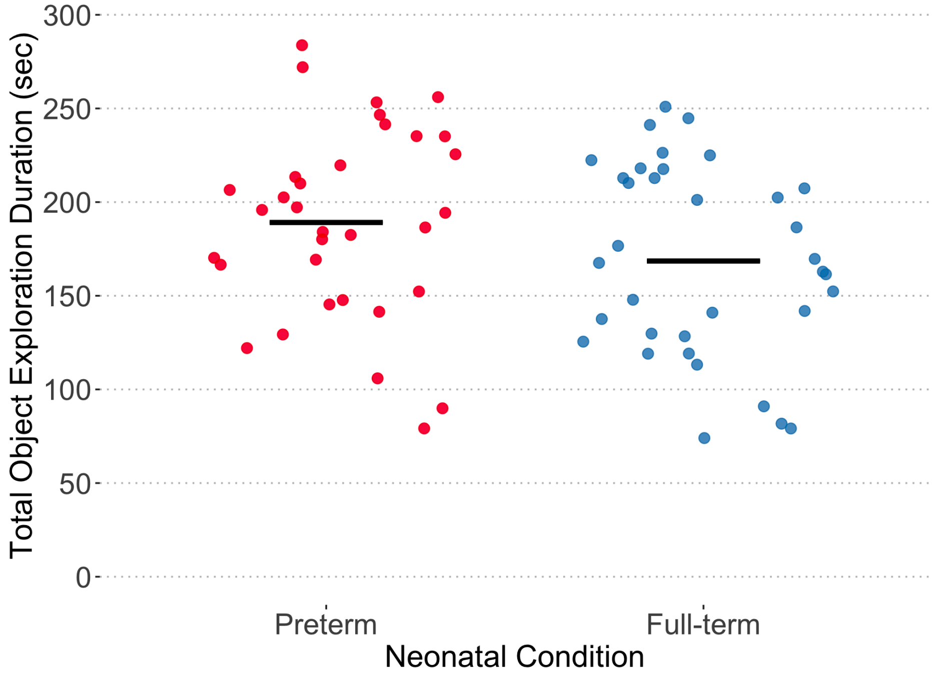
Table 2. Group Differences: Sample Sizes (n), Adjusted Means, Adjusted SDs, ranges, F, p, and partial eta-squared (ηp^2) values for ANCOVAs for preterm and full-term infants controlling related ages. Note that the sample sizes could be different across time points and different variables because children did not attend the related task, or they did not fill out the related form.

	Preterm				Full-Term				ANCOVA		
	n	*M*	*SD*	Range	n	*M*	*SD*	Range	F	*p*	$\eta^2 p$
Time 1											
Time 1 Spatial Language	39	4.31	5.71	0-24	36	6.58	5.56	0-20	0.39	0.54	0.01
Object Exploration (duration)	33	189	51.3	79-284	35	169	51	74-251	0.96	0.33	0.01
Parents' Spatial Input at Time 1	33	20.2	11.6	2-41	35	29.1	13.8	5-66	5.77	0.02*	0.08
Total Number of Utterances of the parents at Time 1	33	308	101	120-510	35	361	119	172-591	3.07	0.09	0.05
Parents' Spatial Input / Total Number of Utterances	33	0.06	0.03	0.01-0.11	35	0.08	0.01	0.03-0.22	3.97	0.05*	0.58
Time 1 Word Comprehension	38	94.2	89.3	0-343	36	138	78.7	17-317	0.2	0.65	0.003
Time 2											
Time 2 Spatial language	20	15.1	15.1	0-38	27	18	13.2	0-38	0.33	0.57	0.007
Time 2 Word Knowledge	20	339	295	0-709	27	411	239	6-711	0.0004	0.99	<.001

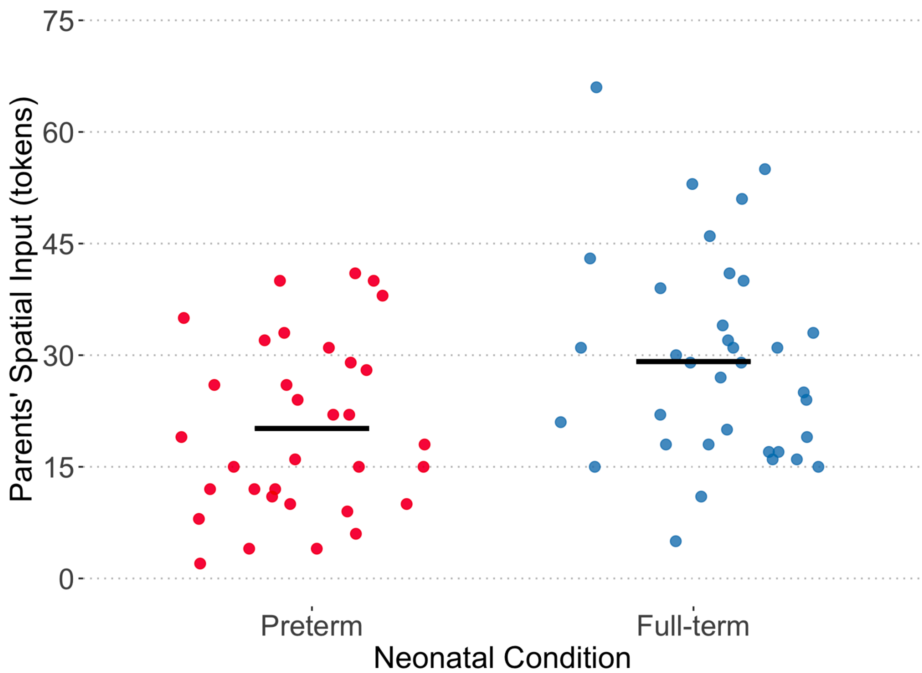
Note. * $p \leq .05$.

Figure 1. (a) Object exploration duration (in seconds) for preterm and full-term infants. (b) Parents' spatial input (word tokens) for preterm and full-term infants. Black lines indicate the mean of each group. Each point represents a single data point (i.e., an infant's data).

(a)



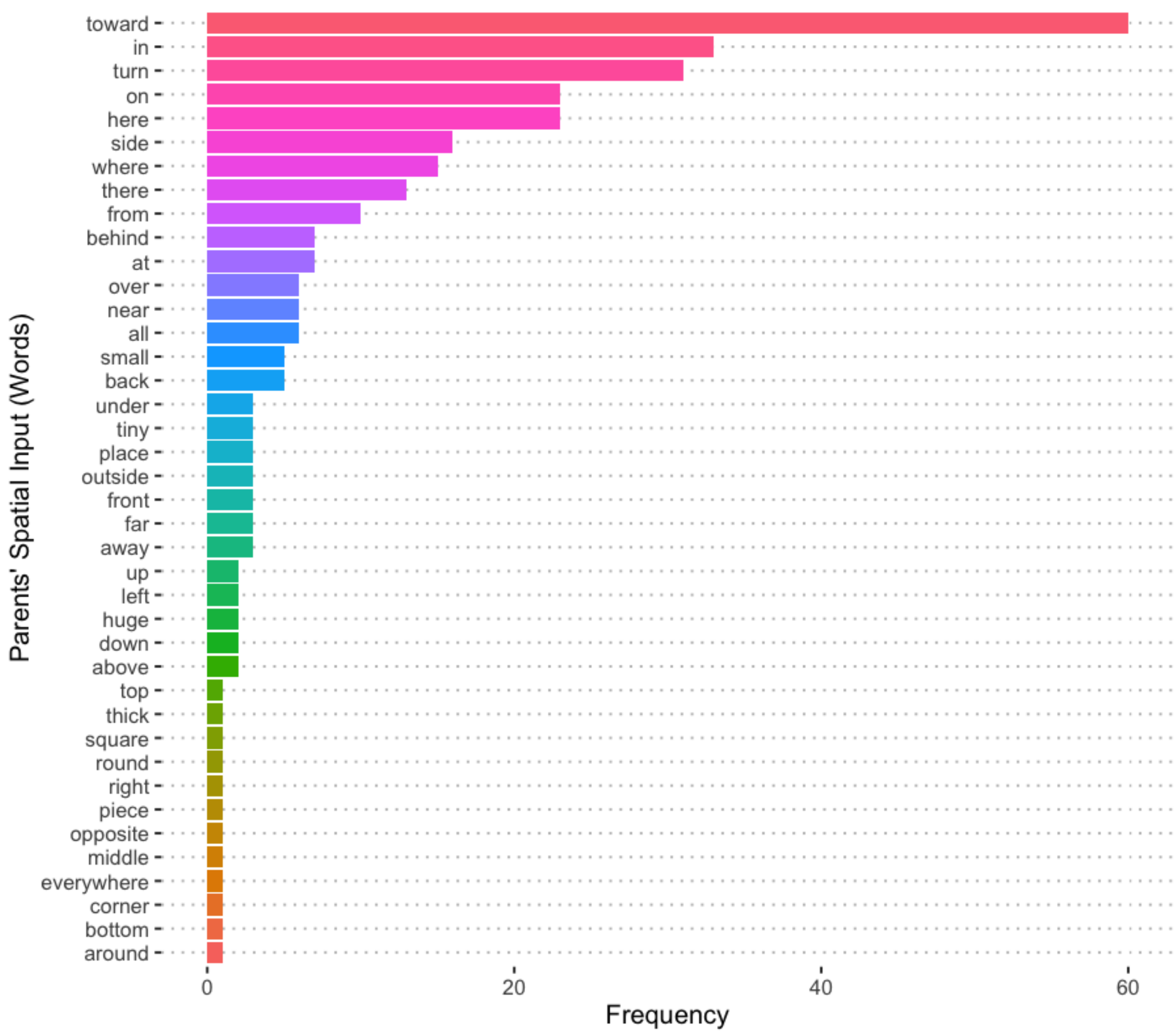
(b)



Parental spatial input at Time 1

For the parents' spatial input at Time 1, the 5 most common words were t*oward, in, turn, on,* and *here* (see Figure 2). Therefore, both location words (e.g., prepositions) and deictics were mostly provided by parents during the play sessions.

Figure 2. The frequency of spatial words provided by parents. Since spatial orientation in Turkish is also expressed through suffixes, we also counted words that include these suffixes. For consistency, the suffixes referring to the same spatial relations were grouped together. For example, "kutuda" (meaning "in the box") was categorized under the postposition "in."



Object exploration subcategories at Time 1

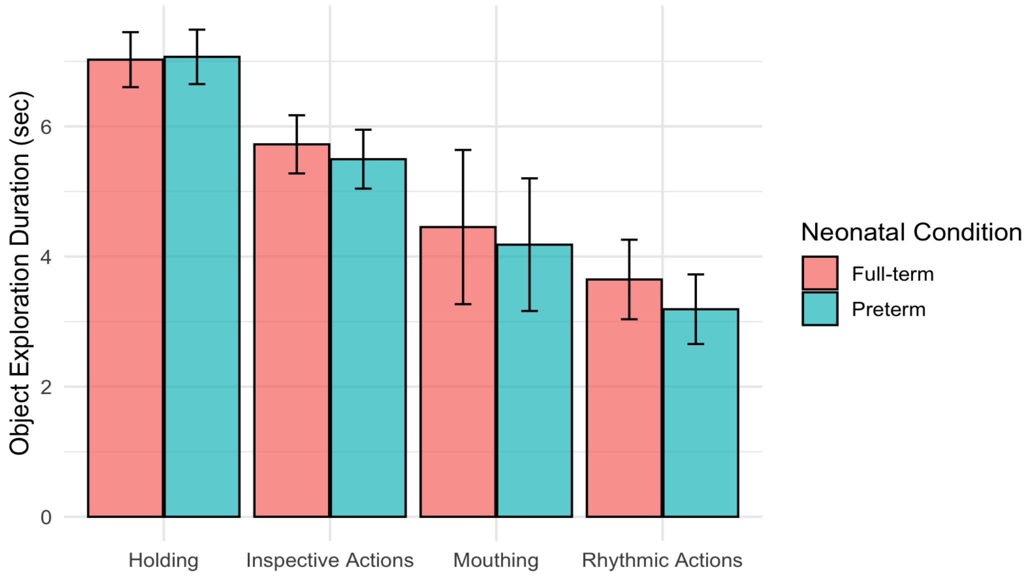
Details of the descriptive data for object exploration coding can be found in Table 3. For total exploration duration, preterm infants were not different from full-term infants on any of the subcategories (i.e. holding, inspective actions, rhythmic actions, and mouthing behaviors), *p*s> .05 (Table 3).

Table 3. Descriptive data for duration of sub-categories in object exploration and group differences: Sample Sizes (n), Adjusted Means, Adjusted SDs, ranges, F, p, and partial eta-squared (ηp^2) values for ANCOVAs for preterm and full-term infants, controlling related ages.

	Preterm (n=33)			Full-Term (n=35)			ANCOVA		
(duration)	Mean	(SD)	Range	Mean	(SD)	Range	F	*p*	$\eta^2 p$
Holding	109	49.1	21.8-205	93	37.6	9.48-182	0.76	0.39	0.01
Inspective Actions	58	41.8	5.12-192	60.9	37.5	1.62-172	0.002	0.96	0
Rhythmic Actions	16.8	12.8	0-50.6	11.4	12.8	0-41.3	0.94	0.36	0.01
Mouthing	5.05	11.4	0-62.4	3.26	8.17	0-43	0.02	0.88	0

We analyzed the relation between object exploration durations and the subcategories of object exploration with a linear mixed effect model. In this analysis, the model included the duration of each object exploration episode as the outcome variable, the interaction between neonatal condition (0 = preterm, 1 = full-term) and the subcategories, and infants' age (continuous) as the fixed effects and one random intercept for the subject. The interaction between neonatal condition and subcategories, the main effects of neonatal condition and age were not significant, all *p*s>0.05. We found that only the main effect of sub-categories was significant, Wald χ^2 (3) = 104.19, $p < .001$ (Figure 3). The post-hoc comparisons using the Tukey adjustments indicated that the durations were significantly higher for holding than the other subcategories, and for inspective actions than rhythmic actions, all *p*s < .05.

Figure 3. The differences among the subcategories and neonatal conditions for the means of single object exploration events' duration in the linear mixed effect model. Error bars represent ±1 SE.

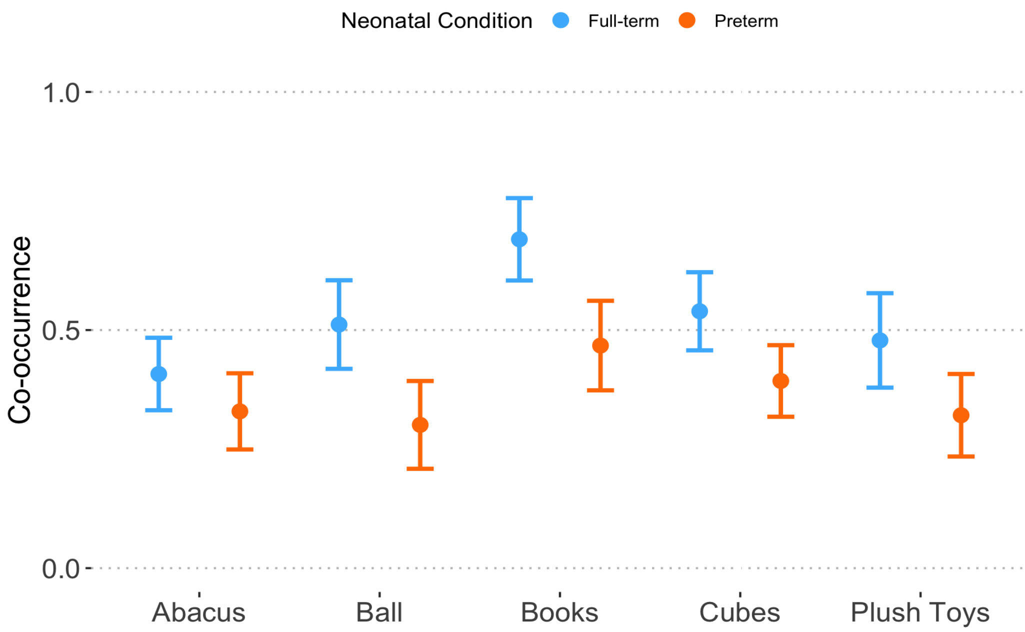


In addition to the differences between preterm and full-term infants for total duration in these subcategories, to examine the relation between the *frequencies* in each subcategory across neonatal conditions, we conducted a chi-square test of independence. We found a significant relation between the two variables, χ^2 (3, 2184) = 15.42, $p < .05$. The post-hoc comparisons using the Bonferroni adjustments indicated that the frequency of *inspection actions* was more for full-term infants than for preterm infants, while preterm infants performed more *rhythmic actions* than full-term infants, all *ps* < .05. However, there was not a significant difference between preterm and full-term infants in holding and mouthing categories all *ps* > .05.

Toys and object exploration at Time 1

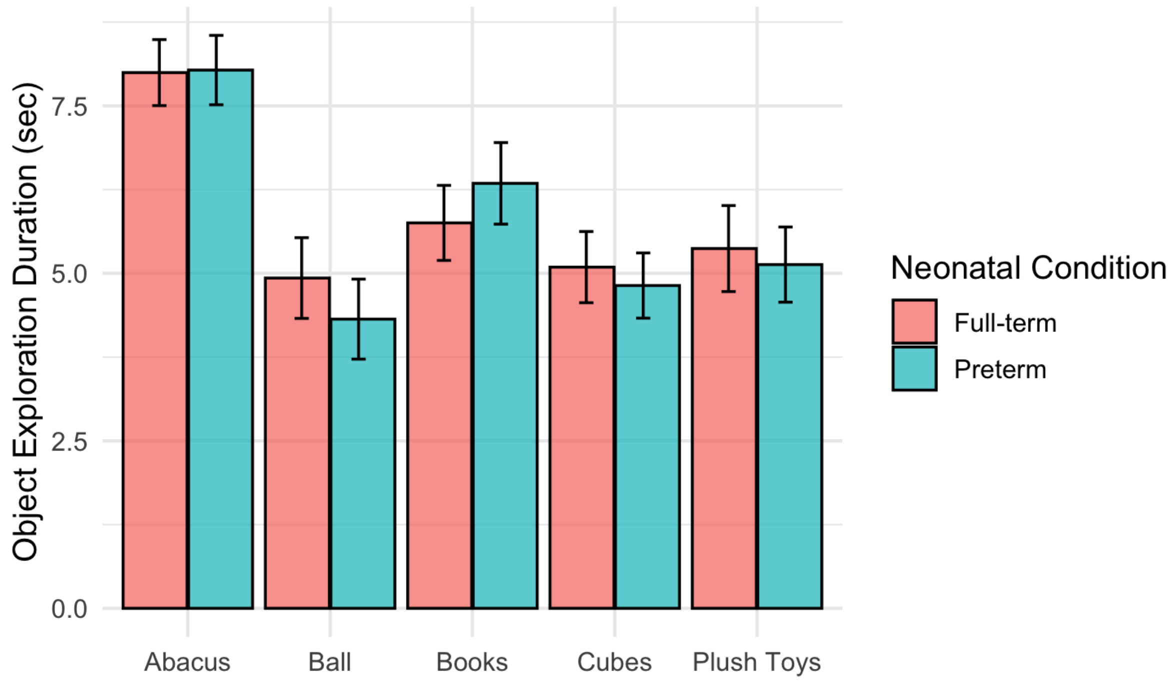
To understand whether parental spatial language input differed with the specific object that infants manipulated, we ran a binomial mixed effect model. In this analysis, the model included the co-occurrences as the outcome variable, the interaction between neonatal condition (0 = preterm, 1 = full-term) and the toy type, and infants' age (continuous) as the fixed effects and one random intercept for the subject. We found that only the main effects of toy type and neonatal condition were significant, Wald χ^2 (4) = 45.77, p < .001; Wald χ^2 (1) = 12.01, p < .001, respectively (Figure 4). The post-hoc comparisons using the Tukey adjustments indicated that the co-occurrences were higher for cubes than abacus, and books than abacus, ball, cubes and plush toys significantly, all *p*s < 0.05.

Figure 4. The differences among the toys that were interacted in the object exploration event in the logistic mixed effect model. Means are represented by dots. Error bars represent ±1 SE.



Furthermore, to understand whether object exploration durations differed with the specific objects infants manipulated, we ran a linear mixed effect model. In this analysis, the model included the duration of each object exploration episode as the outcome variable, the interaction between neonatal condition (0 = preterm, 1 = full-term) and the toy type, and infants' age (continuous) as the fixed effects and one random intercept for the subject. We found that only the main effect of toy type is significant, Wald χ^2 (4) = 92.62, p < .001 (Figure 5). The post-hoc comparisons using the Tukey adjustments indicated that the durations were higher for books than the ball, and the abacus than books, the ball, cubes and plush toys significantly, all *p*s < .05.

Figure 5. The differences among the toys and neonatal conditions for the means of single object exploration events' duration in the linear mixed effect model. Error bars represent ±1 SE.



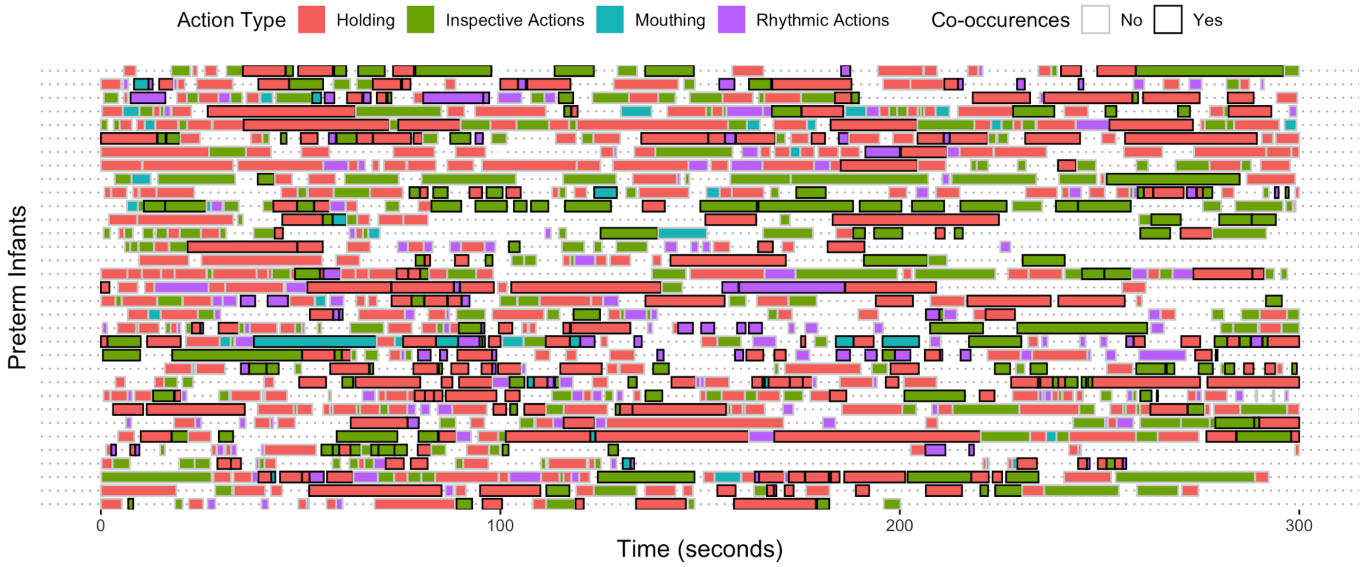
Co-occurrences between object exploration and parents' spatial input at Time 1

44.3% (*SD* = 18.8) of the object exploration events co-occurred with parents' spatial input. We conducted an ANCOVA to test whether preterm and full-term infants have significantly different co-occurrences between object exploration events and parents' spatial input at Time 1, controlling for the child's age. We found that co-occurrences between object exploration and spatial input were significantly lower for preterm (M = 36.1%, SD = 17.1) compared to full-term (M = 52.1%, SD = 17.1), $F(1,65) = 12.71$, $p < .001$, partial $\eta 2$=.16.

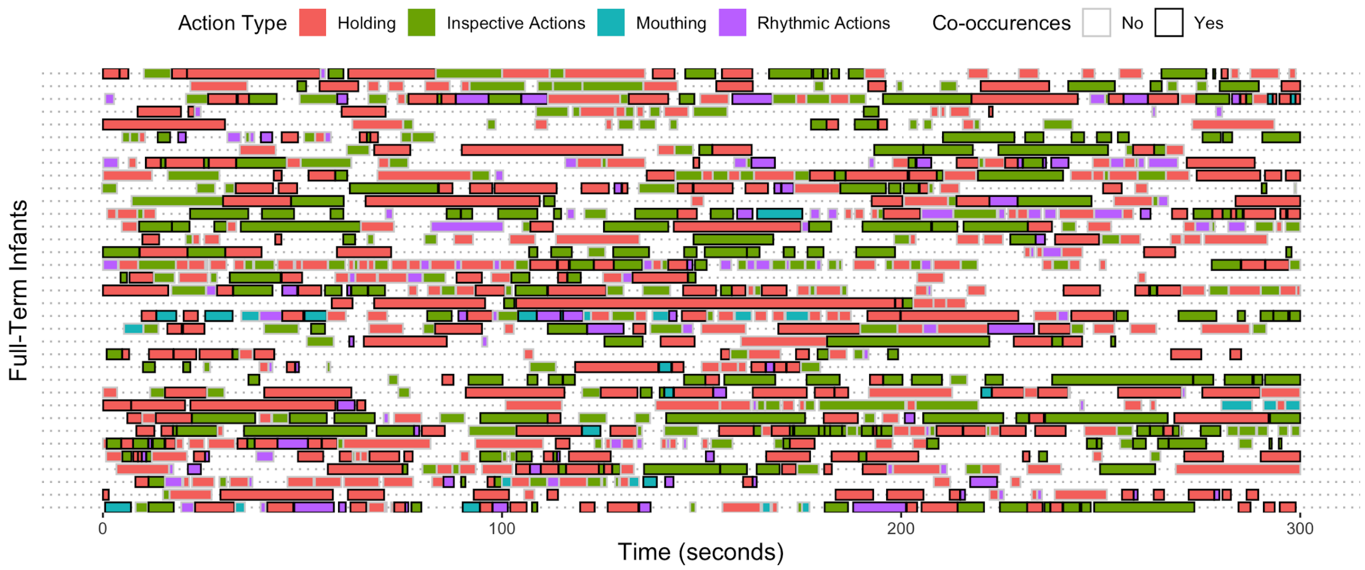
We also conducted a linear mixed-effect model to see whether the duration of object exploration events that co-occurred with parents' spatial input was longer than object exploration events that did not. The model included the interaction between neonatal condition (0 = preterm, 1 = full-term), co-occurrences (0 = no co-occurrence, 1 = co-occurrence), and infants' age (continuous) as the fixed effects and one random intercept for the subject. We found that the duration of object exploration events that co-occurred with parents' spatial input (M = 6.72s, SD = 7.7) was significantly longer than object exploration events that did not (M = 4.66s, SD = 4.62), b = 2.27, SE = 0.42, $p < .001$. The interaction between neonatal condition and co-occurrences, the main effects of neonatal condition and age were not significant, all ps>0.5 (see Figure 6 for the temporal distribution of object exploration event for each neonatal group). The co-occurrence results did not address the effect of the total amount of parents' spatial input and total duration of object exploration events on spatial language, which was analyzed in our third question.

Figure 6. Temporal distribution of object exploration events with co-occurrences. (a) Timelines for each preterm infant's object exploration events. (b) Timelines for each full-term infant's object exploration events.

(a)



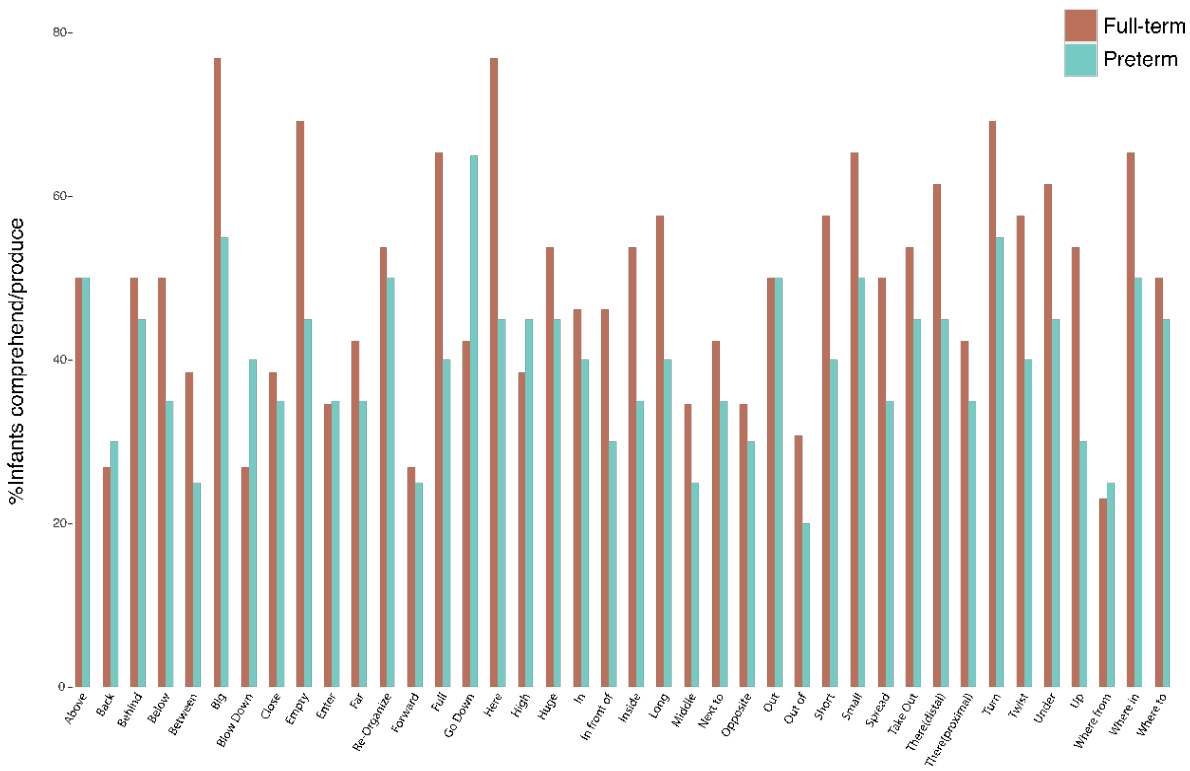
(b)



Children's Spatial Language at Time 2

We did not find significant group differences for child total word knowledge or spatial language at Time 2. For the spatial words at Time 2, the most common words that full-term infants know were big ("büyük") and here ("burada"). 77% of full-term infants knew these words. Moreover, for preterm infants, 65% knew to go down ("in") (for the percentages of other spatial words, see Figure 7).

Figure 7. Percentages of spatial words at Time 2 for preterm and full-term infants. Each bar represents the percentage of infants in each group (preterm or full-term) who can comprehend or produce the corresponding spatial word shown on the x-axis. The percentages were calculated by dividing the number of infants in the group who were reported by their parents as comprehending or producing the word by the total number of infants in that group, then multiplying by 100. Note that the TCDI includes the word "üstünde/üzerinden," which means either "on" or "above." We only kept the word "above" in the Figure for simplicity.



Correlations among variables

Table 4 shows the correlation matrix among different measures. The age at Time 1 was related to spatial language at Time 2, and spatial language at Time 1 was related to parents' spatial input and object exploration at Time 1. Therefore, we decided to include these control variables in the regression analyses.

Table 4. Correlations between different measures.

	Age at Time 1	Age at Time 2	Spatial Language at Time 1	Object Exploration (duration)	Parents' Spatial Input at Time 1	Spatial Language at Time 2
Age at Time 1	1					
Age at Time 2	0.56***	1				
Spatial Language at Time 1	0.36**	0.32*	1			
Object Exploration (duration)	-0.27*	-0.14	-0.30*	1		
Parents' Spatial Input at Time 1	0.22	0.18	0.31**	-0.23	1	
Spatial Language at Time 2	0.35*	0.22	0.24	-0.15	0.15	1

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

The longitudinal links from object exploration and spatial input at Time 1 to spatial language at Time 2

Our third question was whether object exploration at Time 1 and parents' spatial input at Time 1 related to the spatial language of infants at Time 2, interactively or separately. To address this question, we used hierarchical linear regression analyses to examine the predictors of child spatial language at Time 2. For the neonatal condition, we coded preterm infants as "0" and full-term infants as "1." In this model, the first step included neonatal condition (i.e., being preterm or not), infants' age and spatial word knowledge at Time 1. In the second step, the duration of object exploration at Time 1 and parents' spatial input at

Time 1 were introduced. The third step included the interaction term between two variables. This interaction term between object exploration and parents' spatial input was the cross-product of related mean-centered terms.

The model was significant (see Table 5), $F(6,36)=2.65$, $p=0.031$. Neonatal condition, age at Time 1, and spatial words at Time 1 were not significant predictors of spatial language at step 1. Object exploration and parents' spatial input were not significant predictors in step 2. In the third step, the interaction between object exploration and parents' spatial input at Time 1 was significant, $\beta=0.01$, $p=0.007$ (see Table 5). The third step accounted for an additional 16% variance.

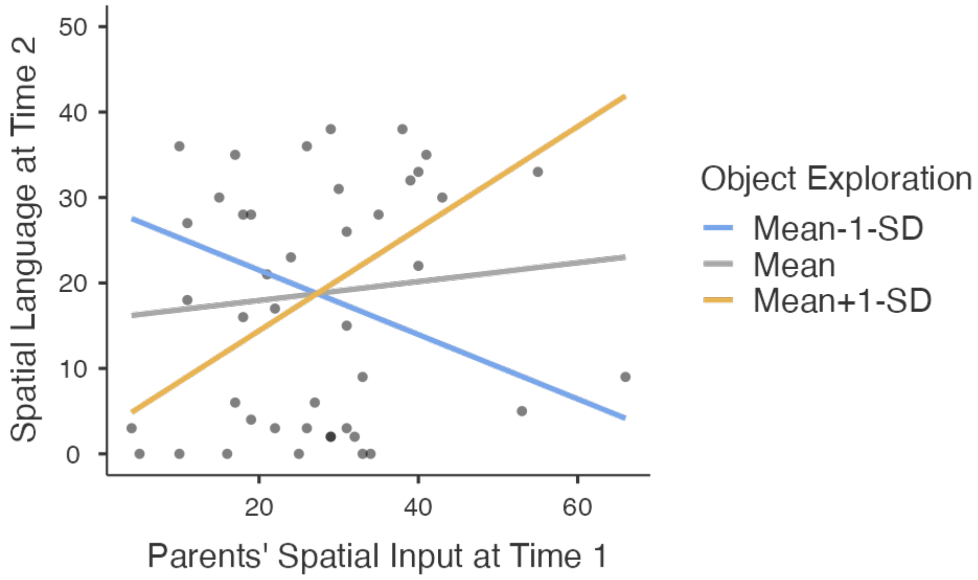
Table 5. The spatial language of infants at Time 2 as the outcome variable with parents' spatial input and object exploration of infants at Time 1 as the predictors.

		Outcome: Spatial language at Time 2				
Step	Predictors	ΔR^2	F-change	*β*	*t*	*p*
1		0.14	2.18			
	Neonatal Condition			-0.8	-0.18	0.86
	Age at Time 1			3.20	1.93	0.06
	Spatial Language at Time 1			0.36	0.99	0.33
2		0.01	0.14			
	Neonatal Condition			-1.11	-0.25	0.81
	Age at Time 1			3.05	1.77	0.85
	Spatial Language at Time 1			0.33	0.86	0.39
	Object Exploration at Time 1			-0.02	-0.34	0.73
	Parents’ Spatial Input at Time 1			0.06	0.33	0.75
3		0.16	8.14			
	Neonatal Condition			-2.24	-0.54	0.59
	Age at Time 1			4.16	2.56	0.02*
	Spatial Language at Time 1			0.23	0.64	0.52
	Object Exploration at Time 1			0.001	0.01	0.99
	Parents’ Spatial Input at Time 1			0.11	0.71	0.48
	Object Exploration x Spatial Input			0.01	2.85	0.007*

Note. * $p < .05$

Simple effect analyses showed that parents’ spatial input was significant only for infants with higher durations of object exploration behavior (1 SD above the mean, simple effect = 0.57, $t = 2.44$, $p <.05$, see Figure 8), and not for those with average (simple effect=0.10, t=0.70, p=0.49) or lower durations of exploration behavior (1 SD below the mean, simple effect = -0.36, $t = -1.75$, p =0.09).

Figure 8. The relation between the interaction term and spatial language at Time 2.



Discussion

This study examined the relations among object exploration, parents' spatial input, and spatial language development in preterm and full-term infants in children's first two years of life. Our main aims were three-fold. First, we examined whether there was a difference between preterm and full-term infants for object exploration and parents' spatial input at around 14 months. We found a significant difference in parents' spatial input between the groups. There was no difference in object exploration duration between the preterm and full-term infants, however, we found differences in object exploration frequencies for specific object exploration subcategories (i.e., rhythmic actions and inspective actions). Second, we examined the co-occurrences between parents' spatial input and object exploration in real time. We found that 44% of the object exploration events co-occurred with parents' spatial input, with a significant difference between preterm and full-term groups. In line with our other hypothesis about the co-occurrences, we found that the co-occurred object exploration events were longer than those that did not. We also examined the relation between the co-occurrences and the toys that infants explored in the play sessions. The co-occurrences were higher for cubes than abacus, and books than other toys in the play sessions. Last, we asked whether object exploration and parents' spatial input were related to the later spatial language of infants interactively or separately. We found that the interaction between parents' spatial input and object exploration at Time 1 predicted spatial language at Time 2, rather than spatial input and object exploration uniquely predicting spatial language.

Our findings indicated that parents provided more spatial input to full-term infants than preterm infants at Time 1. Although preterm infants receive a similar amount of parental input as full-term infants (Adams et al., 2018), parents of preterm infants may produce specific and functional word groups, such as spatial words, less than other words. Receiving less spatial input early on predicts lower performance in later spatial skills and delays in spatial language development. Previous studies have shown that parents' cumulative spatial input between 14 and 42 months predicts the spatial skills of infants (Pruden et al., 2011). However, preterm infants may receive similar spatial input from parents after the first year, which may mitigate the effect of receiving less spatial input at 14 months. For example, Clingan-Siverly and colleagues (2021) found that parents' spatial input and spatial word usage by children do not differ between preterm and full-term preschoolers.

Our results showed no difference in object exploration between preterm and full-term infants. Previous studies showed mixed results about the differences in object exploration between these two groups. Preterm infants up to 2 years of age have impaired motor skills necessary for object exploration, such as asymmetrical fisting (Babik et al., 2017). They spend less time on object exploration than full-term infants at 6 months (Lobo et al., 2015). Zuccarini and colleagues (2017) demonstrated the same results for extremely preterm infants at 6 months. Preterm infants closed the gap at 9 months for object exploration. However, Ruff and colleagues (1984) reported that preterm infants have a lower frequency for some types of object exploration behavior (holding for low-risk preterm infants and rotating, fingering, banging, and transferring for high-risk preterm infants) than full-term infants. Our findings showed that preterm infants' object exploration durations and frequencies were not different from full-term infants at around 14 months of age.

How can we reconcile these seemingly inconsistent findings? Object exploration is an important activity in the first year of life to learn about object features, manipulate objects, and use bodies (Gibson, 1988). However, exploratory behaviors change from simplistic behaviors (such as mouthing and holding) to advanced behaviors (such as functional-relational play or spatial exploration; Belsky & Most, 1982). First, even though preterm infants delay object exploration in the first six months, possibly due to their motor delays, they may catch up with full-term infants over time. This improvement in preterm infants may reflect the role of environmental factors in developmental timelines (Sansavini et al., 2021). Second, preterm infants may be behind full-term infants for advanced object exploration skills. For example, they still only explore nearby objects on the ground due to possible delays in gross motor skills (e.g., Kobaş et al., 2023). Preterm infants may suffer from the integration of old skills into new ones. While full-term infants explore distant and bigger objects with walking, preterm infants may follow them behind in developmental timelines. Alternatively, while full-term infants performed more sophisticated behaviors like inspective actions, preterm infants may still engage with objects using simple behaviors like mouthing or rhythmic actions. We have partial evidence for this in our study. Although the durations for the object exploration subcategories were similar, we found that the frequencies were different. Full-term infants performed more inspective actions and fewer rhythmic actions than preterm infants. These results are consistent with the view that the type of object exploration might vary across groups. Future research should investigate how preterm infants integrate early skills (e.g., object exploration) into new ones, such as walking.

Our findings point to a high co-occurrence between object exploration and parents' spatial input. Previous studies found real-time temporal co-occurrences between object exploration and object naming (Smith, 2013), as well as between object exploration and parents' action verb input (West et al., 2022). Unlike these types of parental input, spatial input is not directly related to the actions during object exploration or play. For example, when a child searches for a toy in a box, parents can respond in many ways, such as "Do you want to get the ball?" or "Are you searching for your ball in the box?". Among these possibilities, some include spatial words like "in," while others do not include any spatial words. Given these possibilities, our finding that 44% of the object exploration events co-occurred with parents' spatial input indicates a high co-occurrence. Object exploration is an opportunity for object naming. Therefore, it is not surprising that parents prioritize these word groups in object exploration events (e.g., Goldenberg et al., 2022; Slone et al., 2023). In the long object exploration events, infants may have more opportunities to hear different word groups. Additionally, parents' spatial input, as well as a variety of parents' linguistic input, boosts object exploration durations (e.g., Schroer & Yu, 2022).

As discussed above, our findings showed that the parents of preterm infants provided significantly lower amounts of spatial input than parents of full-term infants. Moreover, the co-occurrences were different between full-term and preterm infants. Spatial input co-occurred with object exploration events less for preterm infants than in the full-term group. These results may point to the reasons behind potential language-related delays in the preterm group. However, the co-occurred object exploration events were longer than other object exploration events, and this relation did not depend on neonatal condition.

One argument could be that preterm infants' difficulties with attentional mechanisms contribute to these results, as preterm infants may experience challenges with sustained attention even during infancy (Burstein et al., 2021). However, we did not find any significant differences between full-term and preterm infants in terms of object exploration durations during play sessions, suggesting that their attention spans might be comparable. Nevertheless, differences were observed in the frequencies of certain subcategories of object exploration. Full-term infants engaged in more advanced exploration skills (inspective actions) and fewer less advanced exploration skills (rhythmic actions) compared to preterm infants. Therefore, based on our findings, the plausible explanation for the difference in co-occurrence may not be related to attention span but rather to the skills infants use during exploration.

Parents may also use more spatial language when they observe advanced exploration skills such as turning an object to see the other side of the object as an inspective action. The parents of preterm infants may talk less, but they may want to provide spatial input without any distraction or without changing the direction of their children's attention to a new object exploration episode (Schroer & Yu, 2022). Instead, they provide spatial input following their children's sustained focus on an object exploration event. Therefore, instead of providing spatial input for every object exploration event, parents of preterm infants may selectively reward the longer object exploration events with spatial input. Therefore, these parents may help to increase the learning capacity of their infants by optimizing their limited attention capacity. Longer object exploration events are opportunities for this optimization. Overall, longer object exploration events may be an opportunity for different developmental achievements.

We asked about the unique and interactive effects of infants' object exploration and parental spatial input on children's spatial language use. Our findings highlight the interactive effects of object exploration and parents' spatial input at Time 1 on children's spatial language at Time 2. The main effects of object exploration and parents' spatial input at Time 1 did not predict spatial language at Time 2. This interaction indicates that for infants who explore objects more, the role of parental spatial input on the development of infants' spatial words was stronger, regardless of neonatal condition. Object exploration provides referent experiences for representations of spatial relations. Parents' spatial input contributes to learning labels for those referents (Göksun et al., 2025). The frequency of parental input is effective on infants' language development because it promotes the representations of the related words in the input over other words (Lieven, 2010). Neither the input nor its referents (e.g., the visual and manual experiences resulting from object exploration) on their own are as effective in learning spatial words separately. However, our findings highlight that the interaction of these enables the processes for spatial language development.

Besides the interaction between object exploration and parents' spatial input, there may be several obvious and non-obvious pathways (i.e., developmental cascades) behind spatial language development as a developmental achievement (Guo et al., 2023; Oakes & Rakison, 2019). In spatial language development, infants may also learn spatial language via early literacy activities, such as book reading or other explorations and play settings. For example, Oudgenoeg-Paz and colleagues (2015) found that walking attainment predicts the spatial language of infants through gross motor exploration (i.e., engaging toys that promote gross motor movements). Here, we only investigated object exploration with manual and oral actions executed by fine motor skills. Our unique contribution was to examine the role of interaction between object exploration and parents' spatial input. Future studies should more comprehensively compare and contrast different aspects of children's fine and gross motor development about spatial language.

Our findings about the interaction between object exploration and parents' spatial input also demonstrate how early experiences can be related to later outcomes. These findings in Turkish were in line with previous studies that showed either the role of gross motor exploration or parents' spatial input on spatial language in English (Pruden et al., 2011) and in

Dutch (Oudgenoeg-Paz et al., 2015). This consistency across languages and cultures increases the possibility of a developmental cascade based on the interactions between perceptual (manual and visual exploration) and social factors (reciprocal communication between parents and children) for language development, including spatial language during late infancy and toddlerhood (Guo et al., 2023).

Last, our findings contribute to how young children learn spatial language. Infants learn object words or names of living things heavily in the first years of their lives (Golinkoff et al., 2019), but spatial words are challenging to learn (Gentner, 2016). From the developmental cascade perspective, spatial words enable later developmental achievements related to spatial skills. For example, a recent study found a close link between preschoolers' postposition knowledge in Turkish (e.g., under, over, behind, left, right) and their mental transformation scores (Turan et al., 2021). Learning spatial words enables new pathways for later cognitive skills. However, some cascades also enable pathways to learn spatial words.

Language development is based on contingent parent-child engagements that include infants' exploration and parental verbal input (Masek et al., 2021). Following the results and anticipations of our study and previous studies (e.g., Casasola, 2018; Pruden et al., 2011), the interaction of object exploration and parents' spatial input may lead to a cascading effect on spatial language development that will allow new pathways for spatial skills, irrespective of prematurity of children.

Limitations and Future Directions

Our study indicated non-obvious relations for the early spatial development with frame-by-frame behavioral coding in a Turkish language environment. However, the parental reports (CDI) to measure spatial words of infants at Time 2 can be considered a limitation. Measuring language development in infancy is challenging due to infants' limited linguistic skills. The Turkish CDI, like other CDIs, is one of the most popular and reliable parent report instruments, which has been used in many other studies (e.g., Aktan-Erciyes & Göksun, 2019; Kısa et al., 2019; Kızıldere et al., 2022; Kobaş et al., 2021, 2023; Özdemir et al., 2024). However, parental reports may have vulnerabilities to parental bias. Future studies with different methods, such as home observations on early spatial language development with young children, can help measure spatial language development in infancy.

Spatial skills and spatial language were related to walking attainment (Oudgenoeg-Paz et al., 2015). Our study only focused on manual skills when infants were usually stationary, but walking and other gross motor skills can connect differently to spatial language development and parents' spatial input. Future studies should investigate how gross motor skills and object exploration can interactively be associated with parents' spatial input and how these interactions improve subsequent spatial language development.

Last, spatial words are composed of many words referring to the object's size, shape, feature, orientation, and relations between objects. Similarly, parental reports of children's spatial language did not include various spatial word types. Future research can specifically focus on encouraging parents to use different types of words in a play setting to examine their separate roles in spatial language development.

Conclusion

In conclusion, this study investigated the relations among object exploration, parents' spatial input, and spatial language of preterm and full-term infants. We first showed that preterm and full-term groups similarly explored objects during play sessions. The object exploration duration was not different between preterm and full-term infants and parents of full-term infants produced more spatial input than parents of preterm infants. We also examined the duration and frequencies for object exploration subcategories. We found that full-term infants performed more inspective actions and less rhythmic actions than preterm infants, but there was no difference for the durations of these actions between groups.

Regardless of the neonatal condition, infants spent more time for holding than other subcategories and inspective actions than rhythmic actions. Then, we demonstrated that 44% of the object exploration events co-occurred with parents' spatial input. Again, these co-occurrences between object exploration and spatial input were higher for the full-term than the preterm group. Regardless of neonatal condition, co-occurrences were higher for the object exploration events that children explored with cubes than abacus and books than other toys. Last, spatial language at around 26 months was predicted by an interaction between object exploration and parents' spatial input when children were 14 months without group differences. Our findings suggest a potential cascade of object exploration and spatial input on spatial language learning in both preterm and full-term infants. Rather than the unique contributions of these factors on their own, an integrative mechanism leveraging the interaction between object exploration and spatial input can promote children's spatial language development over time.

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