Motor skills, language development, and visual processing in preterm and full-term infants

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Abstract

Language development is intertwined with motor development. This study examined how visual processing might mediate the relation between language development and motor skills in preterm (PT, n = 34, Mean gestational age = 30 weeks) and full-term infants (FT, n = 35, Mean gestational age = 38.9 weeks) at 13 months of age. Infants' visual processing, fine and gross motor skills were tested using the Mullen Scales of Early Learning. Parents reported on infants' language skills (word comprehension and early communicative behavior), using the Turkish version of CDI (TCDI). Results showed that PT infants performed worse than their FT peers on gross motor skills and visual processing, but not on language. When controlling for age and neonatal condition (being preterm or not), visual processing mediated the relation between gross motor skills and word comprehension as well as early communicative behavior. However, for fine motor skills, visual processing mediated the relation between fine motor skills and early communicative behavior but not word comprehension. The relations between motor skills and visual processing were more robust for the PT group than the FT group. Following developmental cascades, these findings suggest that motor skills contribute to language development through visual processing. These relations are prominent for preterm infants who have delays in motor skills. PT children's limited interactions with their environment due to problems in motor skills can be connected to delays in visual processing.

Keywords. Preterm infants, language development, visual processing, motor development

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Infants' motor development is associated with their language development (Iverson, 2010; Walle & Campos, 2014; Libertus & Violi, 2016). Each new motor skill provides an opportunity to gain new experiences, which, in turn, scaffolds language development (Walle & Campos, 2014). The link between motor and language skills can also be mediated by other cognitive skills (e.g., Hellendoorn et al., 2015). Early in development, infants' visual processing (i.e., detecting faces, surfaces, objects, motion, and allocating attention) shows a steep developmental trajectory (Ortibus et al., 2011) that goes hand in hand with motor skills. For example, walking provides greater visual access to people, objects, and places and, thus, new learning opportunities (Adolph & Hoch, 2019). Less is known about how the interaction between motor skills and visual processing can contribute to infants' language development. This link's strength may also vary across different child populations due to cascading effects (i.e., amplification effect of a domain on another domain with nonobvious interactions), such as for children who are born preterm compared to full-term. In the current study, we examine the mediating role of visual processing in the association of motor skills with language development for preterm and full-term infants.

Infants start communication via gestures before producing their first words. They then speak their first word around the end of the first year of life (Bates, 1976). Throughout the second year of life, infant language goes under steep development – especially vocabulary (Parish-Morris et al., 2013). Not all children go through similar developmental trajectories regarding language development. Many factors contribute to this variability in language development, such as attention and memory development, symbolic processing, language environment, exploration of objects, and parental input (e.g., Hoff, 2013; Parish-Morris et al., 2013; Walle & Campos, 2014). Prematurity is another factor that contributes to individual differences (Foster-Cohen et al., 2007). Compared to full-term infants, preterm infants born before 37 weeks of pregnancy are at a higher risk of language delays. This is due to both pre- and post-natal biological and environmental conditions. Infants born very preterm (i.e., gestational age <33 weeks and/or birth weight <1.500 grams) and extremely preterm (i.e., gestational age <29 weeks and/or birth weight <1000 grams) are particularly at risk of delays in both receptive and expressive language development (e.g., Caravale et al., 2005; Foster-Cohen et al., 2007; Sansavini et al., 2011a; Sansavini et al., 2011b). Indeed, the risk of language difficulties increases as gestational age decreases (Foster-Cohen et al., 2007). Extremely preterm and very preterm infants also show developmental delays regarding gesture use, which is one of the early communicative behaviors (Benassi et al., 2016; Sansavini et al., 2011b; Stolt et al., 2016). Less is known about later gestational ages and the sources of individual differences within preterm infants.

Cognitive skills develop by interacting with the environment in which infants are active learners (Smith & Gasser, 2005). Learning experiences can be supported and constrained by children's motor skills. As infants' motor skills develop, they interact with their environment in more varied ways. Gross and fine motor skills amplify the contributions of the visual processing skills on word learning through exploration and visual representation of objects (e.g., Smith, 2013). This interaction brings different opportunities for language development, such as more and richer parental input (Karasik et al., 2014; Walle & Campos, 2014) or visual attention to objects (Smith, 2013).

Gross and fine motor skills *of full-term and preterm infants and relations to language development*

Gross motor skills enable acting in the environment and contain big movements, such as walking or crawling, related to posture and locomotion (Adolph & Robinson, 2015). In the first months of life, full-term infants learn to lift their head and chest. Infants learn to use their arms without any support in the prone position by five months of age, start sitting between 5 and 8 months of age and stand without any support between 9 and 15 months of age. Infants can learn crawling between 5 and 11 months and start walking without any support between 10 and 16 months (Adolph & Robinson, 2015). These gross motor skills are related to language development (e.g., Iverson, 2010; Walle & Campos, 2014; Libertus & Violi, 2016). For example, Libertus and Violi (2016) found that sitting skills at around 3-5 months of age is associated with receptive language at 10-14 months.

Infants' walking skills at the end of their first years are related to their word comprehension and word production skills (Walle & Campos, 2014) as walking experience increases exploration in the environment (Adolph & Hoch, 2019). In line with this, walking attainment predicts expressive language scores between 16 and 28 months (Oudgenoeg-Paz et al., 2012). There are, however, contradictory results on the relation between gross motor skills and language development. For example, Alcock and Krawczyk (2010) did not find any relation between gross motor skills and word comprehension, word production, or gesture use at 21 months of age. Moore and colleagues (2019) argued that the relation between walking and word production is weaker than the relation of word production with other socio-communicative factors (e.g., joint attention). These mixed findings suggest that other factors might influence the relation between gross motor and language skills.

Fine motor skills are small limb movements that contain manual actions, such as reaching and grasping to objects, turning an object, throwing, or rolling objects (Adolph & Franchak, 2016). Object-free movements, such as pointing, gesturing, or signing, are also executed by fine motor skills (Adolph, 2018). Fine motor skills allow infants to explore objects manually, which contributes to word learning in full term infants (e.g., Smith, 2013) and infants under high risk of autism (LeBarton & Iverson, 2013). Bernardis and colleagues (2008) argued that manual actions, such as grasping or reaching, help communicate and identify objects. Mixed findings are also observed about fine motor skills. For example, Alcock and Krawczyk (2010) did not find a significant relation between fine motor skills and word comprehension, word production, or gesture used in full-term infants. This finding intensifies the possibility of additional factors influencing the relations between motor and language development.

Compared to full-term infants, preterm infants show weak performance in both motor domains. Sansavini and colleagues (2011b) indicated that preterm infants' gross motor and fine motor skills are negatively affected by physical factors, such as posture restrictions due to increased time in the incubator, or biological factors, such as underdeveloped limbs or organs at the start of their lives. Very preterm infants have developmental delays regarding gross and fine motor skills at 12 months of age compared to full-term infants (Spittle et al., 2009). As another example, extremely preterm infants show lower locomotor and eye-hand coordination performances than very preterm and full-term infants at 12, 24, and 30 months. Additionally, the gap between extremely preterm infants and other groups increases over time (Sansavini et al., 2014). Very preterm infants are still behind their full-term peers in motor skills at three years old (Caravale et al., 2005; Van Haastert et al., 2006).

Delays in preterm infants' motor skills can be related to delays in their language learning (Sansavini et al., 2011b; Benassi et al., 2016). The relation between motor skills and language development has been investigated in full-term children (e.g., Walle & Campos, 2014) and children with atypical developmental trajectories such as ASD (e.g., Hellendoorn et al., 2015; LeBarton & Iverson, 2013). Only a few studies have investigated this link in the preterm population. In one of those studies, gross motor and fine motor skills at 12 months were related to concurrent gesture production in very preterm infants (Suttora & Salerni, 2012). Benassi and colleagues (2016) also reported that fine motor skills at 12 months were associated with gesture production, but not with receptive and expressive language scores in extremely preterm infants.

These findings suggest possible roles of potential mediators between motor and language development. When infants grasp objects, they typically look at the objects too. When an infant bangs an object on a surface, she hears the sound coupled with banging. Motor skills can be related to different factors associated with these multimodal interactions (Smith & Gasser, 2005).

Visual processing as a mediator on the link between motor and language development

The development of visual processing starts from birth and shows remarkable progress within the first years of life. Infants start to show adultlike visual preferences and have an adultlike visuospatial organization at 6 months, an important milestone for visual processing (Milosavljevic et al., 2019). The effect of visual processing on infants' cognitive skills increases and multiplies with motor skills (Soska et al., 2010). Gross motor skills, such as sitting or walking, enhance infants' visual processing (Adolph & Franchak, 2016). Controlling head, body movements, and posture provides infants to look independently. For example, sitting and locomotor skills of infants are related to visual attention duration (Campos et al., 2000). Mobility also enhances the use of visual processing. Crawling provides infants to change their places and see their environment from different angles. Furthermore, walkers have the opportunity of fast mobility and can see objects in their environment better than crawlers (Adolph & Hoch, 2019). Infants can visually perceive a broader area in the environment through walking, and walkers access faces or distant objects easier than crawlers (Kretch et al., 2014).

As in the case of gross motor skills, fine motor skills are linked to visual processing. For example, infants need the information of objects' appearances, locations, orientation for prospective control of grasping or reaching (Adolph, 2018). Experienced manual actions, which make those actions more precise and noise-free, executed by fine motor skills, increase visual processing (Smith, 2013). For instance, infants visually focus only on one object instead of many objects with a better holding skill when they learn object names (Smith, 2013).

Visual processing is also related to language development. Between 12 and 36 months of age, infants' visual representation system changes to contribute the word mapping process by providing rich representations; thus, object name learning requires visual experiences (Smith, 2013). Visual variability influences learning word types, such as object names or verbs (Twomey, 2014). Visual processing is necessary for early communicative behavior, as well. For example, gesturing requires taking the attention of caregivers to show spatial places or objects from a distant place (Butterworth et al., 2002).

In addition to its direct influence on motor and language development, visual processing can mediate the relation between these skills. For gross motor skills, visual processing can guide interactions with different places or distant objects. Campos et al. (2000) stated that walking brings distant communication opportunities between parents and infants. Following parental movements (e.g., how to play with objects, parents' gestures) in distant places requires visual tracking of these movements. Walkers access more social bids than crawlers related to their looks to the environment (Clearfield et al., 2008). Infants in locomotion visually track their caregivers' gestures better than pre-locomotor infants (Campos et al., 2000). The increased social interactions and visual processing with gross motor skill development can enhance word comprehension and encourage infants to use gestures (Walle & Campos, 2014; Campos et al., 2000).

Visual processing can also mediate the link between fine motor skills and language learning. Manual actions usually require coordination between fine motor skills and visual processing. For instance, infants need to look at a container's spatial features to explore the lid or gap of the container before they put a cube into it. Fine motor skills can also enhance the interaction with objects visually. Grasping and turning objects provide a 3D view of those objects to infants (Soska et al., 2010). Yu and Smith (2012) found that developed fine motor skills, such as grasping skills, provide precise and constant visual information to infants. They attend to objects quickly and can learn objects' names quicker. Following this, Hellendoorn and colleagues (2015) found that fine motor skills between 1.5 and 2.5 years of age predict expressive and receptive language at the end of the third year through visual processing and object exploration in children with ASD. The increase in fine motor controlling of fingers triggers gesture use and early communicative behaviors at the end of the first year (Iverson & Thelen, 1999). This relation can also be mediated by visual processing because infants use early pointing gestures and gesture-like actions to visually attend to their parents at the end of the first year (Carpenter et al., 1998).

Preterm infants' visual processing skills are weaker than full-term infants. A meta-analysis with 16 studies showed that very preterm infants (GA < 32 weeks) have lower scores in visual processing and visual-motor integration than their full-term peers (Geldof et al., 2012). In extremely preterm infants, visual processing correlated with fine motor skills (Goyen, Lui, & Woods, 1998). Sripada et al. (2015) found that visual-motor impairments appear and change specific gray-white matter networks in extremely preterm infants. Hence, neurological and behavioral studies demonstrated that preterm infants have visual processing problems related to motor skills. As Karmiloff-Smith (2009) argued, links between different domains can be more noticeable for infants who follow atypical developmental trajectories such as autism spectrum disorder or preterm birth than infants following typical developmental trajectories. For preterm infants, delays in motor skills can lead to inefficient use of visual processing in the environment, which results in decreases in physical and social interactions. Then, infants' language development can be interrupted. Compared to full-term infants, these delays can lead to a snowball effect for preterm infants, and a delay or progress in one cognitive domain leads to more pronounced problems or improvements in preterm children. Hence, early motor development problems may lead to cascading effects that can disrupt language development (LeBarton & Landa, 2019). Instead of a direct relation between motor skills and language development, motor skills lead to the cascading effect for language development through visual skills (e.g., Hellendoorn et al., 2015; Iverson, 2021; Oakes & Rakison, 2019).

In sum, visual processing that guides motor behavior may be one of the key mediators in the link between motor skills and infants' language development. This relation can be highlighted particularly for infants who show diverse developmental trajectories, such as preterm infants. As developmental change is multidimensional and cumulative (Iverson, 2021), the cascading effect of disruption in motor development on language development delays can occur through visual processing.

The Current Study

We first investigate the role of prematurity on children's language learning, motor development, and visual processing. We then examine the mediating role of visual processing in the relationship between gross motor and fine motor skills and language development (word comprehension and gesture) at 13 months, and possible differences between preterm and full-term infants. We use word comprehension, and early communicative behaviors as indicators of language development at this age group since word production variance is minimal for infants at this age (Walle & Campos, 2014).

Based on the previous findings (Caravale et al., 2005; Foster-Cohen et al., 2007; Sansavini et al., 2014, & Benassi et al., 2016), we expect that (1) preterm infants will have lower scores on word comprehension, early communicative behavior, motor skills, and visual processing than full-term infants. We also predict that visual processing mediates the link (2) between gross motor skills and word comprehension and early communicative behavior, and (3) between fine motor skills and word comprehension and early communicative behavior. Last, due to possible cascading effects in early development across many motor and cognitive domains, we expect that (4) these proposed relations are moderated by neonatal condition (i.e., being preterm or full-term).

Method

Participants

This study was part of a longitudinal study that examines preterm and full-term children's language and cognitive development. We recruited participants through a local hospital's pediatric services database, a rehabilitation center, and social media ads. In this study, we focused on the first wave of data collection when children were 12-16 months of age. Thirty-eight preterm and 36 full-term Turkish-reared children were recruited. Parents of 3 children did not fill up TCDI-1, and we excluded those children from the analyses. The visual processing task of 1 infant was missing, and data of this child was excluded from the analyses. Fine motor tasks of 1 preterm infant and gross motor tasks of another preterm infant were missing. These children's data were also excluded from the related analyses. The final sample consisted of 70 children in two groups: preterm group (PT: 14 girls and 21 boys, *M*age=13 months, *SD*=1.33) and full-term group (FT: 16 girls and 19 boys, *M*age=14.20 months, *SD*=1.18). To test the hypothesis that the relations are moderated by neonatal condition, we coded PT children as "0" and FT children as "1" as a categorical variable in the analyses. According to Fritz and McKinnon (2008), with large (α= 50) and medium (β= 30) effect sizes for .80 power, a minimum of 59 participants are sufficient. We used the standardized regression coefficient for the effect size of α path coefficient, and the partial correlation for the effect size of β path coefficient (MacKinnon, 2008). Our sample size was enough to detect medium effect sizes in the mediation models (for details see Appendix A).

We used corrected ages for the preterm group in this study. The demographic information for each group is presented in Table 1. In the final sample, 13 preterm infants (*M*age=13.5 months, SD=1.73) were reported as having minor medical complications based on cranial ultrasound or being in intensive care after birth. Although having these complications, all preterm infants could attend and participate in the session. These children did not have retinopathy due to prematurity. Before merging these data with the rest of the group, we compared PT children's scores with and without medical complications. Since the sample sizes between these two groups were not similar, we used Kruskal-Wallis analysis as a non-parametric test to check whether there was a difference between these preterm groups. Results showed that PT infants with medical complications did not differ from the rest of the group in their language, visual processing, and motor skills scores (all *p*s > .05, for details, see Table 2). Therefore, we did not divide the PT group into two separate groups according to medical complications for the sake of power. 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
	Mean or %	SD	Mean or %	SD			
% Male	60		54.2		0.233	.63	-
Maternal Education (year)	15.7	1.40	16.1	1.28	-1.26	*.21*	-0.3
GA (weeks)	30.0	3.00	38.9	1.42	-15.79	*<.001*	-3.8
Birth Weight (g)	1492	514	3295	403	-16.32	*<.001*	-3.9

Table 2. Kruskal-Wallis analysis for preterm infants with and without medical complications.

Kruskal-Wallis

	χ^2	**df**	***p***
Visual Processing	0.0298	1	0.863
Fine Motor Skills	0.1039	1	0.747
Gross Motor Skills	2.6949	1	0.101
Word Comprehension	0.2127	1	0.645
Early Communicative Behavior	0.6266	1	0.429

Measures and Procedure

Word Comprehension and Early Communicative Behavior Measures. Parents filled the Turkish Communication Development Inventory-1 (TCDI-1). TCDI-1 is the Turkish adaptation of MacArthur-Bates CDI and can be used for children aged 8-16 months to evaluate their receptive and expressive language and early communicative behavior (Aksu-Koç et al., 2019). TCDI-1 questionnaire has been used to investigate full-term infants' language development (e.g., Kısa et al., 2019; Aktan-Erciyes & Göksun, 2019). Different versions of MacArthur-Bates CDI have been used to examine preterm infants (e.g., Cattani et al., 2010; Zuccarini et al., 2018), but this is the first time TCDI-1 is used to assess preterm infants.

TCDI-1 includes two parts. The first part is the Vocabulary Checklist, including 418 items. The items in the Vocabulary Checklist are used to measure both expressive and receptive language of infants. For this study, we only used the receptive language scores because the variance for word production is minimal at this age (Walle & Campos, 2014). Word comprehension subscale of TCDI-1 has .99 Cronbach's alpha for internal consistency (Aksu-Koç et al., 2019). The second part is the Actions and Gestures Section, including 69 items. Actions and Gestures part includes six sub-categories: communication gestures (16 items), games (8 items), object action (17 items), mom and dad pretending (13 items), adult imitation (14 items), and substitution (1 item). This was used to measure early communicative behavior scores. This subscale of TCDI-1 has .96 Cronbach's alpha for internal consistency. The adaptations of these subscales are considered valid (see Aksu-Koç et al., 2019).

Fine Motor, Gross Motor, and Visual processing Measures. The Mullen Scales of Early Learning (MSEL; Mullen, 1995) was administered to infants by trained research assistants to measure fine motor skills, gross motor skills, and visual processing. Receptive and expressive language subscales of Mullen were not administered. An experimenter-administered standardized assessment, the MSEL, can be used from birth to 68 months of age. The internal reliability of MSEL was found .91 as the median value (Mullen, 1995). Each scale was administered individually. The Gross Motor Scale of the MSEL aims to measure controlling motor behaviors, posture such as sitting, and locomotion skills such as mobility in supine or upright positions. This subscale includes 35 items that evaluate gross motor skills in supine, prone, sitting and upright positions. The Fine Motor Scale measures fine motor planning, fine motor control, and readiness for further fine motor skills such as writing. The Fine Motor Scale consists of 30 items, which starts with questions related to early reflexes and ends with drawing a triangle. We used the visual reception scale to measure visual processing. This scale aims to measure the skills related to visual organization, visual sequencing, visual-spatial awareness. It includes 33 items that start from tracking until remembering different shapes. MSEL was used previously to assess atypical development (e.g., Iverson et al., 2019; Akshoomoff, 2006), preterm children (e.g., Yaari et al., 2018; Harel-Gadassi et al., 2018), and the relation between motor development and language development in typical and atypical development (e.g., Hellendoorn et al., 2015).

The data were collected in the playroom of Cerebral Palsy Turkey Foundation and the playroom of Language & Cognition Lab at XX University. We obtained informed consent forms in the written format from all parents before the testing was started. Every participant has a unique ID for this study to assure anonymity. The data was stored in a secure computer with password. TCDI-1 form was sent to parents via e-mail, or parents filled the form during the visit.

Data Analysis

Our first goal was to examine group differences between preterm and full-term infants for word comprehension, early communicative behavior, visual processing, gross motor skills, and fine motor skills, using ANCOVA (Analysis of Covariance). Another goal was to examine whether visual processing would mediate the relation between motor skills and language skills and whether these relations would be more robust for PT than FT. Following Hellendoorn et al. (2015), we used mediation analysis (Preacher & Hayes, 2004) to examine the role of visual processing on the relationship between motor skills and language skills, controlling neonatal conditions and age. We considered these as the total models in which preterm and term children were analyzed together. We also used the moderated mediation approach (Preacher et al., 2007) to examine whether the mediation model's relations differentiate for preterm infants.

The PROCESS macro for mediation analysis in SPSS 26 (2019) was used for the mediation and moderated mediation analyses (Hayes, 2017). The PROCESS macro offers a powerful way to analyze mediation via the bootstrapping procedure. For the bootstrapping procedure, the sample is resampled with replacement. As a result of this resampling process, an empirically derived representation is created. Confidence intervals of indirect effects in the mediation process are calculated using the available sample (Hayes, 2017). Preacher and Hayes (2004) argued that this approach helps overcome power problems linked to different forms of nonnormality in the sampling distribution. As a result, even small sample sizes can be used within this test. For this study, we used 10000 bootstrapping resamples with 95% confidence intervals.

We also used moderated mediation analysis to test the effect of neonatal conditions on hypothesized relations. We examined whether the neonatal condition would moderate the relations between motor skills, visual processing, and language development. That is, whether the relations differ concerning being a PT or FT infant. The PROCESS macro was used to test this research question. Infants' ages were the covariate in the analyses.

Results

Descriptive information and comparisons for each group are presented in Table 3. We show only adjusted means (adjusted with age) because all the variables correlated with age. Preterm children have significantly lower scores in the Mullen sub-scales for visual processing and gross motor skills than their full-term peers, but not on TCDI or fine motor skills (Table 3). We also divided the preterm infants into groups based on the gestational age to present detailed information. According to Quinn and colleagues (2016), extremely preterm infants are born before 28 weeks, very preterm infants are born between 29 and 32 weeks, and moderate preterm infants are born between 33 and 37 weeks (see Table 4 for the means, SDs, and sample sizes of the subgroups).

Table 3. Group Differences: Sample Sizes (n), Adjusted Means, Adjusted SDs, ranges, F, p, and partial eta-squared (ηp^2) values for ANCOVAs for preterm and term infants at 13 months. *$p < .05$

	Preterm				Term				ANCOVA		
	n	Mean	(SD)	Range	n	Mean	(SD)	Range	F	*p*	ηp^2
TCDI-1 Word Comprehension	36	96.86	(90.50)	0-343	35	136.60	(77.84)	17-317	0.03	.861	.000
TCDI-1 Early Communicative Behavior	36	25.92	(13.50)	2-53	35	34.23	(11.48)	16-57	1.10	.298	.016
Visual Processing	37	17.08	(4.75)	0-22	36	19.64	(2.24)	14-24	5.16	.026*	.069
Gross Motor Skills	36	15.53	(4.26)	0-23	36	19.00	(4.35)	8-26	6.71	.012*	.089
Fine Motor Skills	36	15.03	(4.11)	0-22	36	17.17	(2.17)	14-21	3.42	.069	.047

Table 4. Preterm Groups Descriptive Results: Sample Sizes (n), Means, SDs of extremely preterm, very preterm, and moderate preterm infants at 13 months.

	Extremely Preterm			Very Preterm			Moderate Preterm		
	n	Mean	(SD)	n	Mean	(SD)	n	Mean	(SD)
TCDI-1 Word Comprehension	7	79.4	(68.4)	18	103	(106)	11	98.3	80.6
TCDI-1 Early Communicative Behavior	7	23	(10.0)	18	26.7	(15.2)	11	26.5	13.2
Visual Processing	7	18.04	(3.74)	19	17.7	(5.81)	11	18.5	2.30
Gross Motor Skills	7	14	(3.92)	19	15	(4.89)	10	17.6	2.32
Fine Motor Skills	7	15.06	(2.64)	19	14	(5.22)	10	16.6	1.17

Table 5. Total Mediation Models: 10000 bootstrap samples and 95% confidence intervals are used. Statistically significant indirect effects are written in bold. Unstandardized values are reported here. IV, independent variable (fine motor skills or gross motor skills); M, mediator (visuospatial cognition); DV, dependent variable (receptive language or early communicative behavior); CI, confidence interval. Gross motor analyses: preterm, n = 34, term, n = 35; fine motor analyses: preterm, n = 34, term, n = 35. For the total model, the neonatal condition is one of the control variables. Age is the control variable in all models.
* *p* < .05, ** *p* < .01, *** *p* < .001

	Word Comprehension (DV)						Early Communicative Behavior (DV)					
Visual Processing (M)	Effect on IV on M	Effect of M on DV	Direct effect IV on DV	Indirect effect IV on DV(CI)	Total effect IV on DV	Adj. R^2	Effect of IV on M	Effect of M on DV	Direct effect IV on DV	Indirect effect IV on DV(CI)	Total effect IV on DV	Adj. R^2
Gross Motor Skills (IV)												
Preterm	.74***	6.87*	.74	**5.08 [-.30, 10.07]**	5.81	.45	.74**	1.30**	.83	**.96[.18, 1.71]**	1.79***	.48
Term	.02	13.34*	-.76	.28[-2.46, 1.88]	-.48	.18	.02	.53	.14	.01 [-22, .13]	.15	.20
Total	.39***	7.72**	-.50	**2.97 [.28, 5.59]**	2.48	.34	.39***	1.33***	.45	**.51 [.05, .92]**	.96**	.36
Fine Motor Skills (IV)												
Preterm	1.11***	0.68	8.69	0.75 [-16.32, 11.97]	9.44***	.59	1.11***	1.32*	.62	**1.46[.08, 2.84]**	2.08***	.62
Term	.47**	17.62**	-8.34	**8.26 [.78, 15.71]**	-.08	.18	.47**	1.22	-1.28	.57[-.65, 1.50]	-.71	.21
Total	.98***	7.95*	-.38	7.80 [-1.48, 14.93]	7.42**	.42	.98***	1.72**	-.18	**1.69[.66, 2.56]**	1.51***	.43

Table 5 shows the results of the mediation analyses. The effects of independent variables (gross motor or fine motor skills) on the mediator (visual processing) are presented in the first column. The second column is the mediator's effect on dependent variables when the effects of independent variables are controlled. The direct effect in the third column is the effect of independent variable on the dependent variables (word comprehension and early communicative behavior) when the mediator is controlled. The fourth column is the indirect effect, which is the effect of the independent variable on the dependent variables through the mediator. The total effect of the independent variable on the dependent variable can be checked in the fifth column. The variance in the dependent variable, which can be accounted for by the mediator and the independent variable, can be found in the sixth column (Adj. R^2). In Table 5, we showed the unstandardized coefficients. For the total model, the neonatal condition was coded as a categorical variable ("0" for preterm infants, "1" for term infants) and controlled for the analyses.

Gross motor skills were related to infants' early communicative behavior, not word comprehension, controlling for age, and neonatal condition. Even though the gross motor skills were not directly related to word comprehension, the visual processing scores mediated the relation between gross motor skills and word comprehension (indirect effect in Table 5) and the link between gross motor skills and early communicative behavior (indirect effect in Table 5). When we examined these models at the group level separately, the model was significant only for the preterm infant group (Table 5). The moderated-mediation analysis showed that the relation between gross skills and visual processing was moderated by the neonatal condition (β= -.66, t=-3.70, p<.001), which means that this relation was different for PT infants than FT infants (see Figure 1). An analysis of standard residuals was carried out on the data to identify any outliers, indicating that one of the participants (ID:207) had a -4.95 standard residual value and can be considered an outlier. However, none of the participants in the analysis had a Cook's distance greater than 1; the mean was 0.025; the highest one was 0.86. Based on these results and lack of methodological concerns, we decided to include this participant in the analysis. The neonatal condition did not moderate the relation between visual processing and word comprehension or the relation between visual processing and early communicative behavior (all *p*s >.05).

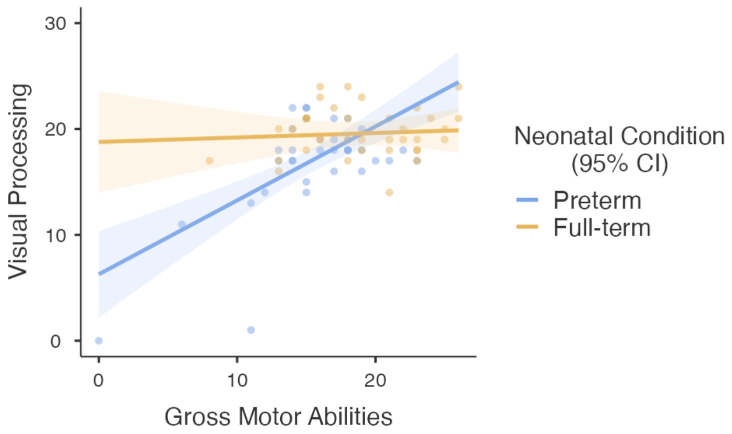

Figure 1. Moderated mediation analysis: The relation between visual processing and gross motor skills across groups. Data points show the scores of every child.

Fine motor skills were related to infants' word comprehension and early communicative behavior, controlling for age, and neonatal condition (total effects in Table 5). These fine motor skills were related to visual processing, and visual processing was related to only early communicative behavior in the total model. Visual processing did not mediate the relation between fine motor skills and word comprehension (indirect effect in Table 5). The moderated-mediation analysis showed that the strength of the relationship between fine motor and visual processing was moderated by neonatal condition (β= -.50, *t*=-2.85, *p*<.01, see Figure 2). Since preterm infants were coded as "0," the negative value means that this relation was different for PT infants than FT infants. We again ran an analysis of standard residuals, which showed that the data did not include any outliers (Std. Residual Min = -2.80, Std. Residual Max = 2.87). None of the participants in the analysis had a Cook's distance greater than 1; the mean was 0.021; the highest one was 0.29. Other pathways were not moderated by the neonatal condition (all *p*s>.05).

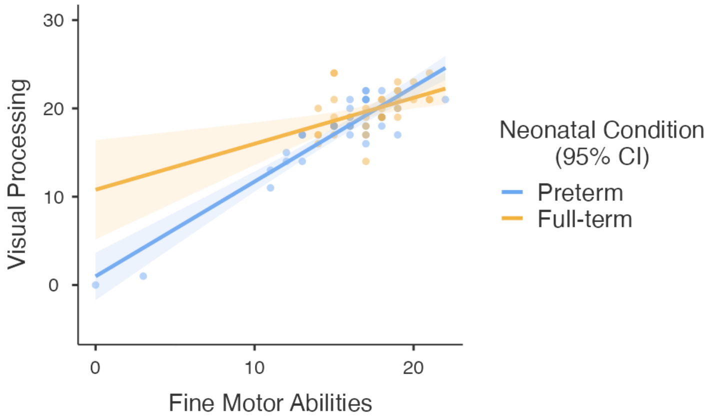

Figure 2. Moderated mediation analysis: The relation between visual processing and fine motor skills across groups. Data points show the scores of every child.

Discussion

This study examined the mediating role of visual processing on the relationship between gross motor and fine motor skills and language development (word comprehension and gesture) of preterm and full-term infants. We predicted that the relations among these variables would be stronger for preterm infants than they were for full-term infants. We found that infants' visual processing skills in both groups mediated the relation between concurrent gross motor skills and language skills (word comprehension and early communicative behavior). Visual processing also mediated the relation between concurrent fine motor skills and early communicative behavior but not word comprehension. As expected, these relations between motor skills and visual processing were different for preterm infants compared to full-term infants.

Preterm and full-term infants at 13 months did not differ regarding their word comprehension or early communicative behavior based on parental reports. Although preterm infants had lower mean scores than full-term infants, preterm infants were not significantly behind their full-term peers when controlling for age. Similar to our findings, a previous study using CDI did not find a significant difference in word comprehension between extremely preterm and full-term infants at 12 months (Benassi et al., 2016). Extremely preterm and full-term infants are expected to have higher differences in language scores since the possibility of receptive and expressive language delays increases as gestational age decreases (Foster-Cohen et al., 2007). Benassi and colleagues (2016) found a significant difference between extremely preterm and full-term infants regarding their early communicative behavior. This finding is different from ours. However, in our sample, preterm and full-term infants were similar in their early communicative behavior probably because we had a mixed group of preterm infants with different gestational ages, and only 7 of them were extremely preterm (see Table 4). Compared to extremely preterm infants, very preterm or moderate preterm infants may not have substantial delays in their early communicative behavior. Besides gestational age and parental input (Adams et al., 2018), the quality of language development can be another explanation. Preterm and full-term infants may have similar vocabulary sizes, but preterm infants may have difficulties in learning different word types such as prepositions or relational verbs. Future studies may investigate learning different word types in these groups. There may also be a small initial gap between preterm and full-term infants, but the gap might become larger as language skills build on each other and become significant when children are older. However, Sansavini and colleagues (2014) found a constant gap in the language domain between preterm and full-term infants, even if age increases. Regardless of group differences, there was considerable individual variability in infants' language skills. Factors that explain this variability is the focus of this paper – specifically relations to the motor and visual skills.

We assessed children's language development with respect to their gross and fine motor skills. Our results also demonstrated that preterm and full-term infants varied in their gross motor skills. As motor-related experiences stimulate and support motor behaviors (Adolph, 2018), preterm infants may have weak postural control or delay in locomotion onset. This decreases the interaction with the environment, leading to lags in the development of specific cognitive skills (Oudgenoeg-Paz et al., 2017). For gross motor skills, visual processing mediated the relation between gross motor and word comprehension and early communicative behavior in infants at 13 months. This mediating role of visual processing might arise from children's interactions with the environment. Each new gross motor skill improves control over posture and locomotion; thus, infants can control their visual skills. For example, locomotion brings new opportunities for visual processing. With locomotion, infants' social interactions increase, like taking the attention of mothers to the specific objects (Clearfield, 2011). These interactive processes are closely related to visual processing, which stimulates learning new words and communicative intentions (e.g., early communicative behavior). Visual processing is also supported by posture control (Smith, 2013). With better posture, infants can focus on objects and actions around them more, which would create interactive environments with their parents. Consequently, these infants can learn words more easily.

Notably, the relation between gross motor skills and visual processing was different for preterm infants and full-term infants. Preterm birth brings problems to posture control and locomotion (Oudgenoeg-Paz et al., 2017). When these children do not control their posture or locomotion, they may not have control over their looks. Neurodevelopmental studies also argue that preterm infants have white matter lesions related to motor deficits (Parodi et al., 2019; Hayman et al., 2019). These deficits influence different brain networks such as thalamocortical pathways associated with visual systems (Tusor et al., 2017; Hoon et al., 2009). Overall, these behavioral and neural problems may bring specific delays in visuomotor integration, spatial search, or visual attention of preterm infants, intensifying delays in one domain over the other.

Contrary to our gross motor findings, the two groups did not differ in their fine motor skills. Previous studies emphasized that extremely preterm infants were behind their full-term peers in fine motor skills (Benassi et al., 2016); yet, as mentioned above, extremely preterm infants were fewer in our sample. For fine motor skills, at the end of the first year, the gap may not be visible for preterm infants outside this vulnerable group. Visual processing mediated the relation between fine motor skills and early communicative behavior but not for word comprehension. Infants, who have enhanced fine motor skills, may focus and arrange objects in spatial dimensions better. The visual processing that is supported by fine motor skills provides necessary inputs for arrangement in spatial areas. For example, infants can sort objects or change spatial relations between objects by putting them under, on, or behind each other. Therefore, they can categorize those objects through their perceptual properties, making it easier to learn their names and stimulate communication with early communicative behavior (Smith, 2013). Infants may also receive more parental input that triggers their communicative intentions (e.g., gesture use). That is, better visual processing becomes more stable with fine motor skills. In contrast, visual processing did not mediate the relation between fine motor skills and word comprehension. Other factors can be related to word comprehension more, such as exploration or social communication as a mediator between fine motor abilities and word comprehension than visual processing.

As in gross motor skills, the relation between fine motor abilities and visual processing was different for preterm and full-term infants. Preterm infants can have problems with eye-hand coordination (Sansavini et al., 2011b). This finding again supports the argument that those problems in fine motor skills can lead to the cascading effect on visual processing problems for infants who are at risk of developmental delays. These delays may be in the form of low severity, but they may impact later cognitive skills such as executive function (Oudgenoeg-Paz et al., 2017) or writing and reading problems (Kerstjens et al., 2011). Problems in these areas may emerge because of the cascading effects of early motor development and visual domains.

Our findings support the embodied cognition perspective, which argues that interaction with the environment using motor skills can influence cognitive skills (Smith & Gasser, 2005). As also argued by the developmental systems approach, acquiring new skills and gaining experience on motor skills shape and transform the environment that an infant behaves in (Adolph, 2019, see also Oakes & Rakison, 2019; Iverson, 2021). Here, we showed that the relation between motor skills and language development may not be direct but mediated by visual experience. New motor skills such as self-locomotion or grasping, improve visual skills (Abney et al., 2018; Adolph, 2019). As actively searching in an environment, visual processing provides spatial information about objects, social information with tracking social agents, and feedback for posture and balance to the infant. For example, infants' body postures determine what they see in physical and social interactions (Franchak, 2020) so that infants receive differential linguistic inputs in these interactions (Clearfield, 2011). Physical posture development in gross motor skills and manual actions in fine motor skills enable visual processing for language learning (Smith, 2013). Infants who have problems in these domains have limited re-shaped or transformed environments (Adolph, 2019). Our results also suggest that preterm infants form different relations between motor skills and visual processing than full-term infants. As a result, preterm infants may lack visually rich experiences due to restrictions in their motor development.

Previous studies usually focused on specific variables such as the age of walking acquisition and connected these specific variables to language development (e.g., Oudgenoeg-Paz et al., 2012). Although walking acquisition onset can be an indicator for the walking experience, different factors can change infants' walking experience, such as walking with diapers or clothes (Cole et al., 2012). Focusing on more global variables such as gross motor skills can be a better indicator of how the experience might be related to language and communicative development. For example, jumping may not be related to language development, but an infant who can jump can be considered as having more experience of standing and walking than an infant who cannot jump.

One of the limitations of this study is focusing on motor skills globally. These global skills can hide some specific connections between motor skills and language development. Hence, future studies should directly examine preterm and full-term infants’ qualitatively different interactions with their environments, such as an object or spatial exploration and the roles of parental input on visual processing, motor skills, and language development. Seeing the world differently within motor stages offers unique experiences that contribute to visual processing skills. However, besides standardized measurements and lab environments, this should also be investigated in naturalistic settings such as home environment (e.g., Herzberg et al., 2021).

Intervention programs that aim to enhance early motor skills can help the visual processing skills of preterm infants. For example, even a brief training with sticky mittens can contribute to the object exploration skills of young infants (Needham et al., 2017). Future studies should also investigate the cascading effect of brief motor skills training on language development through visual abilities for preterm and full-term infants. To observe the cascading effect, besides brief trainings, future research should look at the effect of early motor trainings on later interactions with the environment and development of perceptual skills in longitudinal studies.

In conclusion, this research is among the first that examined the mediating role of visual processing on the relationship between motor skills and early language development in both preterm and full-term infants. We found that visual processing is a mediator between gross motor skills, word comprehension, and early communicative behavior. Visual processing also mediates the relation between fine motor skills and early communicative behavior but not word comprehension. Infants' interactions with their environments, guided by visual processing and motor skills, enhance their language learning. Importantly, the relation between motor skills and visual processing is different for preterm and full-term infants and are prominent for preterm infants who have delays in motor skills. This result indicates a potential developmental cascade. Our findings suggest that delays in motor skills may be related to delays in visual processing, which may decrease the quality and quantity of interaction with preterm infants' environment.

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Appendix A.

For the mediation model with word comprehension and gross motor, the effect size of α path was .42 and β path was .37 and for the model with early communicative behaviors and gross motor, the effect size of α path was .42 and β path was .42. For the model with word comprehension and fine motor, the effect size of α path was .83 and β path was .24 and for the model with early communicative behaviors and fine motor, the effect size of α path was .83 and β path was .35. We considered these are adequate numbers for power of the study with sample size of 69 based on Fritz and McKinnon (2008).