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Genetic and environmental interactions in determining the early lexicon: evidence from a set of tri-zygotic quadruplets*

KARLA K. McGREGOR AND NINA C. CAPONE
Northwestern University

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ABSTRACT

A set of tri-zygotic quadruplets, three girls and one boy, participated in weekly observations from 1;2 to 1;10 (years;months), a period of transition from prelinguistic gesture to 50 words. In the study, one girl served as a genetic mate to her identical twin and a biological risk mate to her fraternal sister. The biological risk mates achieved milestones in lexical development at similar times; however, the genetic mates demonstrated more similarities in pattern of lexical development and in the modality of their word productions. Degree of similarity changed over the observation period. Imposed upon the natural experiment was a within-subject manipulation of the social environment: The experimenters modelled a core vocabulary via the gesture+verbal modalities to the children during each visit. The modelling resulted in increased rates of word learning for three of the children; the child with the greatest biological risk, the boy, derived the greatest benefit. The findings provide unique support for a dynamic, multi-factorial model of lexical development involving the interaction of genetics, the biological environment and the social environment. Furthermore, they illustrate the robustness of early lexical development in the face of biological risks.

INTRODUCTION

The acquisition of complex systems such as language requires the interaction of innate learning mechanisms and environmental support.

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Large-scale twin studies demonstrate relative contributions of both genetics and the environment that vary over language domain and developmental time (Plomin & Dale, 2000). The current study represents a step toward understanding the dynamic interaction between genetics and the environment in determining the lexicon. The study involved longitudinal observation of early lexical development, specifically the transition from gesture to the first 50 words, in three-zygote quadruplets, that is, one identical pair and their two siblings. As a detailed analysis of a narrow slice of development, this case study illustrates the exquisite complexity of genetic and environmental interactions in a way that larger population studies cannot.

This case constituted a natural experiment with several advantages. The first was the opportunity to trace lexical development in four different children of exactly the same age and who shared a similar social environment. That two of the quadruplets were monozygotic twins and the other two were dyzygotic presented a second and rarer advantage – the chance to examine the effects of differing hereditary endowments within a single set of siblings. Although all four children were at-risk, two of the children presented with less perinatal fragility and illness than did the other two. This happenstance presented a third advantage, a window onto the impact of biological risks. Little is currently known about the vulnerability or resilience of lexical development in the face of biological risks.

An important motivation for following this set of quadruplets was the scarcity of data on language development in higher order multiples. The rate of multiple births has increased six-fold since the 1970s, with the introduction and refinement of assisted reproductive technology (CDC, 2001). With the increased prevalence of multiple birth babies comes increased need to document their developmental outcomes.

To date, most of our knowledge of language development in multiples comes from studies of twins. Relative to singletons, twins show slower vocabulary development (Tomasello, Mannle & Kruger, 1986). Dale and colleagues reported twins to lag 3·5 months behind singletons in expressive vocabulary development at age two with more male- than female-twins in the lowest fifth percentile (Dale, Simonoff, Bishop, Eley, Oliver, Price, Purcell, Stevenson & Plomin, 1998). The few reports of language development in higher order multiples involve triplets. An early study of development in six sets of triplets revealed within-subject delays in language development relative to nonverbal cognition and between-subject delays in language as compared to norms for both singletons and twins (Howard, 1946). More recently, McMahon & Dodd (1997) analysed language samples collected from 17 sets of two-to-four-year-old triplets as well as 20 sets of twins and 19 singleton controls. The triplets exhibited more extensive delays than either the singletons or the twins.

Language development and risk

Language, being so crucial to human survival, is robust to certain risks in isolation; however, in combination, multiple environmental and/or genetic risks tend to push children over a threshold of vulnerability. Consider, for example, that in children born at biological risk, there are significant cumulative effects of gestational age (and confounded birthweight), socio-economic status, and neurological status at 0;8 on language status at 2;0, but that outcome is not as well predicted by any of these factors alone (Vohr, Coll & Oh, 1988). Therefore the presence and extent of lexical delays in children of multiple birth, or in singletons for that matter, is unlikely to be attributable to a single factor. The next section summarizes a number of environmental risks, of both the biological and the social type, faced by children of multiple birth.

Environmental risks to language development in multiples

Biological environment. Multiple birth babies are often biologically fragile. The estimated incidence of prematurity (birth before 37 weeks gestation) in twins ranges from 35 to 45%, a rate that is five times that of the singleton population (Malmstrom & Biale, 1990; Taffel, 1992; Martin, MacDorman & Matthews, 1997). Nearly 100% of higher order multiples are born prematurely (Malmstrom & Biale, 1990; Akerman, Hovmoller & Thomassen, 1997). Also, multiples are more likely than singletons to be born at low birthweight (less than 2500 g) (Martin *et al.*, 1997). Even when multiples are matched by gestational age to singletons, the multiples are more likely to exhibit low birthweight (Taffel, 1992). The low birthweight infant is more likely to experience respiratory distress, intraventricular hemorrhage (IVH), cerebral palsy, jaundice, infection, and feeding problems than the higher birthweight infant (Hack, Horbar, Malloy, Tyson, Wright & Wright, 1991).

In singletons, prematurity and low birthweight are associated with a high incidence of developmental delays, especially language delays (e.g. Grunau, Kearney & Whitfield, 1990). As compared to the general population, children born at very low birthweights (less than 1500 g) are almost twice as likely to exhibit language deficits accompanied by cognitive, hearing, or significant neurological deficits (Aram, Hack, Hawkins, Weissman & Borawski-Clark, 1991). Grunau and colleagues (1990) reported expressive and receptive language development to be particularly delayed in three-year-old preterm, very low birthweight children who presented with IVH at birth. Presence of IVH accounted for 33% of the variance in vocabulary scores amongst the preterm/low birthweight children studied.

Social environment. Children of multiple birth are raised in an unusual social environment in that they frequently share adult interaction with one or more same-age children from birth (Savic, 1980). Given this multi-partner context, the language input provided to any individual will be directed either to her (as in the singleton situation), directed to the other child(ren) but overheard by her, or directed to both/all children. The outcome is that twin mothers direct less talk to their children as individuals than do singleton mothers (Tomasello *et al.*, 1986). The amount of input is reduced as well, as the parent must cope with additional caretaking and behaviour control issues. Indeed, mothers of twins are observed to spend less time in play with their children and more time in caretaking (Costello, 1975), to demonstrate fewer and shorter episodes of joint attention, and to use more language that functions to direct behaviour than to comment or question (Tomasello *et al.*, 1986).

Presumably, any social–environmental detriments presented by the twin situation would be exacerbated in cases of higher order multiples because caretaking demands and competition for communicative exchange are increased. Parents of multiples report difficulty in allowing each child his or her own rhythm of feeding, sleep, and play. Instead, for practical reasons, they tend to impose the same schedule on all of the children (Goshen-Gottstein, 1986; Akerman *et al.*, 1997). Even two-parent, high income families report high stress associated with health and development issues, financial problems, and day-to-day care of multiple babies (Malmstrom & Biale, 1990). Given these stresses, together with a lack of community resources for addressing them, Malmstrom & Biale (1990) recommended in their report to the California Department of Health Services that multiple birth families be automatically classified at 'high psychosocial risk' (p. 512).

Input that is characteristic of the twin (or higher-order multiple) situation could slow language development in general; after all, limited, non-contingent, or directive language input is associated with delayed language development among singletons including those with low socio-economic status (Hart & Risley, 1995), those with language disorders (Tiegerman & Siperstein, 1984), and those with mental retardation (Cunningham, Reuler, Blackwell & Deck, 1981). Given the strong influence of the social environment on lexical development (Plomin & Dale, 2000), frequent multi-partner interactions and the complications they present may have a pronounced effect on the early word learning of multiples.

The current study

The quadruplets who participated in this study were considered at risk for language delay because of the unusual language learning environment that results when sharing adult–child communicative interactions with same-age siblings from birth and because of the constellation of biological risks – prematurity, low birthweight, perinatal distress and illness – that accompany multiple births and higher-order multiple births in particular.

The purpose of the study was to describe in detail the expressive communication of the quadruplets from the onset of communicative gesture to the acquisition of at least 50 words. In addition, we hoped to take advantage of naturally occurring variations in genetic make-up (identical vs. fraternal) and extent of biological risks (higher vs. lower) within this set of quadruplets to demonstrate some relative effects of the biological environment and genetics on early lexical acquisition. In particular, the comparison of one of the girls to her fraternal sister (who served as her biological risk mate) and to her identical sister (who served as her genetic mate) was key.

That social environment was relatively constant across the children in the current study was an advantage allowing for easier interpretation of the effects of genetics and biological risks. At the same time, this lack of variation limited examination of the effects of the social environment on word learning. To circumvent this limitation, we introduced a within-subject manipulation of the children's social environment. Specifically, we implemented an abbreviated language intervention protocol that involved frequent modelling of a core vocabulary in the gesture + verbal modalities. Modelling has a long history in language intervention with children (see Fey, 1986 for a review) and use of gesture to enhance language learning has been proven efficacious for children who are normally developing (e.g. Goodwyn & Acredolo, 1993) as well as children who have language impairments (see Capone & McGregor, in press for a review). Although the primary purpose of the language intervention protocol was to determine the effects of an environmental manipulation on word learning, the protocol also focused our observations on the use of a consistent stimulus set thereby facilitating comparison of developmental patterns between children.

In this study, we examined the rate at which each child reached milestones for both trained and untrained gestures/words as well as more qualitative aspects of early lexical development such as shape of growth curves, preferred modalities, and lexical learning styles. By casting a wide net, we hoped to capture similarities between genetic mates as well as similarities between biological risk mates. Given a multi-factorial model of language development, we predicted that similarities of both sorts would emerge. In addition, we predicted an effect of social environment, namely that trained lexical items would be acquired before untrained lexical items. Of primary interest was the dynamic combination of genetic, biological– and social–environmental influences on lexical development.

METHOD

Participants

One set of three-zygote quadruplets participated in this longitudinal case study beginning at age 1;2 (chronological age [CA]; 0;11 prematurity

TABLE 1. *Comparison of perinatal health*

Indices	ID-HI	ID-LO	FRA-LO	FRA-HI-MA
Birthweight	737 g	850 g	850 g	992 g
Hospitalization	15 wks	10 wks	9 wks	13 wks
Medical concerns	respiratory distress	respiratory distress	respiratory distress	respiratory distress
	anaemia	anaemia	anaemia	anaemia
	left IVH	unresponsive to sound*	heart murmur	left IVH
	right IVH		partially collapsed lung	right IVH
	pneumonia			PVL
				CP
				serratia
				blood clot
				staph infection
				bilateral hydroceles
				hernia

Note: IVH = intraventricular hemorrhage, PVL = periventricular leukomalacia, CP = cerebral palsy.
* Hearing impairment was ruled-out and lack of response was attributed to over-stimulation.

adjusted age) and ending at age 1;10 CA. They also participated in a single follow-up session at 2;5 CA. In this paper, the four children, ID-LO, ID-HI, FRA-LO, and FRA-HI-MA, are designated by initials conveying their genetic status, identical (ID) or fraternal (FRA); and their risk status, lower (LO) or higher (HI). The one male child has an additional designation, MA.

Genetics. That ID-LO and ID-HI were monozygotic twins was determined by the delivering physician's examination of the placenta. Although it has long been known that this is not a foolproof method for determining zygosity (Strong & Corney, 1967), the monozygotic status of ID-LO and ID-HI was further confirmed by their appearance. They could not be distinguished physically. In contrast, their sister FRA-LO differed from them in size, facial features, and hair colour and texture.

Biological environment. The quadruplets were born at 26 weeks gestation and so their premature status predisposed them to varying degrees of health problems. Their birthweights ranged from 737 to 992 g. All required intubation secondary to respiratory distress and were anaemic. Other significant medical history appears in Table 1.

All of the children were biologically fragile at birth; however, ID-LO and FRA-LO presented with fewer biological risks to development than did ID-HI and FRA-HI-MA. ID-LO and FRA-LO were identical birthweights, their post-natal hospital stays differed by only one week, and they presented with similar, though not identical, health concerns. Although they were not perfectly equated for biological risks, they were clearly at lower risk than were their siblings ID-HI and FRA-HI-MA. Of particular importance, ID-HI and FRA-HI-MA suffered IVH in both left and right hemispheres, hers were grade II–III and his were grade III–IV. FRA-HI-MA also incurred left hemisphere periventricular leukomalacia (PVL) an injury to the white matter, which is frequently co-morbid with cerebral palsy.[1] At the onset of the current study, FRA-HI-MA presented with cerebral palsy characterized by a right hemiparesis. During the course of the study, he underwent surgical repair for a hernia and he experienced persistent feeding problems. Given the severity of his IVH and his numerous health concerns, FRA-HI-MA presented with the highest biological risks of the four.

At study onset, all of the children demonstrated delays in development as evidenced by their enrolment in physical and developmental therapies. Also, all but FRA-LO received occupational therapy. All children were able to sit, to creep, and to feed themselves with their fingers. The one exception was FRA-HI-MA, who was not yet creeping. None of the children were enrolled in speech-language therapy at the beginning of the study. FRA-HI-MA and ID-HI began working with a language therapist at the close of the study proper but before the follow-up visit.

Social environment. The quadruplets were first-born children of a Caucasian, upper-middle class, English-speaking family. Their primary caregiver was their mother who was also a speech-language pathologist. As such, she was aware of normal developmental milestones and techniques for facilitating language development. A female nanny assisted with the children's daily care and their father was present in the evenings and on weekends. Together, their parents, nanny, and therapists provided a rich language learning environment for these children. Daily activities were structured around predictable routines and abundant toys and preliteracy materials were available.

Maternal report measures

Maternal reports supplemented direct observations of the quadruplets' prelinguistic and lexical development. Prior to the study, the mother completed the *Communication and Symbolic Behavior Scale Caregiver Questionnaire* (CSBS, Wetherby & Prizant, 1993). Her answers to this questionnaire provided descriptions of each child's prelinguistic communication. Approximately five months after the study began (children's

[1] We have classified IVH and PVL as biological–environmental factors because they are likely consequences of prematurity and fragility associated with multiple fetuses in the intrauterine environment. However, we cannot rule out the possibility that these conditions may have had some genetic basis as well.

CA = 1;7), the mother completed the *MacArthur Communicative Development Inventory* (MCDI Fenson, Dale, Reznick, Thal, Bates, Hartung, Pethick & Reilly, 1993). Because MCDI results indicated that only one of the children had reached the 50-word mark at that time, the study continued for three additional months. Another MCDI completed after the three additional months indicated that all of the children had surpassed the 50-word mark; therefore, the study was discontinued.

Procedure

The children were observed weekly for a period of eight months. The only exception to the weekly sampling rate occurred between sessions 11 and 12 when the family took a two-week vacation. Seven months following the final observation session, a single follow-up session was conducted.

Observations took place as each child, either of the experimenters (the authors), and the mother played for ten minutes with consistent toy sets. The children had equal numbers of interactions with the two experimenters. During observation sessions the experimenter modelled gesture + verbal labels (e.g. two fingers extended upward + *bunny*) embedded in context-appropriate utterances at least three times for each of the target words. The children occasionally allowed hand-over-hand modelling of the referential gestures. Approximately once monthly, there was an observation session similar in every way to the others except that (1) it included novel toys and (2) it involved no gesture models. The purpose of these novel sessions was to assess generalization of learned targets to untrained exemplars in the absence of the scaffolding provided by gestured input. At follow-up, each child interacted with an experimenter and the mother using both toy sets. The follow-up session documented whether observed differences between the children were maintained.

Stimuli

The training set included eight target gestures/words (*fish*, *more*, *thank you*, *big*, *little*, *book*, *fall down*, *all gone*). Four additional gestures/words (*toothbrush*, *elephant*, *bunny*, *drink*) were added at session 13 because the children had learned many of the original set. The target gestures/words were chosen to represent a variety of semantic and pragmatic functions. In particular, it was important that the set included semantic types that went beyond object labels so that any differences between children in word type preference could be easily determined. The examiner modelled the gestures as suggested by Acredolo & Goodwyn (1996). There were two toy sets, a training set and a novel set, each of which included cause-and-effect objects, stuffed animals, pictures, puzzles and books. There were at least three items per set that were likely to elicit each of the target gestures/words.

Coding

Videotapes of all sessions allowed coding of dependent measures and estimation of inter-coder reliability. The first applied codes concerned the communicative behaviour exhibited by the child: pre-linguistic gesture, untrained gesture/word, or trained gesture/word.

As described in Bates, Camaioni & Volterra (1975), a prelinguistic gesture was a spontaneously produced *give*, *show*, or *point* action. Consistent with Goodwyn & Acredolo (1993), hand waving (*bye-bye*) and head nods were not coded as prelinguistic gestures because they are routinized forms. If a prelinguistic gesture occurred as part of a routine (e.g. giving an object while putting toys away) only the first three productions were tallied to ensure that estimates of gesture production were not inflated.

An untrained gesture/word was a spontaneously produced utterance that labelled a relevant aspect of the context but that was not part of the training set. To ensure reliability, these utterances had to (1) contain at least one consonant or two vowels of a recognizable word or (2) involve a manual or facial sign that conveyed the form or function of a recognizable referent.[2] Forms omitted from analysis were sound effects, the words *yes* and *no*, the deictic forms *this* and *that*, and any counting or alphabet routine (see Goodwyn & Acredolo, 1993).

A trained gesture/word was a production of one of the 12 items in the training set. These productions met the criteria listed above for untrained words except that all productions, imitated, elicited, and spontaneous, were coded. Although four of the trained gestures (*more*, *big*, *book*, *fall down*) were modelled with two hands, any one-handed productions made by the children were also coded so that FRA-HI-MA was not penalized for limitations due to hemiparesis.

The subset of trained gestures/words was subsequently classified according to modality, whether gesture, verbal, or gesture + verbal. In addition, all trained gesture/word types were examined to see whether they were used symbolically. Symbolic status was inferred if the child produced the trained gesture/word spontaneously for at least two referents from the training toy set and at least one referent in the novel toy set.

Reliability

Identification of all communicative events ($n = 2408$) was determined by the consensus of both experimenters. Communicative events were subsequently coded independently for type and, if a trained form, for modality.

[2] Although most untrained forms were words, the children did use a few consistent gestural labels that were not part of the training set. Examples included patting the head to label *hat* and sticking out the tongue to label *frog*. Therefore, we included both words and gestures when coding untrained forms.

Reliability coding was conducted for 15% of the sessions. Point-by-point agreement between independent coders was 95% for type of communicative event. Across children, agreement on coding of type ranged from 94% (for ID-LO) to 99% (for FRA-HI-MA). Point-by-point agreement between independent coders was 90% (range = 73–100%) for modality classification. Disagreements in coding discovered during reliability checks were resolved by the consensus of both experimenters.

Summary

The quadruplets differed in degree of shared genetics and in degree of biological fragility but they shared a similar social environment for language learning. Comparing the patterns of language development exhibited by the children allowed some conclusions about the role of genetics and the biological environment in determining early word learning. Most critical was the similarity of ID-LO and ID-HI as compared to ID-LO and FRA-LO, the former pair because they shared identical genetic makeup but differed in biological risks and the latter pair because they had similar degrees of biological risks but differed in genetic makeup (and because sex was controlled in both pairings). Where biological environment plays a greater role in determining early word learning, ID-LO and FRA-LO should be more similar to each other than should ID-LO and ID-HI. Where genetics plays a greater role, ID-LO should be more similar to her identical twin ID-HI than to her fraternal twin FRA-LO. Because he presented with the greatest degree of biological risks to development, FRA-HI-MA provided additional data regarding the vulnerability of early lexical development to variations in the biological environment. Finally, the children's responses to a manipulation of their social environment – a language intervention protocol – allowed conclusions about the influence of the social environment on the emergence of first words.

RESULTS

The quadruplets' gesture and vocal development at study onset as determined by maternal responses on the CSBS is summarized in Table 2. All of the children babbled and communicated with prelinguistic gestures and eye gaze. None used words or referential gestures. There were differences between the children as well. According to maternal report, genetic mates ID-HI and ID-LO did not seek social interaction to the extent of the other children. ID-LO was described as the quietest of the four. She babbled during solitary play but she did not babble to get attention or to request objects. FRA-LO was the most advanced of the four at study onset, being the first to coo and babble and the only one to demonstrate pointing

TABLE 2. *Comparison of gestural and vocal development at study onset*

Indices	ID-HI	ID-LO	FRA-LO	FRA-HI-MA
Gesture repertoire	reach	reach	reach point	reach
Babble repertoire				
(consonants)	b,t,d,k,g	m,b,t,d,f,k,g	p,b,t,d,k,g	m,b,t,d,k,g,h
(syllables)	reduplicated isolated CVs	reduplicated	reduplicated isolated CVs	reduplicated
Babble functions	play communication	play	play communication	play communication
Frequency of initiations	rare	rare	frequent	frequent

behaviour. Receptively, FRA-HI-MA appeared weaker than his sisters. He did not respond to words other than his own name.

Communicative behaviours

The children's communicative behaviours, classified as prelinguistic gestures, trained gestures/words, or untrained gestures/words, and measured in tokens observed per session interval, are summarized in Figure 1. During the first month of the study (sessions 1–4), all of the children communicated primarily with prelinguistic gestures. Without exception, *give* and *show* gestures were more common than *point* gestures. Three of the children, ID-LO, FRA-LO, and FRA-HI-MA also began using trained linguistic forms during sessions 1–4. For ID-LO these were *fish* and *all gone*, for FRA-LO they were *fish*, *thank you*, and *fall down*, and for FRA-HI-MA the first trained linguistic form was *fish*. ID-HI began using the trained linguistic forms, *fish* and *all gone*, the following month. FRA-LO was the first to use untrained linguistic forms, producing *bubble* in session 3. ID-LO followed by producing *bug* in session 7. ID-HI followed two weeks later with *pop*. FRA-HI-MA was the last to learn an untrained form. He produced *boy* in session 15, roughly three months later than his first trained form.

At follow up, when the children were 2;5, ID-HI still relied heavily on prelinguistic gestures to communicate and, like her brother FRA-HI-MA, she did not produce sentences. In contrast, the lower risk mates, ID-LO and FRA-LO, produced two and three word combinations such as *want more*, *no more blow*, *you got* (the letter) *B*, and *another rabbit*.

In summary, the rate at which the children moved from prelinguistic gestures, to trained gestures/words, to untrained gestures/words and, finally, to early sentences was best predicted by degree of biological risk. FRA-LO demonstrated all communicative types of interest, prelinguistic gestures and trained and untrained gestures/words during the first month of study. ID-LO and then ID-HI followed; FRA-HI-MA was notably slower to develop. He rarely communicated during the first three months of the

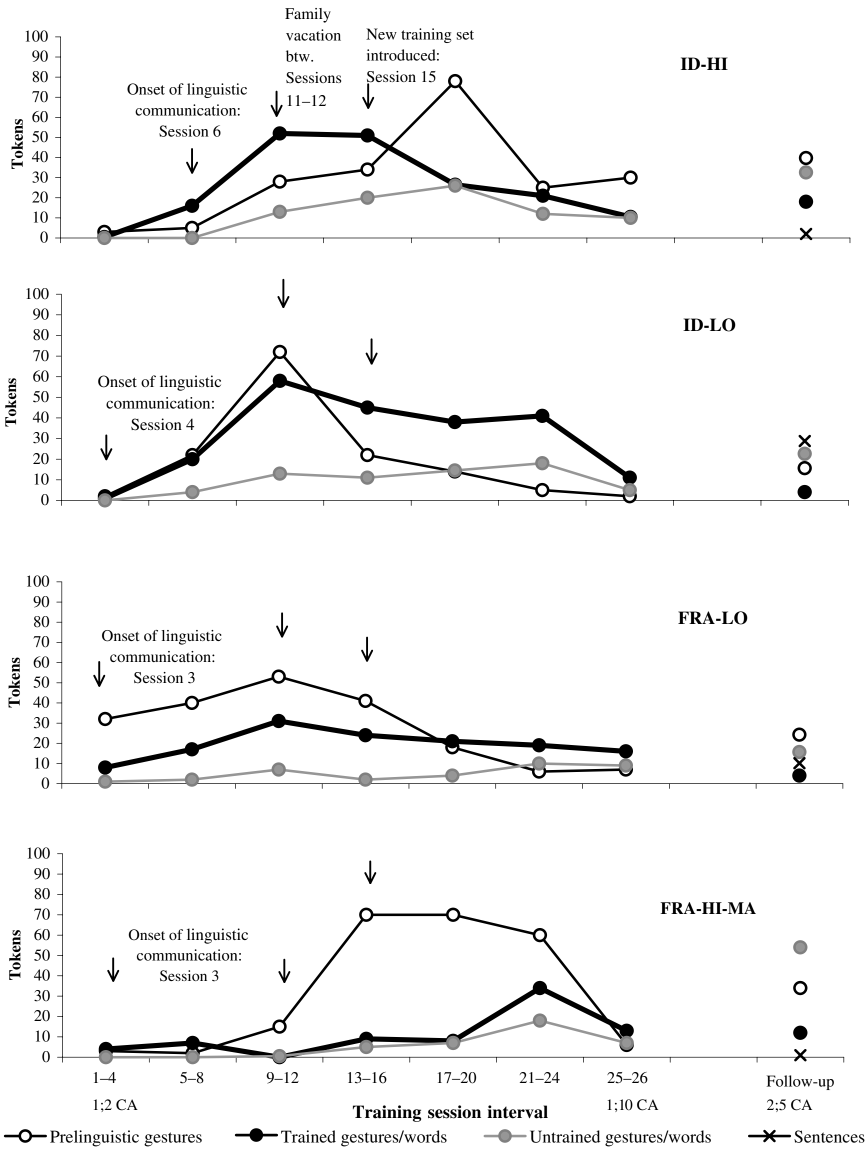

Fig. 1. Productions categorized by child, communicative behaviour and training session interval.

study and he remained dependent on prelinguistic gestures for a longer period of time than his sisters did. At follow-up, only the lower risk twins, ID-LO and FRA-LO, combined words into sentences.

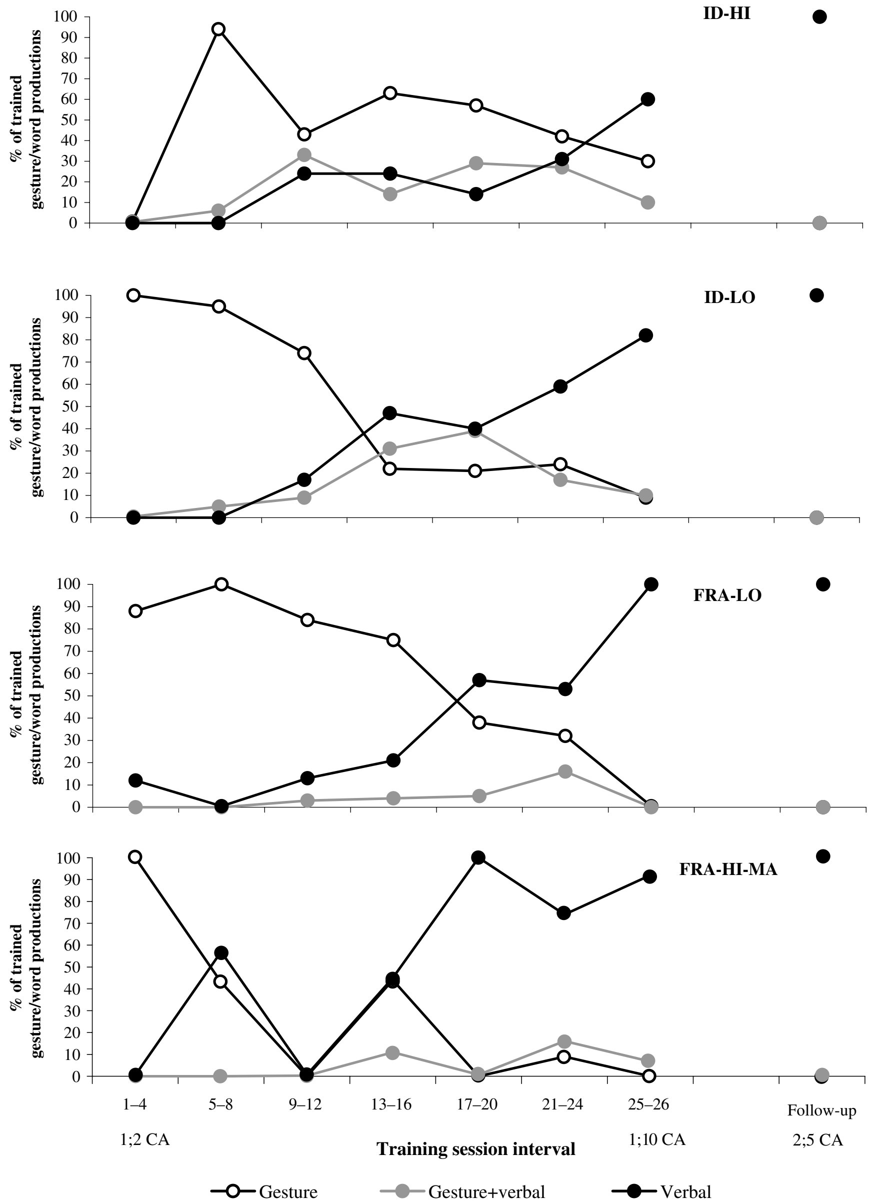

Fig. 2. Trained gesture/word tokens categorized by child, modality of production and training session interval.

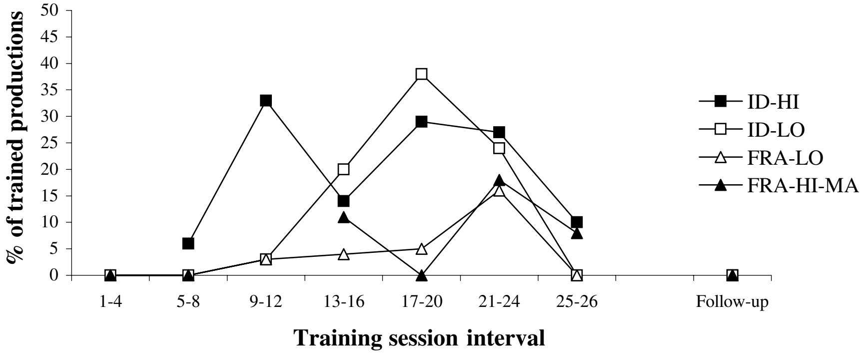

Fig. 3. Percentage of trained tokens produced in the gesture + verbal modality characterized by child and training session interval.

Trained forms

The next two sections concern the production of trained gestures/words only.

Modality of productions. Figure 2 characterizes modality usage as measured by the percentage of trained gesture/word tokens. Not surprisingly, all of the quadruplets showed an initial preference for gestured expression and an eventual transition to predominantly verbal utterances. The timing of that shift varied across children. FRA-HI-MA's transition was earliest and most gradual (sessions 5–16); ID-HI's was latest (sessions 21–25). The lower risk mates, ID-LO and FRA-LO, were predominantly verbal by sessions 13–16 and 17–20, respectively. During their transition to spoken words, the genetic mates, ID-LO and ID-HI, made greater use of gesture + verbal forms than did their fraternal siblings (see Figure 3). At follow-up, all children were using verbal productions exclusively.

Symbolic status. Recall that those trained gestures/words that were produced spontaneously for at least two different referents in the training toy set and at least one referent in the novel toy set were designated as symbolic. During the course of the study, the lower risk mates, ID-LO and FRA-LO, acquired four trained symbols; the higher risk mates, ID-HI and FRA-HI-MA, acquired three. Onset of symbolic communication also patterned according to risk. The lower risk mates, ID-LO and FRA-LO, first evinced symbolic communication at 1;4, the higher risk mates, ID-HI and FRA-HI-MA, two months later. The gesture/word types meeting symbolic criteria are marked in Tables 3–6.

Fish and *more* were the first targets to be used symbolically by each child. None of the children used *little*, *big*, *toothbrush* or *thank you* symbolically. Overall, the forms that acquired symbolic status were those that functioned to label objects or actions or to make requests. Forms that were less

TABLE 3. *ID-HI's spontaneous expressive lexicon*

Session	Chronological age	Trained gestures/words	Untrained gestures/words
1	1;2		
2			
3			
4			
5	1;3		
6			
7		fish, allgone	
8	1;4	more	
9			pop
10		falldown	
11	1;5		
12		book	woof-woof, monkey, bug
13			bottle, bubbles, bear
14	1;6		pooh
15			baby, dog
16		more[s], allgone[s], fish[s]	
17	1;7		girl, bird
18			push, bath
19			balloon, cup, here, sit, block, car
20	1;8		ball
21			
22			
23	1;9		truck, hat, boat
24			chair, drum
25			
26	1;10		glasses

[s] Trained gesture/word met criteria for symbolic usage.

functional, that is, those that marked attribution (*little*, *big*) or politeness (*thank you*) did not achieve symbolic status.

Spontaneous expressive vocabulary

The next three sections concern spontaneously produced, trained and untrained forms.

Size. Tables 3–6 also document the relative number of gesture/word types that the quadruplets produced spontaneously during the eight months of observation. By the final session, ID-HI had produced five trained and 27 untrained gestures/words; ID-LO had produced eight trained and 28 untrained gestures/words; FRA-LO had produced eight trained and 15 untrained gestures/words; and FRA-HI-MA had produced six trained and 14 untrained gestures/words.

Table 7 presents the MCDI results collected when the children were 1;7 and 1;10. At 1;7, ID-LO and ID-HI had expressive vocabulary sizes

TABLE 4. *ID-LO's spontaneous expressive lexicon*

Session	Chronological age	Trained gestures/words	Untrained gestures/words
1	1;2		
2			
3			
4		fish	
5	1;3		
6			
7		more	bug
8	1;4	allgone, more[s]	pop
9			
10		book	boy, monkey
11	1;5		bottle, bird
12		fish[s]	
13			block
14	1;6		ball, help, push
15			puppy, dog, cat, duck, girl, bear, bubbles, frog
16			
17	1;7	elephant, falldown	open, box
18			night-night
19			
20	1;8	toothbrush	
21			
22			woof-woof, pooh
23	1;9		balloon, car
24		falldown[s], elephant[s]	
25		bunny	on
26	1;10		man, shirt

[s] Trained gesture/word met criteria for symbolic usage.

that were within normal limits, even when their chronological age, rather than adjusted age, was used as the basis for normative comparison. Their fraternal siblings had smaller expressive lexicons. Both scored at the tenth percentile given their chronological age, a level generally taken to be a clinically significant cut-off (Thal & Tobias, 1994). All of the children improved their standing by the time of the second MCDI report. Given their chronological age, all were within normal limits; given their adjusted age, all were firmly within the average range.

Rate. Figure 4 compares the rate of expressive vocabulary development among the quadruplets as measured by cumulative number of spontaneously produced gesture/word types observed by the experimenters. Although biological risk mates FRA-LO and ID-LO acquired their first words roughly one month earlier than ID-HI, the three sisters demonstrated similar rates of lexical development between ages 1;3 and 1;6. After 1;6, the genetic mates, ID-LO and ID-HI, demonstrated comparable spurts in rate of lexical growth. In contrast, their sister, FRA-LO, demonstrated

TABLE 5. *FRA-LO's spontaneous expressive lexicon*

Session	Chronological age	Trained gestures/words	Untrained gestures/words
1	1;2		
2			
3		fish, falldown	bubbles
4			
5	1;3		
6			
7		more	pop
8	1;4	more[s]	
9			block
10		allgone	
11	1;5		
12		book	ball, pooh
13			box
14	1;6		
15			
16			woof-woof
17	1;7		
18			
19			
20	1;8		push
21			tub
22			monkey, hat
23	1;9		glasses
24		falldown[s], book[s]	
25		elephant, bunny, bunny[s]	butterfly
26	1;10	toothbrush	bear, ball

[s] Trained gesture/word met criteria for symbolic usage.

linear growth rather than a spurt. Finally, their brother, FRA-HI-MA, demonstrated a vocabulary spurt and also the slowest rate of development.

As a check on the validity of these observations, we compared the relative ranking of vocabulary size in Figure 4 to that reported in Table 7. According to both experimenters' observation and MCDI results, ID-LO was most precocious and FRA-HI-MA was least precocious. What differs between the two measures is the relationship between ID-LO and her sisters. Experimenters' observations suggest that ID-LO and ID-HI knew more words than FRA-LO whereas MCDI results suggest that the three girls were similar in their vocabulary knowledge at that time. Anecdotally, FRA-LO was the most challenging child to sample because she participated in fewer and briefer episodes of joint attention with the examiners than did her siblings. As such, she may not have demonstrated the extent of her word knowledge during the observation sessions. Alternatively, the validity and reliability of a parent report of four different children of the same age and of similar developmental level are not established and therefore

TABLE 6. *FRA-HI-MA's spontaneous expressive lexicon*

Session	Chronological age	Trained gestures/words	Untrained gestures/words
1	1;2		
2			
3		fish	
4			
5	1;3		
6			
7			
8	1;4		
9			
10			
11	1;5	allgone	
12			
13			
14	1;6		
15		toothbrush	boy
16		fish[s]	bottle, man, butterfly
17	1;7		
18			
19		bunny	bear, ball
20	1;8		pooh, bathtub
21			
22			bubble
23	1;9		monkey
24		falldown, more, bunny[s]	boat, bug
25			light
26	1;10	more[s]	pop

[s] Trained gesture/word met criteria for symbolic usage.

difficulties inherent in providing multiple reports may have contributed to the inconsistencies in the results.

Semantic categories. As documented in Tables 3–6, the quadruplets' early lexicons consisted largely of object labels. Other represented semantic categories included predicates (e.g. *fall down*, *pop*, and *all gone*), sound effects (e.g. *woof-woof*) routines (e.g. *night-night*), and closed class items (e.g. *on*).

Maternal reports on the MCDI allowed a more thorough analysis of the semantic categories represented in the children's expressive vocabulary at two points in time (see Figure 5). At both 1;7 and 1;10, object labels were predominant for all children. The most notable change from 1;7 to 1;10 was an increase in the proportionate representation of predicates in the children's lexicons. Closed-class items were few at both reports. Overall, semantic categories varied little with genetics or with biological risks. Both the experimenters, in their observations of trained and untrained gestures/words, and the mother, in her MCDI reports, noted a preponderance of object labels.

TABLE 7. *Size of expressive lexicons as measured by the MacArthur Communicative Development Inventory at chronological ages of* 1;7 *and* 1;10

	1;7			1;10		
Child	Types	%tile CA*	%tile AA**	Types	%tile CA	%tile AA
ID-HI	43	15	35	148	25	50
ID-LO	77	30	55	184	35	60
FRA-LO	34	10	30	157	30	55
FRA-HI-MA	21	10	25	70	15	40

* %tile CA = percentile score from MCDI using chronological age mates as comparison group.
** %tile AA = percentile score from MCDI using adjusted-for-prematurity age mates as comparison group.

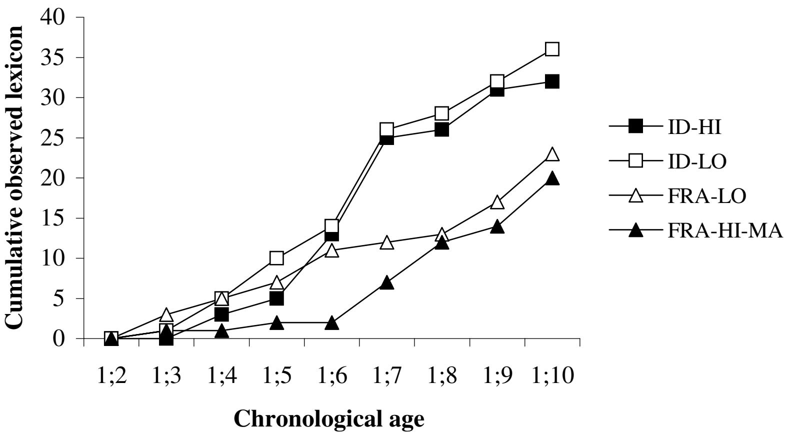

Fig. 4. Number of word types in the cumulative expressive lexicons characterized by child and chronological age. Data are based on experimenters' observations of spontaneously produced gestures/words.

DISCUSSION

Early language, being highly dynamic and strongly context-bound, lends itself to detailed longitudinal observation in naturalistic settings (Dromi, 1987). Longitudinal case studies have been instrumental to our understanding of early lexical development (e.g. Leopold, 1939; Bowerman, 1978; Dromi, 1987); however, such studies rarely allow control over any of the myriad of environmental and genetic factors that may influence that development. The current case study represented an advantage in this regard. Because these were three-zygote quadruplets, genetic factors were well controlled. One twin pair shared identical genetic make-up, the other

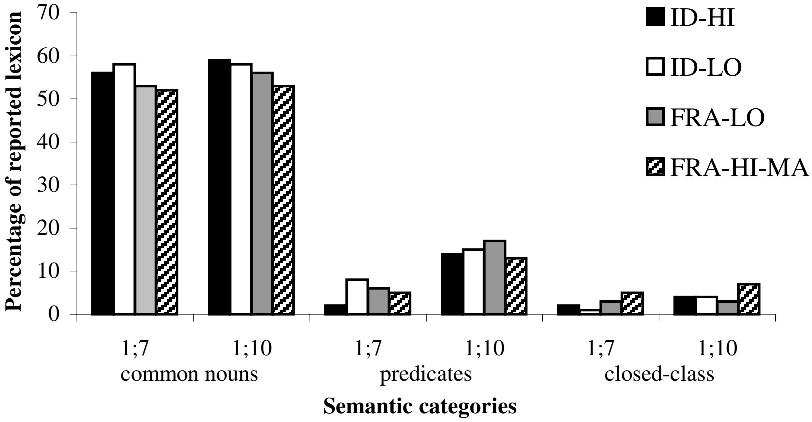

Fig. 5. Semantic categories (as defined in Bates *et al.*, 1994) represented in the cumulative expressive lexicons as reported on the MCDI at 1;7 and 1;10 CA for each child.

siblings shared partial genetic make-up (with each other and with the identical twins). Happenstance allowed some control over the biological environment as well. Two of the girls, ID-LO and FRA-LO, presented with similar biological risks and lower biological risks than their siblings. Against a backdrop of similar social environment, we introduced a manipulation. We taught a core vocabulary of gesture+spoken symbols. By longitudinal observation of the emergence of trained and untrained gestures/ words in this rare set of quadruplets, we gained a detailed picture of the dynamic interplay of genetic, biological–, and social–environmental influences on the early lexicon.

What can similarities among four at-risk children teach us about lexical development?

Much of what we know about language development is based on data averaged across groups of children. The result is a useful, if mythical, set of expectations about developmental sequences demonstrated by the average child (see Bates, Marchman, Thal, Fenson, Dale, Reznick, Reilly & Hartung, 1994 for a discussion). By examining children who come to the task of language development facing environmental risks, the robustness of these sequences becomes evident. Here we emphasize two ways that the quadruplets, despite their risks, developed in a highly typical fashion: their transition from gesture to words and the content of their early lexicons.

Each quadruplet demonstrated communication in the gesture modality before the verbal modality. This is characteristic of other young language learners. The prelinguistic gestures *show*, *give*, and *point* emerge, in sequence, around 0;10 (Bates *et al.*, 1975). In particular, pointing serves as a pre-cursor to spoken word use and it is often combined with early word productions (Iverson, Capirci & Caselli, 1994). Goodwyn & Acredolo (1993) found that, on average, children can communicate with representational gesture (e.g. sniffing to represent flower) approximately one month before they can communicate with representational words. The current findings are largely consistent with the literature: ID-HI and FRA-HI-MA communicated with gesture for one month, and ID-LO for two months, before their first verbal productions. FRA-LO was communicating with both gesture and verbal productions from the first month of observation.

Object labels were disproportionately represented in the quadruplets' early lexicons, constituting 52–59% of all words in their expressive vocabulary depending on the child and the time of sample. Since Nelson's (1973) study, investigators have recognized that children vary in noun focus but that, on average, children have more nouns in their early lexicons than any other single word type. More recently, crosslinguistic studies have documented the consistency with which children from diverse language communities favour noun learning despite important variations in degree of noun biases between languages (Gentner & Boroditsky, 2001).

The quadruplets' knowledge of nouns can be compared to norms provided by Bates *et al.* (1994). These investigators gathered MCDI reports from 1803 children between 0;8 and 2;6, children whose vocabularies ranged from 0 to 680 words. Substantial style variation was noted in degree of noun bias, especially in children with fewer than 200 words in their lexicons. Compared to these norms, each of the quadruplets can be described as having a referential style. Given their respective vocabulary sizes, each scored between the 85th and 90th percentile for percentage of nouns in the total vocabulary at 1;7. At 1;10 the percentiles fell but, ranging from the 60th to the 70th percentile, remained above average. Style differences are often attributed to environmental variables with first-borns from high socioeconomic backgrounds being more referential than others are (Bates *et al.*, 1994). The consistency of referential style among these four children, who varied in biological risks but shared the advantages of being raised by parents of economic means and high levels of education, provide unique support for this explanation.

What can variation among four at-risk children teach us about lexical development?

Similarities and differences between the quadruplets are summarized in Table 8. Briefly, the biological environment played an important role in rate of development. The two female twins who were lower in biological risks developed more quickly than their higher risk siblings did. In contrast,

TABLE 8. *Comparison of lexical development*

Indices	Genetic mates		Biological risk mates	
	ID-HI	ID-LO	FRA-LO	FRA-HI-MA
Rate of growth				
Onset of linguistic communication	1;3[a]	1;2	1;2	1;2
Onset of symbolic communication	1;5	1;3	1;3	1;6
Word combinations at follow-up	no	yes	yes	no
Nature of growth				
Vocabulary acquisition spurt	yes	yes	no	yes
Gesture + verbal combinations	high	high	low	low

[a] Onset given in chronological age.

genetics seemed a better relative predictor of the more qualitative aspects of lexical growth, with the identical twin girls demonstrating highly similar patterns of growth and dissimilar patterns to their respective biological risk-mates. These patterns of variation are interpreted in more detail in the next two sections.

Genetic influence

The critical evidence for genetic influence on the early lexicon was the similarity between the identical twins. Although ID-HI was slower to reach milestones, she was similar to her genetic mate, ID-LO, in the QUALITATIVE nature of her lexical growth. Their various similarities related to a spurt in rate of acquisition that began at 1;5 and 1;6 for ID-HI and ID-LO, respectively. This is in contrast to FRA-LO who demonstrated more linear growth. Both nonlinear and linear growth curves have been reported in the literature. For example, Dromi's daughter Keren demonstrated curvilinear vocabulary growth with a spurt at 1;4 and a decline about three weeks later (Dromi, 1987). During those three weeks, she increased the size of her expressive lexicon by one third. About eight weeks after the spurt, she began to combine words. In contrast, Clark's son Damon demonstrated more gradual growth and less distinct one-word and two-word stages (Clark, 1993).

The identical twins were also more like each other and less like their fraternal sister FRA-LO in the modality of their utterances. Compared to FRA-LO, the identical twins displayed proportionately higher use of gesture + verbal combinations. Over time, this usage constituted a U-shaped developmental trajectory. Though rare during the first and last months of the study, as many as 30–40% of their utterances were produced in the gesture + verbal modality in the middle months of the study. These middle months, during which the children were roughly 1;4 to 1;9, encompassed the period of the vocabulary spurt. For the identical twins, gesture + verbal combinations may have functioned to aid expression during their word spurt, a period of rapid mapping of labels to their conceptual referents. Gesture has been shown to scaffold children's communication during instances of high processing demands (Alibali & Goldin-Meadow, 1993).

Environmental influence

Biological environment. The critical evidence for a biological–environmental influence on early lexical development was the similarity between the lower risk twins, ID-LO and FRA-LO. Although FRA-LO reached prelinguistic milestones earlier, ID-LO quickly caught up during the period of lexical development. The two met milestones such as first trained word and first symbol usage at similar points in time and at earlier points than did ID-HI. Furthermore, only the lower risk mates were using word combinations at follow-up. In contrast, the genetic mates ID-HI and ID-LO demonstrated different rates of lexical development despite sharing complete genetic endowments and very similar social environments. ID-HI's slower lexical development is likely due to her higher risk status. Recall that ID-HI and her brother, FRA-HI-MA, experienced bilateral IVH at birth. Brain damage of this type is highly predictive of later language delay (Grunau *et al.*, 1990).

FRA-HI-MA's lexical development was the most dramatic example of biological environmental effects. His lexical development lagged behind his sisters' in many ways. In the third month of the study, he did not communicate at all during the observation sessions. He was dependent on prelinguistic gestures to a greater extent than his sisters were. He had a smaller lexicon at all points measured. He was the last of the four to transition to spontaneous utterances and, along with ID-HI, he was late to produce symbols and word combinations. Recall that, in addition to a bilateral, grade III–IV intraventricular haemorrhage, FRA-HI-MA had cerebral palsy. This motor limitation likely slowed his lexical growth as it reduced his ability to produce and practice words with either his hands or his mouth. In addition, his hemiparesis likely curtailed certain interactions with his world, thereby reducing language learning opportunities. Add to this mix that boys are slightly but reliably slower than girls to develop language in optimal circumstances (Fenson *et al.*, 1993) and that they are at greater risk for language impairments than girls (Tomblin, Records, Buckwalter, Zhang, Smith & O'Brien, 1997) and FRA-HI-MA's slow lexical development is not unexpected.

Social environment. At 1;10, each child scored within normal limits on the MCDI. While ignoring neither ID-HI and FRA-HI-MA's subsequent delays in word combining nor their eventual enrolment in language intervention, the children can be said to have remarkably strong early lexical development. Given that the social environment was a relatively controlled variable between children, we can only speculate that the quality care and stimulation provided by the adults in these children's lives constituted a protective effect that counteracted some of the environmental risks that are frequently associated with the multiple situation.

The design of this case study included a within-subject manipulation that permitted firmer conclusions about the effects of differing language learning environments on early lexical development. Specifically, the experimenters modelled a core vocabulary of 12 gestures/words to the children during each visit. This environmental manipulation resulted in a faster rate of learning for three of the four children; those three learned at least one trained gesture/word before they learned any untrained gestures/words. Training represented an advantage of two weeks, three weeks, and three months, for ID-HI, ID-LO, and FRA-HI-MA, respectively. For all four children, *fish* was among the first three gestures/words learned. The estimated age of acquisition for fish is 2;6 with a range of 1;5 to 3;7 (Carroll & White, 1973). The quadruplets first acquired the word between 1;2 and 1;3. This unusual first word is further evidence of the influence of the enhanced vocabulary models.

The vocabulary modelling procedure was more limited than traditional early language interventions but not unlike those interventions in use of multiple exemplars, high redundancy, and gestured input. As such, this case study suggests the effectiveness of early intervention for facilitating lexical development. Intervention may be considered a positive social–environmental factor within the complex mix of factors that shape lexical development.

Dynamic interactions between genetic and environmental factors

The data reviewed above demonstrate a complex interplay between genetics, biological environment, and social environment in determining early lexical development. The relative contribution of these factors is likely to be highly variable across individuals and cannot be generalized. Consider that, in cases of genetic disorders, the effects of genetic factors are exacerbated. For example, among children with specific language impairment, genetics accounts for 73% of variation in expressive vocabulary as compared to only 25% of variation within the normal population (Dale, Simonoff, Bishop, Eley, Oliver, Price, Purcell, Stevenson & Plomin, 1998). The relative effects of environmental influences vary with extremes as well. For example, secure mother–child attachment buffers early language development in children of extremely low socio-economic circumstances but contributes little to the variance in language ability among children of more means (Morisset, Barnard, Greenberg, Booth & Spieker, 1990). For the quadruplets in the current study, it is likely that the influence of the biological environment on their language development is greater than that seen in children who present with no biological risks.

In this case study, variability in the relative contribution of genetic, biological, and social–environmental factors constitutes an important finding in and of itself. It is remarkable that despite partial overlaps in their genetic, biological and social–environmental profiles, between-child variation was readily apparent. One example was that the child facing the greatest biological risks, FRA-HI-MA, derived the greatest benefit from the manipulation of his social environment via the word training protocol. He was able to gesture trained forms three months before untrained forms emerged. In comparison, the advantage for his sisters was measured in weeks. Variation of genetic and biological–environmental influences within the individual quadruplets over time was also evident. For example, in rate of development, ID-LO was similar to her genetic mate during the prelinguistic period but more similar to her genetic mate during the period of first words.

In the current study, we noted shifts across a narrowly defined period of development, the emergence of first words. Using a wider developmental lens and a large population sample, Plomin & DeFries (1998) noted that, overall, genetic influences on language increase from childhood to adolescence. From a theoretical viewpoint, all word learners present with a highly individual combination of factors that shape their development. These quadruplets demonstrate the exquisitely complex and dynamic interplay of these factors.

CONCLUSIONS

In many ways, the lexical development of these four at-risk children was unremarkable and highly similar to the course of lexical development reported in the extant literature. As such, this case study illustrates the robustness of the human capacity for word learning and the validity of developmental generalizations such as 'gesture before words' and 'nouns before verbs'. In other ways, each child demonstrated individual patterns of lexical development. The variable patterns among the quadruplets are consistent with models in which genetic, biological, and social–environmental factors interact to determine the course of early lexical development.

Although a multifactorial model of cause in language development is widely accepted, much supporting evidence for the model involves large-scale population trends across many years of development. The current study is unique in providing evidence of multiple causation within a constrained period of developmental time and among genetically similar children being raised in a highly similar social environment. As such, the current study highlights the complex and dynamic nature of multiple causation in a way that large group studies cannot. Furthermore, the current study illustrates that language intervention can serve as a causal factor in early lexical development. That the child at greatest biological risk derived the most benefit from the environmental enrichment of language modelling is a hopeful message for parents and interventionists alike.

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