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Changes in Infant Directed Speech in the First Six Months

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The Mother–Infant Phonetic Interaction model (MIPhI) predicts that, compared with adult directed speech (ADS), in infant directed speech (IDS) vowels will be overspecified and consonants underspecified during the infants' first 6 months. In a longitudinal natural study, six mothers' ADS and IDS were recorded on 10 occasions during the first 6 months after their infants were born. Acoustic–phonetic measures, including the first two formant frequencies and duration for vowels and the duration of the fricative /s/, were used to test the MIPhI model with differences between IDS and ADS during the infants' first 6 months. Repeated measures analyses showed the fricative /s/ duration was stably longer in IDS, corresponding to an overspecification throughout the 6 months. The unexpected smaller vowel space for IDS than ADS was stably maintained over the six months, suggesting an underspecification of vowels. Vowel duration, which was generally longer in IDS than ADS, however, changed over time, decreasing in difference between IDS and ADS during month 3 and 4. Results invite adjustments to the MIPhI model, in particular related to infants' needs for perceptual enhancement of speech segments, and to the course of infant neurological and communicative development throughout the first 6 months.

Key words: infant directed speech; development

INTRODUCTION

Infant directed speech (IDS) is speech used in interaction with infants. IDS is different from adult directed speech (ADS) in a number of ways. IDS generally has shorter utterances and longer pauses, as well as a higher mean fundamental frequency (F0) with a wider F0-range (see Gallaway and Richards, 1994, for a review). Acoustic–phonetic attributes of segments in IDS also differ from ADS, both in consonants (Sundberg and Lacerda, 1999) and vowels (Burnham *et al.*,

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2002; Kuhl *et al*., 1997). In previous research (Kitamura and Burnham, 2003; Kitamura *et al*., 2002; Stern *et al*, 1983) it has been suggested that prosodic attributes of IDS change over time to accommodate infant development, but there is a need for longitudinal studies of acoustic–phonetic attributes of segments in IDS. Studying mothers' IDS to their infants over a period of time would reveal whether the proposed accommodation of infant development also carries over to the acoustic–phonetic attributes of segments in IDS.

MIPhI Model

Some researchers (e.g. Cross, 1977; Solokov, 1993) have proposed that the language children hear is 'tuned' to their linguistic needs. This is based on the finding that a parent's mean length of utterance (MLU) increases with a child's MLU (Cross, 1977; Solokov, 1993). Sundberg (1998) developed and adapted this idea for acoustic–phonetic attributes of speech in the Mother–Infant Phonetic Interaction Model (MIPhI model). She describes IDS as part of a two-way interactive process between an adult and an infant.[1] Being exposed to speech from his/her mother, an infant's sensitivity to the language-specific properties of the mother's IDS is increased. The mother, in turn, uses the infant's vocalizations to evaluate the infant's phonological ability, and adjusts her IDS to this level. According to the MIPhI model, adjustments of the ambient language in IDS lead to over- or underspecifying segments in speech to infants. The concept 'specification' is closely related to the Hyper & Hypo theory (Lindblom, 1990). According to Lindblom's theory, compared to adults, young listeners have scarce experience with speech and are less able to predict the message. Therefore, infants are spoken to more clearly, making phonetic segments longer and more audible, which reduces ambiguity due to coarticulation. This clear speech corresponds to hyper-speech. An adult, on the other hand, has extensive experience with speech and is more able to anticipate the message. Speech containing coarticulation and shorter segments characterizes hypo-speech. Sundberg uses the terms over- and underspecification for hyper- and hypo-speech, respectively (Sundberg, 1998).

Specification refers to relative perceptual salience in speech and overspecified segments are supposedly more audible (Sundberg, 1998). Infants prefer the prosody of IDS (Werker and McLeod, 1989), and characteristics of prosody in speech (e.g. F0 and F0 range) are expected to be overspecified (e.g. by a higher F0 and a wider F0 range) throughout the first 6 months after an infant is born (Sundberg, 1998). A vowel is characterized as overspecified if its vowel duration is increased and/or its vowels space (F1, F2) is expanded (Sundberg, 1998). Generally, a longer vowel or consonant will be acoustically more salient. For example, a stop consonant will be overspecified with a general increase in voice onset time (VOT) since that extends the voiced component, but at the same could maintain a distinction between voiced and voiceless stops (Sundberg, 1998). Underspecification does the reverse, making a speech sound less perceptually salient to a listener. A vowel is underspecified if its vowel space is smaller and/or its duration is shorter compared to another vowel, while a stop consonant would be underspecified if there is a general decrease of VOT, and in addition, the difference between voiced and voiceless stops could decrease.

A foundation for perceptual salience of segments in the MIPhI model is sonority (Sundberg, 1998). Sonority refers to the degree of openness in the vocal apparatus when articulating a segment (Goldsmith, 1990) or loudness relative to other sounds (Ladefoged, 1975). Whereas vowels are sonorous sounds, obstruents, for example stops, are on the opposite end of the sonority continuum (Laver, 1995). In addition, consonant categories may take longer to develop for infants than vowel categories (Werker *et al*., 1996). Taking advantage of what is easy for an infant to perceive at any point in time, the MIPhI model hypothezizes overspecification of vocalic segments and underspecification of consonants in IDS to infants throughout the first months (Sundberg, 1998). As infants become older, acoustic–phonetic attributes of obstruents will gradually approach and be close to the attributes of ADS at 6 months.

The fricative /s/ falls into the group of obstruents with a slight constriction of the vocal tract (Goldsmith, 1990). An /s/ is nevertheless a flexible consonant, and its duration can be very long (e.g. Klatt, 1974). One study has shown that in Norwegian, [s] is the longest in duration of all consonants in initial, medial and final position in a word (Fintoft, 1961). Like other fricatives, /s/ is also produced by maintaining a relatively stable articulation throughout its duration, compared to, for example, a stop consonant, which has a closure and opening phase (Kent and Read, 1992). Among fricatives, /s/ is relatively sibilant, with a comparatively high pitch and high intensity, from an auditory perspective (Laver, 1995). Therefore, whereas /s/ is an obstruent consonant, it also has attributes similar to a vowel. As an obstruent, the MIPhI model would predict /s/ to be underspecified, for example with a shorter duration in IDS than in ADS. However, because of its relative salience, /s/ may be treated more like a vowel in IDS, in which case it would be expected to be overspecified, for example, with a longer duration as has been observed for vowels in IDS (Bernstein Ratner and Luberoff, 1984).

The MIPhI model gives a foundation for predicting how acoustic–phonetic attributes of IDS are adapted to infant development during the first 6 months of the infant's life, and proposes that the different attributes of vowels and consonants in mothers' IDS compared to ADS will show different developmental paths based on the infant's age and linguistic development.

Longitudinal Studies of IDS

Age-related changes in prosody have been observed in IDS. IDS to newborn, four, 12 and 34-month-old infants were recorded by Stern *et al*. (1983) who found a generally higher F0 in IDS than in ADS merged over age groups, supporting the MIPhI model. A particularly high F0 was found in IDS to 4-month-olds. During the recordings in this study, different experimental settings were used: Neonates were lying on the mothers' laps, and 12- and 24-month-olds were crawling and walking on the floor while spoken to, whereas 4-month-olds sat face-to-face on the mothers lap while the mother spoke to them. That IDS to the 4-month-olds differed from that to other infants could have been confounded by the different experimental settings for the different aged infants.

Studying mean F0 and F0 range in Australian English IDS to infants at birth, 3, 6, 9, and 12 months, support for the MIPhI model were observed in Kitamura and Burnham (2003), where affective quality of utterances in IDS seems to change as infants develop. A higher mean F0 was found in IDS than in ADS. A higher average F0 was found in IDS at 6 and 12 months, while F0 range peaked at 9 months, possibly related to periods of socialization and changes in amount of experience with the ambient language. In a related study of Australian English and Thai IDS, Kitamura *et al*. (2002) found that IDS to newborn infants has a relatively low average F0, minimal F0 range and neutral intonation slope compared to IDS to older infants. F0 range was greater in IDS than ADS, and decreased as infant age increased. They propose that newborns may need speech that is less attention evoking, and more soothing. In addition, these studies showed that while for Australian English, mean F0 was highest in IDS to 6-month-olds, for Thai, it was highest in IDS to 9-month-olds, indicating language related differences in IDS prosody.

The above studies show age related changes in IDS, proposing an accommodation of IDS according to different needs at different ages. Although Sundberg (1998, 2001) and Sundberg and Lacerda (1999) address the development of acoustic–phonetic attributes of segments in IDS from birth until 2 years old, to our knowledge, there is no longitudinal study of the development of acoustic–phonetic aspects of segments in IDS compared to ADS. There are however, studies of acoustic–phonetic attributes of segments in IDS.

Segments in IDS

Studies of stop consonants in IDS show that voice onset time (VOT) in stop consonants differs between IDS and ADS (e.g. Baran *et al*. 1977; Sundberg and Lacerda, 1999). Supporting the MIPhI model, Sundberg and Lacerda (1999) found that VOTs in IDS to 3-month-olds were, in general, shorter in IDS than ADS, and that the differentiation was poorer between voiced and voiceless stops in IDS compared to ADS (Sundberg and Lacerda, 1999). Further support comes from the finding that VOT is shorter in IDS to 12-month-olds in a subset of the data containing 20 exemplars for each stop (Baran *et al*., 1977). Malsheen (1980), found that in IDS to two out of six children a greater difference appeared between voiced and voiceless stops in IDS compared to ADS, mainly caused by the longer VOT duration for voiceless stops. This supports the MIPhI model where it is predicted that around 12 months, the underspecification of stops would have approached ADS VOT levels. However, the model is not supported by a recent study of Norwegian IDS (Englund, in press). In this study, voiced and voiceless stops had generally longer VOT in IDS throughout the infants' first 6 months and the distinction between voiced and voiceless stops was the same in IDS than in ADS. This counters predictions from the MIPhI model that VOT would be shorter and voiced and voiceless stops would be less distinct in IDS, than in ADS.

In addition to consonants, vowels differ between IDS and ADS. Generally, vowels are longer in IDS compared to ADS (e.g. Bernstein Ratner and Luberoff, 1984). This could be the result of a slower speaking rate, which infants have been shown to prefer (Cooper and Cooper, 2000). Moreover, a wider vowel space (for /a/, /i/, and /u/) based on differences in first (F1) and second (F2) formant frequencies was found in a study of American English, Russian and Swedish IDS to 2–5-month-old infants (Kuhl *et al*., 1997). The same has been observed for Australian English (Burnham *et al*., 2002). A connection between these characteristics of vowels in IDS and infant perception is shown in Liu *et al*. (2003) where the degree to which mothers had a larger vowel space in IDS compared to ADS was positively correlated with how well their infants discriminated speech sounds shown through a head-turn task.

While other studies (Kuhl *et al*., 1997; Burnham *et al*., 2002) have used a method where the size of the vowel space areas in ADS and IDS were compared, Englund and Behne (in press) carried out detailed analyses of formant frequencies for individual vowels to compare the vowel spaces in IDS and ADS. The vowel spaces for IDS and ADS from Englund and Behne (in press) are presented in Figure 1.

Figure 1 shows that the vowel space for IDS is stretched along the F1 dimension and is somewhat compressed along the F2 dimension compared to the vowel space for ADS. Whether the IDS space is larger than the ADS space is unclear. Further details about the mean formant frequencies in ADS and IDS for F1 and F2 for the three vowel qualities from Englund and Behne (in press) are reported in Table 1.

To test the MIPhI model and to cover the general need for longitudinal studies of acoustic–phonetic attributes of IDS, the current study investigates

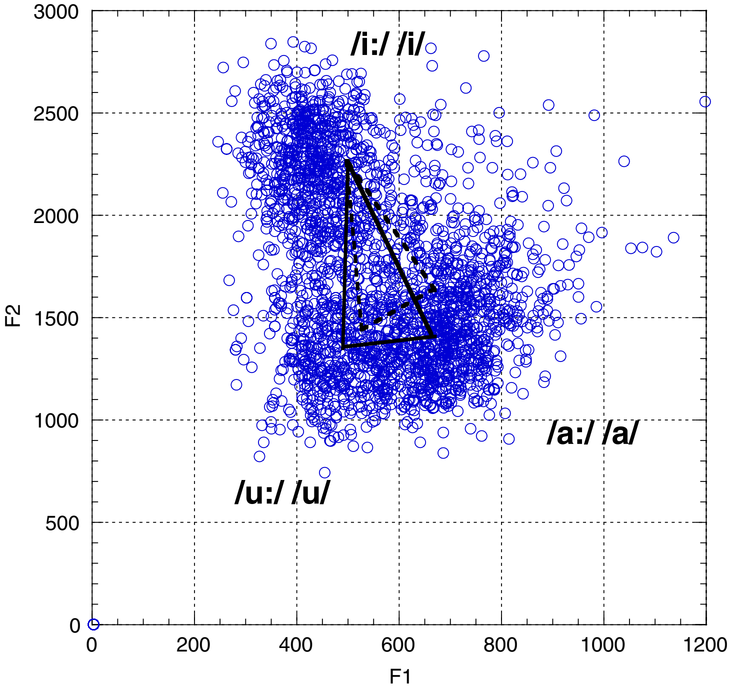

Figure 1. Vowel spaces representing the first formant frequency (F1) in Hertz on the *x*-axis and second formant frequency (F2) in Hertz on the *y*-axis for /a-a/, /i:-i/ and /u:-u/ from Englund and Behne (in press) collapsed over the children's first 6 months for ADS (solid lines), and IDS (dotted lines). Circles show each vowel plotted for F1 and F2 for IDS and ADS.

Table 1. Mean formant frequencies reported in Englund and Behne (in press) for F1 and F2 in ADS and IDS for /a-a/, /i:-i/ and /u:-u/ collapsed over 6 months

	ADS	IDS	ADS	IDS
	F1	F1	F2	F2
/a:/-/a/	664	679	1362	1640
/i:/-/i/	449	455	2211	2207
/u:/-/u/	490	519	1336	1457

segments in ADS and IDS longitudinally during the first 6 months after birth. There is a general lack of studies of /s/ in IDS and exploring this segment in a longitudinal study would be a way of testing the underlying principle of sonority in the MIPhI model. In addition, the magnitude of the vowel space area for Norwegian IDS has not previously been studied. The importance of understanding IDS in a broader perspective by exploring possible cross-linguistic differences motivated such an exploration in the current study. Stern *et al*. (1983) point out that the setting where IDS is recorded may be vital in understanding time-related changes in IDS. The current study examines IDS recorded in the same natural setting throughout the first 6 months after an infant's birth.

Aims and Predictions for the Current Study

The aim of the current study was to study development of acoustic–phonetic attributes of segments in IDS during the first 6 months after birth. The MIPhI model predicts vowels, as sonorous and acoustically salient sounds, to be overspecified in IDS throughout an infant's first 6 months. Longer vowel duration is expected for IDS compared to ADS throughout this period.

In addition, a larger vowel space area was predicted for IDS compared to ADS throughout the first 6 months. While the study of formant frequencies for Norwegian IDS showed a shift in the vowel space (Englund and Behne, in press), other research (Kuhl *et al*., 1997; Liu *et al*., 2003) and the MIPhI model predict the vowel space for this corpus to be larger in IDS than ADS.

As an exploratory part of the study, the fricative /s/ was included. The /s/ is a consonantal sound with less sonority than vowels. According to the MIPhI model it should follow the development of other consonants, and be underspecified during the first months, but gradually approach ADS /s/ by 6 months. Consequently, /s/ duration is expected to be shorter in IDS than ADS generally, but the magnitude of the difference between IDS and ADS is expected to be smaller at month six compared to month one.

These predictions of the MIPhI model are tested in the current longitudinal study of mothers' vowels and /s/ in IDS and ADS during the first 6 months after birth.

METHOD

The method employed here is also reported in Englund and Behne (in press) and Englund (in press). The method attempts to take into account that communication between a parent and infant is an intimate part of everyday life, and may be difficult to mirror in a laboratory setting. The home of a mother and infant is assumed to be a more natural setting since they can be alone in a familiar room while making the IDS recordings and the ADS recording can be made based on a relaxed adult conversation in a setting the mother is used to.

Design

In a natural quasi-experimental factorial design, ADS and IDS productions for each of six mothers were recorded in 10 sessions, resulting in 120 recordings. The independent variables were 'vowel quantity' with two levels (long and short) and 'month' with six levels (month 1–6). Vowel duration, fricative duration and size of the vowel space, each calculated as difference-scores between ADS and IDS, were dependent variables.

Recruitment and Participants

Although fathers are actively involved with infants and their IDS has been studied (e.g. Shute and Wheldall, 1999), during an infant's first months the mother is often the primary caregiver. With the aim to study the person providing regular speech stimulation, the mother's IDS is a natural place to look. Mothers were recruited and briefed about the project through maternity groups at public health-care centres. After their children were born, six Norwegian mothers with full-term healthy infants contacted the experimenter to participate in the study. One spoke urban Eastern Norwegian, the other five spoke a 'Trønder' dialect, which is spoken in the Trøndelag area in Norway. The mothers' mean age was 27 years (26–28). Experience with children could potentially affect amount and/or content of IDS. One mother had an older daughter, and the rest were primiparas. Two mothers had experience working with children, one as a nurse and one as an au pair.

Some of the mothers hesitated to start the study right after birth, so the infants' ages differed when recordings started, varying from 3 to 7 weeks. Consequently, the 10 recordings for each infant were regrouped to six levels (month 1–6), based on an infant's actual age when the recording was made. For example, if an infant was 5-weeks-old when the first recording was made, no recording would represent month one for that infant's mother; however, since recordings were made approximately every 2 weeks, for this mother, two recordings would be included in month two. The mean ages of infants within each month, and the percentage of segments drawn from each month are presented in Table 2.

Table 2 shows a slight unevenness in the percentage of segments extracted from the recordings across months, with particularly few segments from the first month. This is due to the cases where recordings started after an infant was 1-month-old. A consequence of this is a potential instability in the data for month one. Data for month one was nevertheless included in the data set in order to possibly contribute to the larger picture of the differences between IDS and ADS across an infant's first 6 months. Mother 3 did not complete the sixth recording and Mothers 2 and 6 did not complete recording 10, which resulted in less data at these time points for these mothers.

Table 2. Mean age and age range of infants, percentages of the total number of vowels and /s/ extracted from the recordings over the children's first 6 months

Month of recording	Age range (weeks)	Mean age (weeks)	% vowels	% /s/
Month 1	0–4	4	7,0	6,6
Month 2	5–8	7	19,5	16,6
Month 3	9–12	10	21,2	22,8
Month 4	13–16	14	16,8	15,6
Month 5	17–20	18	16,7	17,2
Month 6	21–24	24	18,8	21,2

Procedure and Equipment

Each mother was recorded in 10 sessions. To use a setting where a mother would interact spontaneously with her infant and which could be repeated during the child's first 6 months, the experimental setting for IDS was a room at home, typically in the bathroom (see Englund and Behne, in press). Since all participating families lived relatively close to the university, a mother would call the experimenter when the infant needed a nappy change and the experimenter would arrive within minutes. The mother was instructed to do as she normally did when changing the baby's nappies, and in addition recorded IDS herself, wearing a Shure dynamic headset microphone (model WH20) connected to a Sony Digital Audio Tape recorder Walkman (TCD–D8) attached to the back of her waist.

ADS was recorded in the living room of the family's home during a conversation between the mother and the experimenter. To maintain a natural situation for the mother during ADS recordings, she was allowed to have the infant present and to take breaks if requested. During the ADS-recording, the experimenter and the mother wore similar microphones, and together with the Sony DAT-recorder, these were attached to a Behringer eurorack mixer (type MX602).

There was a highly variable duration of the recordings (from 10 to 45 min). A typical ADS recording was 30 min long and a typical IDS recording was 15 min.

Acoustic Analyses

Research on IDS has often used the vowels /a/, /i/ and /u/, (Bernstein Ratner, 1984; Bernstein Ratner and Luberoff, 1984; Kuhl *et al.*, 1997; Burnham *et al.*, 2002). These have also come to be treated as the corners of the vowel space, reflecting articulatory extremes. For these reasons, the same vowels were studied here, including long and short vowels, for a total of six vowels: /a:, a, i:, i, u:/ and /u/. Within natural running ADS and IDS, 2583 vowels occurred in the material, 1057 were long and 1526 were short. The /s/ was represented with 891 tokens.

Surrounding segments may affect the quality and duration of vowels, as well as of consonants (Kent and Read, 1992). For this reason, many studies focus on a limited set of phonetic environments (e.g. Kuhl *et al.*, 1997), often with surrounding stops which can simplify measurements and thereby reduce the amount of variance in measurements. During ADS recordings, mothers were asked to remember words they had used during the IDS recordings. It turned out they remembered very few, and therefore the same word rarely appeared in both IDS and ADS. In order to have a representative sample of phonetic contexts for each segment, the study included all occurrences of the vowels /a:, i:, u:, a, i, u/ within words in focal position in the sentence.

Since vowel duration differences between speech types is sometimes affected by whether function words or content words are studied (Bernstein Ratner, 1985), the relative percentage of segments from content and function words was aligned for IDS and ADS. The number of content words was very high (96%) relative to function words (4%) in IDS and with a slightly higher proportion of function words in ADS (respectively, 95% and 5%), possibly due to more complex sentence structures in ADS. The relative percentage of content and function words were aligned by randomly selecting and excluding a sample of function words from the ADS sample.

In the final sample, 94% of the syllables used from IDS and ADS had primary stress, 6% secondary stress, and less than 1% came from unstressed syllables. Since the IDS and ADS were nearly equal in percentage of vowels preceding and following a liquid (12% in IDS and 14% in ADS), glide (1% in IDS and 1% in ADS) or nasal (7% in IDS and 8% in ADS), no alignment was made for neighbouring segments between the two speech types. The rest of the vowels were surrounded by stops (80% in IDS and 77% in ADS).

Recordings were originally digitized at a sampling rate of 48 kHz. Acoustic analyses were carried out using Praat, version 4.0 (Boersma and Weenink, 2002). Based on fast Fourier transform (FFT) analyses, spectrograms were used as the basis for acoustic measurements. Formant frequencies were computed by linear predictive coding (LPC). In Praat, recordings were resampled at 11 kHz and low pass filtered at 5.5 kHz. Based on visual inspection of the spectrogram, the beginning and end of a vowel were identified, where formants and F0 were clearly visible in the spectrum. In cases when they were not, as well as in cases of noise, creaky voice or when there was a heavy puff of air, vowels were excluded from the analyses.

Because of the dynamic nature of a vowel, and the highly diverse phonetic environments vowels were selected from, more than one time point was used when measuring formants (Huffman, 1997). In Kuhl *et al.* (1997), for example, mean formant frequency was calculated based on the beginning, midline and end of the vowel and resulted in the same pattern of results for each of the three measurement locations. However, averaging across three points, the mean formant would include two points, the first and last point, that are especially vulnerable to influences from surrounding segments. To obtain mean formant frequencies that more readily reflected the whole vowel, all sampled time points within the identified vowel were included in the calculation of mean formant frequency for the vowel. Vowel duration was measured in milliseconds from the start to the end of the periodic energy where formants were clearly visible.

The vowels and /s/ occurred in many different phonetic environments in the recordings, including both content and function words. The same number of content words and function words were represented in IDS as in ADS. The fricative /s/ was extracted from all positions within words and sentences, and fricative duration was measured from the start to the end of visibly evident noise in the spectrum.

RESULTS

In this section, the method for calculating the dependent variables, vowel space and differences between speech types, are described first. This is followed by results for vowel duration, vowel spectra and fricative duration in the two speech types.

Calculations

Vowel Space

Vowel space areas for each observed vowel in IDS and ADS, and for each of the 6 months, were calculated using the following formula, also described in

Liu *et al*. (2003):

$$\text{Vowel space area} = |((\text{F1i} \times (\text{F2a} - \text{F2u})) + (\text{F1a} \times (\text{F2u} - \text{F2i})) + (\text{F1u} \times (\text{F2i} - \text{F2a}))/2)|,$$

where F1i is the first formant frequency for the vowel /i/, etc. The vowel space area denotes the size of the area within the lines drawn between the vowel /a/, /i/ and /u/ (see Figure 1).

Difference Scores

Englund and Behne (in press) reported results for speech type, vowel quality and vowel quantity for vowels averaged across infants from birth to 6 months. In the current study, the main independent variable of interest is 'month'. IDS could change over time causing an effect for the independent variable 'month'. However, if ADS also changes over time, the time-related changes in IDS may be of no relevance to the infant. More relevant for the current hypothesis of time-related changes in IDS, is the difference between IDS and ADS at any given point in time. Therefore, most of the further analyses are based on calculated difference-scores between ADS and IDS for each dependent variable with 'month' as independent variable.

Vowel space areas were calculated for each participant separately for long and short vowels for each level of the independent variable 'month', and the value for the IDS vowel space was subtracted from the value for the ADS vowel space (vowel space difference-score=vowel space ADS−vowel space IDS). This vowel space difference-score was used for most of the further analyses, one for each participant for long and for short vowels for each of the 6 months. The vowel space and vowel space difference-scores were calculated before aggregating the data for carrying out repeated measures analyses. Vowel quantity was included as a control factor in the current study. As quantity is realized mainly by duration in Norwegian (e.g. Behne, Moxness and Nylund, 1996; Kristoffersen, 2000; Nylund, 2001), no difference in vowel space area was expected between long and short vowels during any of the 6 months studied.

For vowel duration and fricative duration, difference-scores were calculated by subtracting duration for IDS from duration for ADS for each participant at each of the 6 months.

Analyses

The high inherent variability in the data motivated conducting a reliability analysis (Cronbach Alpha). This showed a relatively high reliability across mothers for F1 (0.92), for F2 (0.73), for vowel duration (0.75), and for fricative duration (0.5). The lower reliability for fricative duration could result from the large variety of contexts this segment was extracted from, including both the long and short /s/ which occur post-vocalically in Norwegian (Kristoffersen, 2000). A random selection of measurements were done by two raters, resulting in an inter rater reliability (Cronbach Alpha) of 0.96.

One of the mothers spoke a different dialect from the other five, and as a precaution against the possible dialectal influence on results, the vowel space, vowel duration and fricative /s/ duration were each tested in a one-way ANOVA, with dialect as the independent variable. Results showed no reliable effect of dialect on vowel space [$F(1) = 0.534$, n.s.], but vowel duration for the one urban eastern Norwegian mother was reliably shorter ($M = 75$ ms) than for the Trønder dialect ($M = 101$ ms) [$F(1) = 7.314$, $p < 0.05$]. A comparable ANOVA for the fricative /s/, showed no reliable effect of dialect on fricative duration [$F(1) = 0.764$, n.s.]. With only one mother representing urban eastern Norwegian, the dialectal effect on vowel duration is possibly an individual effect, and since the difference was only found with vowel duration, productions by the mother with the eastern Norwegian dialect were grouped with the rest of the data.

Vowel Duration

A one-way repeated measures analysis was carried out with 'month' (1–6) as an independent variable and the difference-score between speech types for vowel duration as a dependent variable. Results showed a reliable difference in difference-scores across the independent variable 'month' [$F(5, 15) = 7.392$, n.s.]. Vowel duration for IDS and ADS at each of the 6 months collapsed over vowel quantities and qualities are presented in Figure 2.

In ADS, vowels are expected not to vary substantially across the 6 months. However, as Figure 2 illustrates, vowels in ADS and IDS both vary in duration over time. ADS vowels at month one seem to be shorter than is the case for months two through six. As was seen in Table 2, fewer vowels were extracted from recordings in month one compared to the other 5 months, which may have led to less reliable data for month one. Focusing then on months two through six, the difference in vowel duration between speech types appears relatively large at month two and months five and six, but much smaller at months three and four. The difference-scores across the six months were further investigated in paired samples t-tests, the results for which are presented in Table 3.

Table 3 shows the above-mentioned difference between month one and three and month one and four as well as between month two and four to be reliably different. However, differences between the other months are not reliable.

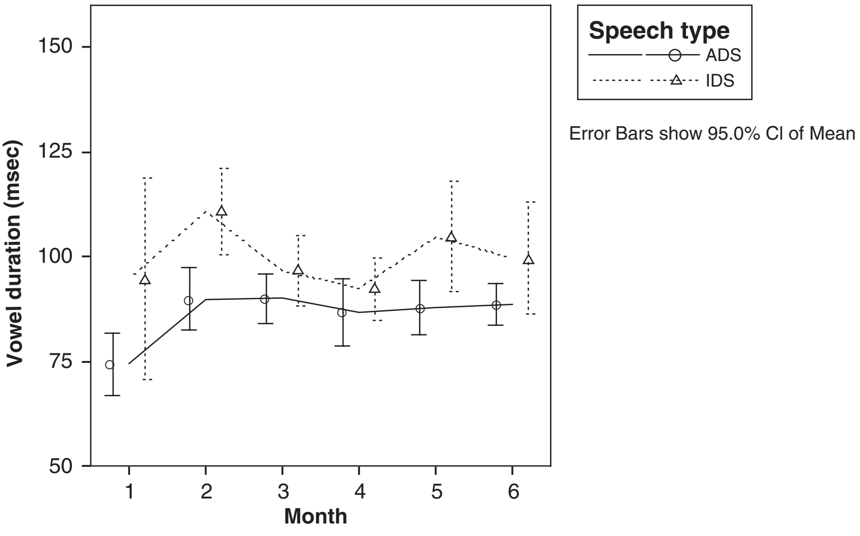

Figure 2. Developmental trend for mean vowel duration in milliseconds and error bars collapsed across all vowels studied in ADS (solid line) and IDS (dotted line) over the children's first 6 months.

Table 3. Results from paired samples t-tests for vowel duration over the children's first 6 months

Months	df	t-value	p-value
Month 1–Month 2	5	−0.237	0.828
Month 1–Month 3	5	−6.96	<u>0.006</u>
Month 1–Month 4	5	−3.85	<u>0.031</u>
Month 1–Month 5	5	−1.33	0.276
Month 1–Month 6	5	−2.43	0.093
Month 2–Month 3	5	−1.06	0.340
Month 2–Month 4	5	−2.74	<u>0.041</u>
Month 2–Month 5	5	−0.96	0.382
Month 2–Month 6	5	−0.90	0.408
Month 3–Month 4	5	−0.02	0.988
Month 3–Month 5	5	0.54	0.613
Month 3–Month 6	5	0.41	0.697
Month 4–Month 5	5	1.57	0.176
Month 4–Month 6	5	1.94	0.110
Month 5–Month 6	5	−0.18	0.867

Underlined are the p-values for reliable differences below the significance level of 0.05.

Vowel Spectra

A goal for the current analyses was to study the magnitude of the difference in vowel spaces between speech types over time. Using speech type as an independent variable would establish its effect on the size of the vowel space, but not whether the magnitude of the difference between speech types changes over time. For this, a difference-score was necessary. In this way the magnitude of the difference between ADS and IDS becomes implicit in the data as the difference-score as dependent variable. Using the difference between speech types as both independent and dependent variable is impossible and consequently, 'speech type' (ADS and IDS) was not an independent variable.

Since the vowel space area was not tested for Norwegian IDS and ADS in Englund and Behne (in press), another goal for the analyses was to identify possible general differences between IDS and ADS vowel spaces, and a general analysis of the difference between speech types was needed before the difference-scores were calculated. In Figure 1, the vowel spaces may appear to be comparable in size for IDS and ADS. A one-way analysis of variance was carried out with speech type (ADS and IDS) as an independent variable and size of vowel space as a dependent variable. The analysis surprisingly (cf. e.g. Kuhl *et al.*, 1997) showed a reliably smaller vowel space in IDS ($\mu = 300\,476$) than in ADS ($\mu = 357\,321$) [$F(1) = 10.252$, $p < 0.01$].

Corresponding to Figure 1 is a two-dimensional presentation of the F1–F2 chart for the three vowel qualities /a:/-/a/, /i:/-/i/ and /u:/-/u/ for IDS and ADS in Figure 3.

In Figure 3 vowel triangles for each of the 6 months illustrate the same pattern of results as was observed in Figure 1 where the 6 months were collapsed. Compared to ADS, the vowel space in IDS is shifted compared to in ADS.

Having established that the vowel space for IDS was smaller than that for ADS, the analysis for the change over time was carried out on the calculated difference-scores. A repeated measure analysis of variance was carried out with vowel quantity (long and short) and 'month' (1–6) as independent variables and vowel

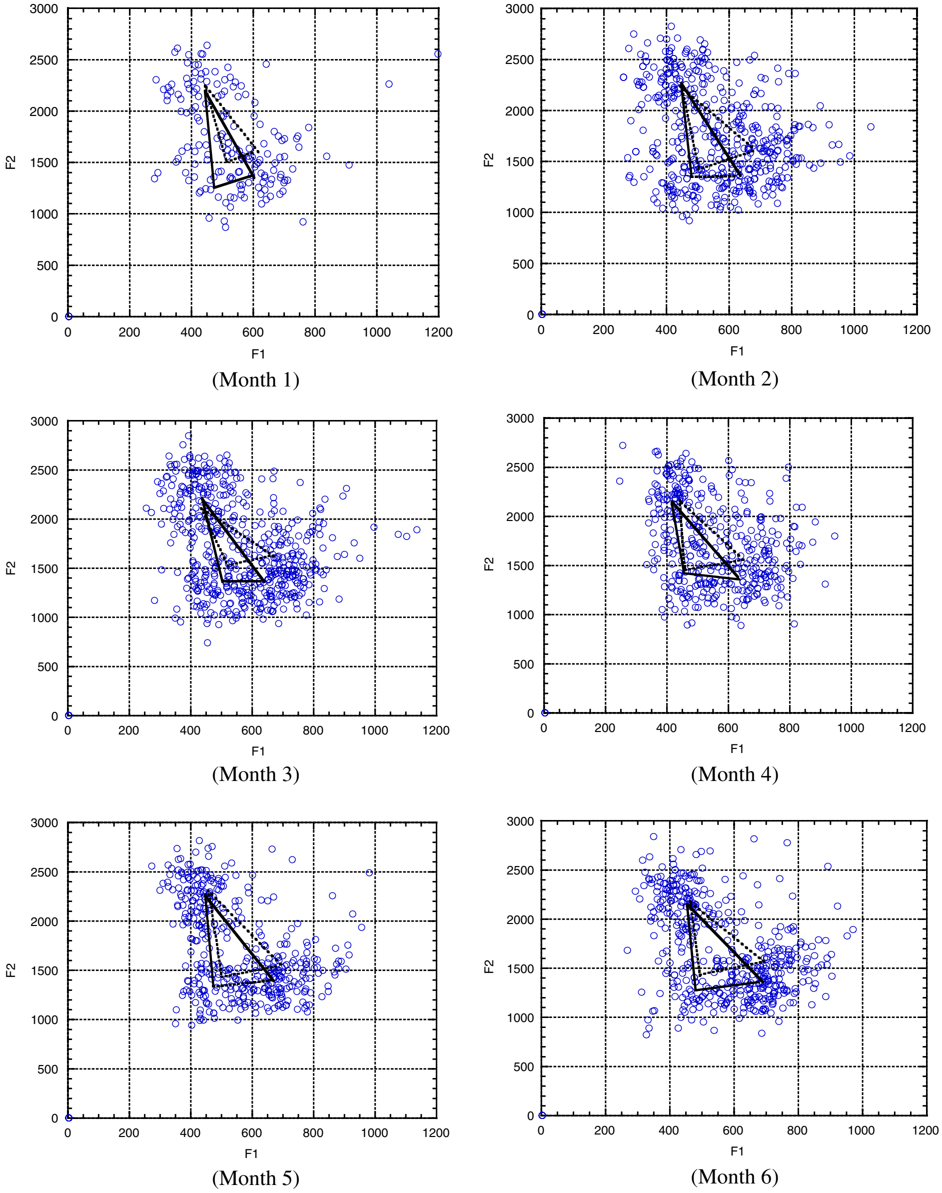

Figure 3. Vowel spaces representing the first formant frequency (F1) in Hertz on the *x*-axis and second formant frequency (F2) in Hertz on the *y*-axis for /a-a/, /i:-i/ and /u:-u/ for each of the children's first 6 months. As in Figure 1, the solid line shows the ADS vowel space and the dotted line shows the IDS vowel space, with the six pairs of vowel spaces corresponding to each of the 6 months.

space difference-scores between IDS and ADS as the dependent variable. Consistent with Englund and Behne (in press) the analysis showed no reliable effect of vowel quantity [$F(1, 3) = 0.896$, n.s.]. There was neither a reliable effect of 'month' [$F(5,15) = 0.242$, n.s.], nor there was an interaction between vowel quantity and month [$F(5,15) = 1.013$, n.s.].

Fricative /s/ Duration

The lack of studies on the fricative /s/ in IDS motivated a general analysis of speech type before calculating difference-scores. A one-way ANOVA was carried out with speech type (ADS and IDS) as the independent variable and fricative duration as the dependent variable. A reliably longer fricative duration was evident for IDS ($\mu = 120$ ms) than for ADS ($\mu = 105$ ms) [$F(1) = 18.83$, $p < 0.001$]. Mean fricative durations for each of the six different months are presented in Figure 4.

Figure 4 shows that fricative duration difference between speech types seems to change over time. As with vowel spectra, the main interest was the developmental difference between ADS and IDS, and after difference-scores were calculated, speech type could no longer be an independent variable. Instead, the magnitude of the difference between speech types was the dependent variable. However, a repeated measures analysis of variance with 'month' as independent variable and mean difference-score in fricative duration between IDS and ADS as dependent variable showed no reliable effect of 'month' on fricative duration difference-scores [$F(5) = 1.48$, n.s.]. The unreliable effect of 'month' did not motivate any further analyses of the levels within 'month'.

Summary of Results

Contrary to the predictions from the MIPhI model, 'month' only had an effect on vowel duration, which was generally longer in IDS than ADS. The vowel duration difference-scores between IDS and ADS show that the difference between IDS and ADS decreases during month three and four. Also contrary to

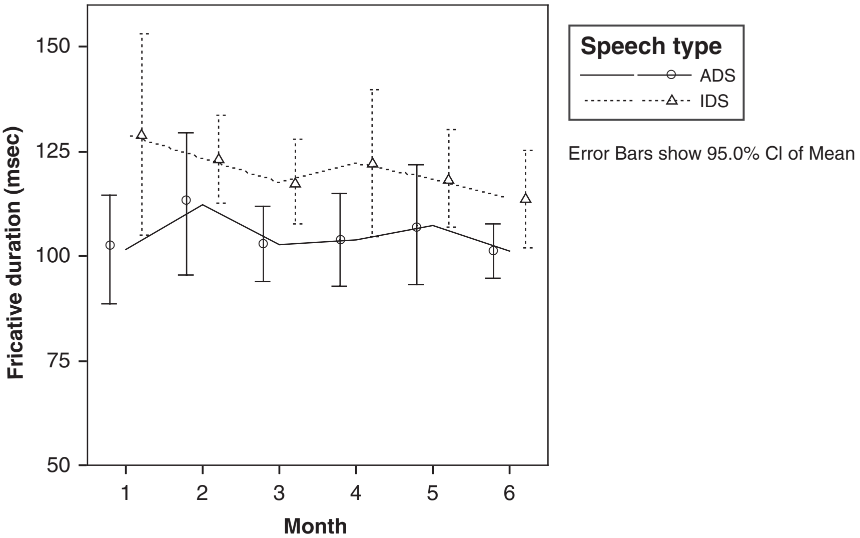

Figure 4. Developmental trend for fricative duration in milliseconds and error bars for /s/ in ADS (solid line) and IDS (dotted line) over the children's first 6 months.

predictions from the MIPhI model, the expected larger vowel space area turned out to be a smaller vowel space area in IDS compared to ADS, implying the current data do not resemble those of Kuhl *et al*. (1997). In addition, the size of the difference in vowel space area is stable across the 6 months of the study. Stability over time is also shown for the unexpected longer fricative duration in IDS compared to ADS. As vowel space did not interact with vowel quantity or month, the difference between long and short vowels is restricted to a general durational difference.

DISCUSSION

The current study aimed to follow acoustic–phonetic changes in vowels and the fricative /s/ in IDS and ADS during an infant's first 6 months after birth. The MIPhI model's account for the current findings is discussed in close connection to the concepts of over- and underspecification in IDS. Changes over time are discussed in more detail, together with theoretical implications from the current results.

Relative Specification

As the main theoretical background for the study, the MIPhI model predicts that adults modify their IDS based on the concept of sonority, focusing on the general syllabic and rhythmic structure in speech by enhancing contrasts between sonorous and less sonorous segments in speech to the perceiving infant. Consequently, the MIPhI model predicts that the sonorous vowels are overspecified in IDS while the less sonorous consonants are underspecified in IDS.

Overspecified Vowels

Overspecification of vowels implies generally longer vowel duration in IDS compared to ADS, as has been found for Norwegian (Englund and Behne, in press). Perceptually, vowel duration is a temporal cue, and temporal cues may be especially useful for infants, based on the finding that infants maintain the ability to perceive foreign contrasts tied to temporal cues until 4–8 years (Burnham, 1986), and that removal of contrastive duration information has a large effect on the discrimination of vowel contrasts (Bohn and Polka, 2001). If infant speech perception is decisive for IDS content, enhancing temporal cues in languages with temporal contrasts, like the Norwegian contrast between long and short vowels, could be advantageous.

Previous research has shown language-specific differences in IDS adaptations. Kitamura *et al*. (2002) showed that mean F0 and pitch range were lower in Thai IDS than Australian English IDS. They pointed out that, since Thai is a tone language, and uses pitch to signal lexical distinctions, this attribute may be constrained for lexical contrasts in IDS. They proposed this lexical constraint as an explanation for the lower F0 in Thai IDS compared to Australian English IDS. Since duration is used to indicate the quantity contrast in Norwegian (Behne *et al*., 1996), this argument would presuppose that duration in Norwegian IDS is constrained for lexical contrasts, which it is not, shown by the generally longer vowel duration in IDS than ADS (Englund and Behne, in press). This suggests that the durational difference between Norwegian long and short vowels is not lexically constrained in IDS, contrary to Kitamura *et al*. (2002), but does not rule out the possibility that there may be other language-specific characteristics of Norwegian IDS.

Overspecified Fricative /s/

Being an obstruent, the MIPhI model predicts /s/ to be generally underspecified during an infant's first 6 months, albeit with gradually increasing specification during this period. The current results on the contrary show /s/ to be longer in IDS than ADS, corresponding to an overspecification of /s/ in IDS. Although previous research shows discrepant results for other consonants (Malsheen, 1980; Baran *et al*., 1977; Sundberg and Lacerda, 1999), a recent paper from the same corpus as the current study (Englund, in press) reports a generally longer VOT in IDS than in ADS, corresponding to overspecification also for stop consonants in IDS. Together, the current results for /s/ and related VOT findings show obstruents to be overspecified in Norwegian IDS, which is not accounted for by the MIPhI model.

The /s/ has the possibility of having a very long duration (Klatt, 1974; Fintoft, 1961). Since VOT duration is longer in Norwegian IDS than ADS (Englund, in press), the longer /s/ would be needed in Norwegian IDS to maintain the manner of articulation distinction between stops and fricatives. In this way, the distinction in manner of articulation between stops and fricatives motivates the increase in /s/ duration in IDS in the current data.

Since a slower speaking rate would result in all segments being longer in duration, the relatively long obstruents in Norwegian IDS may be explained as a consequence of decreased speaking rate in IDS. This might also have explained the increased vowel duration observed for IDS. However, if this were the case, we would also expect a larger vowel space in IDS due to the decreased speaking rate, which is not the case with the current vowels. When, in addition, speaking rate could not explain the longer VOTs in IDS found in Englund (in press) based on the same corpus, speaking rate can be ruled out as the sole explanation for the longer vowel and fricative duration in the current study.

Underspecified Vowel Space

As size of vowel space was not calculated in Englund and Behne (in press), the current study aimed to explore this attribute of Norwegian IDS vowels. Kuhl *et al*. (1997) found hyperarticulated vowels in IDS shown by a larger vowel space, which corresponds to overspecification. In the present study, vowel spaces did not appear to be overspecified. On the contrary, the smaller vowel space in IDS than ADS during the 6 months studied suggests an underspecification of Norwegian IDS vowels based on the vowel spectra.

It takes time for the vocal apparatus to reach an extreme place of articulation and stretching the vowel space may lead to an increase in duration (Lindblom, 1967). This would not be a problem for long vowels, but for short vowels, this increase in duration may affect the quantity contrast between long and short vowels. As long and short vowels are mainly distinguished by a difference in vowel duration, expanding the vowel space for only long vowels would add an additional cue to the vowel quantity contrast that is not there in the language. Therefore, expanding the vowel space might be avoided altogether in Norwegian IDS. However, like Norwegian, Swedish distinguishes long and short vowels (Elert, 1965), but no similar avoidance to expand the vowel space is seen in

Swedish IDS (Kuhl *et al*., 1997). From this, IDS again appears to differ across languages, even languages which have phonological similarities.

Contrary to what might be expected, Norwegian and Swedish IDS seem to differ. Among differences between studies of Swedish IDS and Norwegian IDS is the experimental method. The current methodological approach was slightly different from that used in other studies. It may not be easy to tap into IDS in its natural form because it is part of an intimate relationship between an infant and a mother. Different experimental settings can potentially elicit different communication between a mother and infant, which could in turn affect acoustic–phonetic attributes of IDS. For example, Sundberg and Lacerda (1999) recorded mothers interacting with their babies in a sound-treated studio. The approach taken in the current study aimed to elicit natural IDS and ADS in a relaxed setting. Achieving this aim is difficult for both IDS and ADS. Leaving the mother and infant alone for the IDS recording was anticipated to be a sufficiently relaxed situation for obtaining natural IDS. The mother did not have a personal relationship with the experimenter, but subjective evaluation of the ADS recordings supported that they are from a relaxed conversation. Judging from the differences between the settings used for Norwegian and Swedish, the more natural recording situation could have contributed to the differences in IDS observed for these languages.

Longitudinal Development

Central to the present study was following longitudinal patterns of acoustic–phonetic segments in IDS relative to ADS. The MIPhI model predicted vowels to be stably overspecified throughout an infant's first 6 months. In addition, while consonants are predicted to approach ADS attributes by 6 months, they are underspecified the first months.

No Change Over Time in Vowel Spectra, /s/ or VOT

Vowel space differences between IDS and ADS were stable over the 6-month-period studied. One of the interpretations of the results from Englund and Behne (in press) was that the vowels in IDS were articulated further forward than was the case for ADS possibly caused by a visual enhancement of IDS vowels. If this interpretation of a visual enhancement in IDS is relevant, and such an enhancement occurs in IDS, results from the current study suggest that this visual enhancement is likely stable in IDS to infants during their first 6 months after birth. A comparable stability is observed in the current results for the fricative /s/, which has a consistently longer duration in IDS than ADS throughout the 6 months, without changing over time. These findings are also consistent with the results for the related study of VOT in Norwegian IDS stops (Englund, in press). Results showed stably longer VOT in IDS stops during the 6 months after birth. Together, findings for vowel spectra, /s/ and VOT show stability in IDS segments relative to ADS segments throughout an infant's first 6 months, with the notable exception of vowel duration.

Change Over Time in Vowel Duration

Vowel duration is generally longer in IDS than ADS throughout an infant's first 6 months (also observed in Englund and Behne, in press). However, this difference in vowel duration between speech types decreases during months three and four, but has a marked difference in duration between speech types from month five to six. With few speech samples representing month one, month two may provide a more representative pattern of results during the period infants are very small.

An increase in speaking rate is known to influence vowel duration (Wayland and Miller, 1994). For the current pattern of results, this would imply that a mother speaks slowly to her infant during the first 2 months after birth. Around 3 months of age, the synaptic development in the human auditory cortex reaches a peak, but before four months of age synaptic activity is likely to be slow and unsynchronized (Huttenlocher and Dabholkar, 1997). Auditory behaviour changes by 3–4 months, showing rapid search for the source of an auditory signal not shown before that time (Muir *et al.*, 1989). Together with other attributes of IDS, the increased duration in segments in early IDS may accommodate potentially slower processing of auditory stimuli before 3–4 months. Cooper and Cooper (2000) have shown that infants between 1 and 4 months prefer to listen to IDS with a slow speaking rate compared to a more normal speaking rate. When a mother begins to speak faster as the infant becomes 3–4 months-old, infant neurological development may be facilitating auditory processing, thereby increasing the amount of input that can be processed in a short period. However, as mentioned above, speaking rate alone cannot explain the current results for duration of segments in IDS.

Possibly related to the maturing brain, infants also undergo changes in their social communicative pattern. When an infant is three to four months old (between 10 and 16 weeks), a communicative shift in mother–infant communication is believed to take place, with the onset of a special period, traditionally called 'turn-taking' (Boysson-Bardies, 1999). The turn-taking period is described by some as being marked by exchanges of vocalizations, where the mother speaks to the child (or the child to the mother), who in turn vocalizes, upon which the mother responds. This exchange appears as an early form of a 'conversation' between the two. Lasting approximately two to three weeks (Boysson-Bardies, 1999), this period is not well studied. As Kitamura *et al.* (2002) pointed out; there may be a close connection between IDS changes and infant socialization. An infant hears not only IDS but also possibly an amount of ADS spoken in everyday situations. If there is a large difference between IDS and ADS, this will possibly be noticeable to an infant. A small difference between them may not be equally noticeable for an infant. If the communicative factor of reciprocity guides IDS during this period, suppressing vowel duration differences between speech types during turn taking could draw infant attention away from the special characteristics of IDS and towards speech (both IDS and ADS) as part of social interaction. Notably, related to this point is the observation that only vowel duration is more similar between speech types around that time.

From another point of view, we may see turn-taking as mainly dependent on a mother's efforts, and not dependent on infant control. If the infant is uttering sounds randomly, the mother may need to 'drop in' whenever her infant is quiet, and to keep quietly attentive as the infant is vocalizing. Therefore, a mother may need to increase speaking rate during her turn in the communicative turn-taking in order to produce short phrases and sentences when her infant has a quiet period, thereby producing a smaller difference in vowel duration during this period compared to before and after. However, this does not extend to spectral characteristics of IDS during this period, and the picture of events in IDS seen through a longitudinal perspective seems to be more complex than merely explained by speaking rate and turn taking. Although, with a time-related shift in overspecification of some aspects of vowels, together with the results for consonants shown in the current and another study of Norwegian IDS (Englund, in press), it is evident that the MIPhI model in its current form does not account for all aspects of IDS.

Theoretical Implications

As the MIPhI predicts a stable overspecification of vowels by longer duration in IDS than ADS and underspecification of /s/, albeit with the underspecification being smaller at month six than month one, the current result contradicted the model on several points. Table 4 shows predictions from the MIPhI model compared to the results from the current study together with previous results for Norwegian IDS (Englund and Behne, 2005; Englund, in press).

The MIPhI model builds on the assumption that IDS should be adapted to infant preference and attention, by sonority guiding relative over- and under-specification of segments in IDS. In addition, overspecification of vowels is supposedly stable over time while consonantal underspecification is supposed to change somewhat over an infant's first 6 months. The MIPhI model was not based on longitudinal data, and as such, the subtle differences appearing from this longitudinal study may not be included in the model. The discrepancy between predictions with respect to both relative specification and change over time in acoustic–phonetic attributes in IDS, illustrated in Table 4 may suggest minor revisions to the model.

A model that builds on the basic principles laid out by the MIPhI model may generally account for the current and previous results for IDS, and for Norwegian IDS in particular. The assumptions of the MIPhI model that infant perceptual, neurological and social needs will guide the attributes of IDS, in addition to the idea that IDS makes speech salient to an infant, makes a solid foundation for such a model of IDS, with the complexity in data from detailed longitudinal studies like the current adding to this foundation.

Any attribute of IDS is part of the language in which it is spoken, and Sundberg (1998) mentions the phonetic characteristics of the ambient language as a factor for mother–infant communication. Nevertheless, from another point of view, IDS cuts across languages. This would imply that specifications of speech in a language-general sense are made in IDS to accommodate a developing infant's perceptual needs. In this respect, Sundberg (1998) points out that both

Table 4. Prediction from the MIPhI model for vowels and consonants in IDS together with findings from the current study and a previous study on stop consonants

Attribute	MIPhI model predictions	Findings		
Vowel duration	Stably overspecified	Longer vowels for 6 months	Unstably overspecified	Longer vowels but not at month 3–4
Vowel spectra	Stably overspecified	Larger vowel space for 6 months	Stably underspecified	Smaller vowel space for 6 months
/s/ duration	Unstably underspecified	Shorter duration approaching ADS by 6 months	Stably overspecified	Longer /s/s for 6 months
VOT[a]	Unstably underspecified[a]	Shorter duration approaching ADS by 6 months[a]	Stably overspecified[a]	Longer VOT for 6 months[a]

[a] Are predictions and results from Englund (in press).

vocal production and body/facial gestures may be part of mother–infant communication. She describes IDS as being highlighted, for example, by the /a/ being articulated with a more open mouth, and an /u/ with more lip rounding (Sundberg, 1998). For Norwegian IDS, Englund and Behne (in press) found a general movement of back vowels to a more front position, and suggested that these results for IDS vowels may be explained as perceptually salient to infants because of their articulatory visibility. The resulting smaller vowel space observed in the current study may be a consequence of this possible visual enhancement. Together with Sundberg's observations for Swedish, the current findings and results from Englund and Behne (in press) support the inclusion of the visual modality of speech as a language-general means of overspecification of IDS which may be realised differently across languages.

Beyond the possible visual enhancement of speech sounds in IDS, vowels, which are inherently perceptually salient by their longer duration than most consonants and as carriers of pitch, may not need to also be overspecified by vowel spectra in IDS. Since duration may be a preferred cue for an infant (Bohn and Polka, 2001), having increased vowel duration in IDS may be adequate to make them overspecified. On the other hand, consonants, which are shorter and less perceptually salient than vowels, are in need for overspecification in IDS, and in Norwegian IDS are being specified by longer duration for the fricative /s/ as well as longer VOT for stops (Englund and Behne, in press), reflecting a selectivity in how different phonetic segments are highlighted to an infant through IDS.

Each language is a system in itself and at the same time, represents language-general principles. Sonority of speech sounds may account for the relative specification seen for vowels and consonants, as is the case with Swedish IDS. As Sundberg (1998) points out, this makes the general rhythmic and syllabic structure perceivable (Sundberg, 1998). However, in other languages, such as Norwegian, relative plasticity, rather than sonority, may offer a basis for the specifications that are made in IDS, albeit for the same perceptual, neurological and social reasons. An example of this has been shown in the current study with the increased duration observed for vowels, although with fluctuations, and the fricative /s/, generally found to be maintained throughout an infant's first 6 months. In addition to this, adjusting the spectral pattern of vowels may be highlighting the visual modality in IDS throughout the infant's first 6 months. In this way the speech cues that are enhanced may exemplify the malleability of IDS.

Conclusions

The expectations from the MIPhI model that vowels in speech to infants would be overspecified but that consonants would be underspecified throughout the infant's first 6 months were not supported from the current study. The current results of overspecified vowel durations and underspecified vowel spectra in IDS as well as overspecified fricative /s/, together with previous results for vowels and consonants in Norwegian IDS suggest the need for adjustments in the MIPhI model to take into account more detailed changes in IDS during an infant's first 6 months. The basic principles of the MIPhI model with over- and under-specification of segments in IDS serve as a solid foundation for developing a theoretical account for IDS, where the language in question guides which adaptations are made in speech to infants. The current and previous results point to a relatively stable, but nonetheless selective, acoustic–phonetic under-, and overspecification of segments in IDS, possibly adapted to perceptual, neurological and social communicative needs during an infant's first 6 months.

Note

1. In specific descriptions, Sundberg (1998) primarily refers to IDS by mothers.

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