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ARTICLE

Mothers' and fathers' infant-directed speech have similar acoustic properties, but these are not associated with direct or indirect measures of word comprehension in 8-month-old infants

Audun ROSSLUND[1], Silje HAGELUND[1,2], Julien MAYOR[2] and Natalia KARTUSHINA[1]

[1]Center for Multilingualism in Society across the Lifespan, University of Oslo, Norway
[2]Department of Psychology, University of Oslo, Norway
Corresponding author: Audun Rosslund; Email: audun.rosslund@iln.uio.no

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Abstract

Previous research on infant-directed speech (IDS) and its role in infants' language development has largely focused on mothers, with fathers being investigated scarcely. Here we examine the acoustics of IDS as compared to adult-directed speech (ADS) in Norwegian mothers and fathers to 8-month-old infants, and whether these relate to direct (eye-tracking) and indirect (parental report) measures of infants' word comprehension. Forty-five parent-infant dyads participated in the study. Parents (24 mothers, 21 fathers) were recorded reading a picture book to their infant (IDS), and to an experimenter (ADS), ensuring identical linguistic context across speakers and registers. Results showed that both mothers' and fathers' IDS had exaggerated prosody, expanded vowel spaces, as well as more variable and less distinct vowels. We found no evidence that acoustic features of parents' speech were associated with infants' word comprehension. Potential reasons for the lack of such a relationship are discussed.

Keywords: infant-directed speech; fathers; language acquisition; word comprehension

Introduction

Parents intuitively modify their speech when talking to infants: they slow it down, heighten and vary the pitch of their voice, lengthen vowels, and expand the vowel space area. These prosodic and segmental adaptations, commonly referred to as infant-directed speech (IDS) and found across a number of languages (Cox et al., 2022), have been suggested to make speech more attractive to infants (The ManyBabies Consortium, 2020), to foster social-emotional bonding (Benders, 2013; Kalashnikova et al., 2017), and to facilitate language learning, by making speech clearer, among others (Golinkoff et al., 2015). Yet, an unquestionable focus on mothers' over fathers' speech (Ferjan Ramírez, 2022), inconsistent results on the role of IDS in language development (Suttora et al., 2017), and suggestions that IDS might be less clear than adult-directed speech (ADS) (Miyazawa et al., 2017) call for a thorough examination of the acoustic properties of IDS, in both parents, and their potential impact on infants' language outcomes using direct (eye-tracking) and indirect (parental report) measures.

The current study aims were two-fold: (1) to examine, in Norwegian parents to 8-month old infants, whether there are differences in the prosodic and segmental properties between IDS and ADS, and if these differences are comparable in mothers and fathers; and (2), to examine the relationship between the prosodic and segmental features of IDS and infants' language development, using direct (eye-tracking) and indirect (parental reports) measures of infants' word comprehension. In what follows, we review, first, the literature on the acoustic features of mothers' and fathers' IDS, their role in infants' language development and potential mechanisms underlying the relationship before presenting research on Norwegian IDS, the aims of the study and our hypotheses.

Mothers' and fathers' infant-directed speech

The so-far limited number of studies on the prosodic and segmental features of fathers' IDS report mostly similarities, but also some differences as compared to mothers' IDS (for a thorough review, see Ferjan Ramírez, 2022), which might differ across languages. For example, a seminal study by Fernald et al. (1989) demonstrated, across five languages, that both mothers and fathers to 10–14-month-old infants used higher pitch and slower articulation rate in IDS vs ADS, while only mothers used a wider pitch range, and mothers' maximum pitch in IDS relative to ADS was higher than fathers, while fathers' pause duration in IDS relative to ADS was longer than that of mothers. Benders et al. (2021) reported that Dutch fathers to 8–16-month-old infants used both higher pitch and wider pitch range in IDS, and, in addition, in contrast to Fernald et al. (1989), fathers had a more extreme change in pitch range when compared to ADS (within and across utterances) than mothers; proposed to reflect their 'burst of energy' interaction style (see Feldman, 2003). German mothers and fathers to 6–9-month-old infants also demonstrated similar prosodic exaggerations in IDS (i.e., higher pitch and wider pitch range), in both book-reading and play-type contexts, and, in addition, were found to similarly expand their vowel spaces in IDS (Weirich & Simpson, 2019). By contrast, Hungarian mothers to 5- and 16-month-old infants expanded their vowel spaces more than fathers, while there were no gender differences in parents to 25-month-old toddlers (Gergely et al., 2017). Finally, in Norwegian, both mothers and fathers to 18-month-old toddlers showed similar acoustic adaptations (from ADS to IDS), including exaggerated pitch, pitch range, vowel space expansion and increased vowel variability, but, in contrast to mothers, fathers did not display vowel lengthening (Rosslund et al., 2022).

In sum, these studies suggest that fathers typically follow the same prosodic and segmental adaptations in IDS as mothers, with the possibility that a more dynamic and energetic interaction style in fathers is manifested in more extreme pitch excursions. Yet, given the limited number of studies, and the small sample sizes therein, any strong claims on fathers' IDS remain premature. As fathers are increasingly involved in childrearing (Cabrera et al., 2000, 2018), and shared parental leave is becoming more common in many societies (Brandth & Kvande, 2020; Craig & Mullan, 2010), moving away from the 'maternal template' (Ferjan Ramírez, 2022, p. 1) seems justified. If we want to understand the role of ecologically valid communicative environments on infants' early language development, then BOTH the mothers' and the fathers' input must be examined. So far, as the following section demonstrates, in an attempt to examine the impact of IDS on infants' language development, fathers have largely been overlooked.

Facilitating role of (mothers') IDS on direct and indirect measures of early language

In what follows, we review the current knowledge on the impact of various prosodic and segmental properties of (mothers') IDS on infants' language outcomes, either measured indirectly through parental reports (typically, expressive or receptive vocabulary sizes, e.g., Kalashnikova & Burnham, 2018), or directly through infant testing (typically their performance in behavioural tasks, e.g., Liu et al., 2003).

An analysis of the literature reveals that pitch modulation and expansion of the vowel space area are the two most prominent acoustic parameters in IDS contributing to better language outcomes in infants. For instance, wider pitch range in mothers' IDS to their 3-month-old infants was associated with larger vocabulary at 12 months of age (Porritt et al., 2014). In addition, higher pitch and wider pitch range, when introducing unfamiliar words, predicted increased vocabulary growth in toddlers from 18 to 24-months of age (Han et al., 2023). Similarly, laboratory studies have shown that pitch variability (in female-voice stimuli) promotes minimal word pair learning in 14-month-old infants, suggesting that such variability enables infants to extract the required lexically relevant cues (Galle et al., 2015; Rost & McMurray, 2009). Expansion of the vowel space area, on the other hand, has been claimed to render speech sound production clearer and, thus, to facilitate sound processing and word learning in young infants. More extreme articulation of the corner vowels that delimitate the vowel space naturally leads to its expansion, which, hypothetically, allows for a broader distribution of other vowels, and, thus, enhances the distance between the nearby categories (Liu et al., 2003). In line with this hypothesis, studies have shown that more prominent vowel space expansion in mothers' IDS, as compared to ADS, was related to larger vocabulary in 18-month-old toddlers (Kalashnikova & Burnham, 2018), improvements in language outcomes in toddlers with cochlear implants (Dilley et al., 2020), better consonant discrimination in 9 and 12-month-old infants (Kalashnikova & Carreiras, 2021; Liu et al., 2003), better word recognition in 19-month-old toddlers (Song et al., 2010, who additionally reported a positive effect of slow speaking rate), also when controlling for pitch modulations (Lovcevic et al., 2022). More generally, higher exposure to mothers' IDS at 12 months of age was associated with larger vocabulary at 24 months of age (Ramírez-Esparza et al., 2014), suggesting, together with the other above-mentioned studies, that mothers' IDS promotes early language learning.

Yet, other studies failed to reveal a robust relationship between the acoustic properties of mothers' IDS and language outcomes, challenging the above-mentioned interpretations. For example, a meta-analysis (Spinelli et al., 2017) reported that the amount of pitch variation in mothers' IDS was strongly related to infants' pre-linguistic skills (e.g., imitation and vocalisations); but only weakly to their linguistic skills (e.g., word comprehension and production). A different study showed no correlation between various measures of mothers' IDS (temporal and spectral, as pitch and pitch range) and word recognition in 15-month-old infants (Suttora et al., 2017). As far as the vowel space is concerned, Song et al. (2018) revealed no relationship between the size of the vowel space in mothers' IDS to 17-month-old infants and their performance in a word comprehension task at 19 months of age, and Rosslund et al. (2022) found no association between vowel space expansion and 18-month-old toddlers' expressive vocabulary size. Taken together, the results of these studies suggest no robust relationship between the prosodic and segmental features of IDS, on the one hand, and direct and indirect measures of language competence on the other hand, painting an overall inconsistent picture of the facilitating role of IDS. As shown in the following section, recent acoustic analyses have challenged the view that IDS presents infants with a clearer language input as compared to ADS.

Is (mothers') IDS really providing a clearer input to the child?

A growing body of research, using advanced acoustic analyses, provides evidence against the hypothesis of enhanced clarity of IDS, implying that the traditionally reported vowel space area may be a too crude proxy for the 'clear speech' claim. Vowel categories in IDS appear to be less distinctive, as compared to ADS: they are separated by smaller acoustic distances (Cox et al., 2023; Cristia & Seidl, 2014); and spectral differences between them are reduced (Martin et al., 2015). In addition, vowels in IDS appear to be more variable, as revealed by larger within-category variability (Cristia & Seidl, 2014; Englund, 2018; McMurray et al., 2013; Miyazawa et al., 2017; Rosslund et al., 2022) and larger change in the spectral dynamics over the vowel duration (Miyazawa et al., 2017). Thus, a growing body of research shows that vowels in IDS are less distinctive and more variable (overlapping) than in ADS.

Resting on the assumption that IDS facilitates language learning, does it mean that infants learn better in more variable, 'noisy' speech? It seems unlikely given the results of some experimental studies, showing that infants fail to learn new words and display poor sound discrimination if the acoustic relevant cues are highly variable (Cristia, 2011; Kartushina & Mayor, 2022; Rost & McMurray, 2010). On the other hand, if mothers' sound categories are tightly (compactly) distributed in the acoustic space, infants show better word learning (Rost & McMurray, 2010) and sound discrimination (Cristia, 2011). In fact, infants might tune to the fine-grained acoustic features of individual speech sounds irrespective of the overall expansion of the vowel space (e.g., exemplified with the consonants /s/-/ʃ/ in Cristia, 2011). Similar sensitivity to the compactness of speech sounds in mothers' speech has been shown in older toddlers (Bosch & Ramon-Casas, 2009, 2011), suggesting that input shapes children's phonemic representations even beyond the first year of life (see also Mayr & Montanari, 2015). In sum, the results of these studies show that infants rely on the acoustic properties of (mothers') speech to build their phonemic representations, and that low variability in relevant acoustic cues can facilitate the establishment of phonemic categories and word learning. Thus, when investigating the facilitating role of IDS on language outcomes, it is relevant to: (1) supplement traditionally reported measures of speech clarity, such as vowel space expansion, with measures of underlying variability, and (2) not limit our analyses to the impact of parents' adaptation in IDS (as compared to ADS, e.g., Kalashnikova & Carreiras, 2021), but also to characterize the acoustic input in IDS directly, i.e., the signal that the infant actually receives (e.g., Liu et al., 2003; Porritt et al., 2014).

Norwegian IDS and the current study

Norwegian speech is phonologically complex and uses formants, pitch accents (that is, variation in intonation, exemplified by [¹hendər] *hands* vs [²hendər] *happens*), and

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lengthening ([tɑːk] *roof* vs [tɑk] *thank you*) to distinguish vowel-contrasting minimal word pairs (for more on Norwegian phonology, see Kristoffersen, 2000), suggesting that Norwegian-learning infants need to tune to a remarkable variation of acoustic cues (Kartushina & Mayor, 2019, 2022). The current knowledge on Norwegian parents' IDS comes from two unique samples from two distinct dialectal[1] and geographical areas: six mother-infant dyads, aged 0–6 months, in Central Norway (Englund, 2018; Englund & Behne, 2006) and 21 parent-toddler dyads (including five fathers), aged 18 months, in Northern Norway (Rosslund et al., 2022). In both samples, parents used higher and more variable pitch in IDS, as compared to ADS, which suggests that, despite natural variability in pitch, Norwegian parents emphasize pitch even more in this register. In fact, parents' adaptations of pitch between IDS and ADS registers were positively associated with toddlers' parent-reported expressive vocabulary (Rosslund et al., 2022). Across both samples, vowels were lengthened in IDS, but vowel categories were also found to be more variable and less distinct, with increased within-category variability in IDS having a negative impact on toddlers' expressive vocabulary (Rosslund et al., 2022). The two samples, however, differed with respect to the vowel space expansion (higher expansion reported in Rosslund et al., 2022; but not in Englund, 2018), which can be attributed to either methodological differences between the two studies, dialectal differences between the samples, or differences in infants' ages. The latter would suggest that certain properties of Norwegian IDS, as, for example, vowel space expansion, vary over the course of a child's development, supporting the hypothesis that parents tune their speech to the specific age-related linguistic needs of their children (Cox et al., 2022). To date, in Norwegian, no data exist on the acoustic properties of IDS addressed to infants between 6–18 months of age, or from parents speaking the majority Eastern (Oslo area) dialect. Furthermore, and similarly to other languages, the knowledge on Norwegian fathers' IDS is limited, and no comparisons exist between the impact of Norwegian IDS on direct or indirect measures of infants' language competence.

The current study addresses the above-mentioned limitations and examines Norwegian parents' IDS to their 8-month-old infants. The aims of the study are two-fold: (1) to examine whether there are differences in the acoustic properties between IDS and ADS, and if these differences are comparable in mothers and fathers, and (2) to assess whether properties of parents' IDS (as adaptation and as acoustic input, see below) predict infants' word comprehension when assessed by direct and indirect measures, i.e., eye-tracking task performance and parent-reported vocabulary, respectively.

For our first aim, we examined an extensive range of acoustic measures in IDS, as compared to ADS, in Norwegian-speaking parents interacting with their 8-month-old infants. These measures were: phrasal pitch, pitch range (within phrases), pitch change (between phrases), articulation rate, vowel duration, vowel space areas (both measured when delimited by the three corner vowels and the seven border vowels, the latter providing a more accurate estimation of the extension of the articulatory displacements compared to the vowel space delimited by the corner vowels only, see Sandoval et al., 2013), vowel variability and vowel distinctiveness (see Method for details). For an optimal control of the linguistic context between the registers and across speakers (Steinlen & Bohn, 1999; Wang et al., 2015), parents were asked to read a customised picture book to their infant (IDS) and to the experimenter (ADS). In line with previous above-reviewed

[1]Norway is characterised by its dialect diversity, with differences in lexicons, phonemic realisation, and pitch accent patterns across dialects (see e.g., Mæhlum & Røyneland, 2012).

research (key studies in parentheses), we expected, as per pre-registration (https://osf.io/wyasm/) the following between-register differences:

- Higher pitch in IDS (Cox et al., 2022)
- Wider pitch range in IDS (Cox et al., 2022)
- More prominent pitch change in IDS (Benders et al., 2021)
- Slower articulation rate in IDS (Cox et al., 2022)
- Longer vowel duration in IDS (Cox et al., 2022)
- Increased vowel space expansion in IDS (Cox et al., 2022)
- More variable vowel categories in IDS (Cox et al., 2023; Rosslund et al., 2022)
- Less distinct vowel categories in IDS (Cox et al., 2023; Rosslund et al., 2022)

Based on the above-reviewed literature showing that, overall, fathers also adapt their IDS, we expected that both mothers' and fathers' IDS in our sample would follow the above patterns, although with some nuances. First, given that, when infants are 8-months old, mothers would likely have spent more accumulated time with their child as compared to fathers (Norwegian Labour and Welfare Administration, 2022), we expected mothers to show larger differences between the registers for six of eight measures, as they would have more time to potentially fine-tune the speech signal to infants' needs (Han et al., 2020; Leung et al., 2021). Two exceptions would be the measures of pitch range and pitch change, where we expected fathers to show stronger effects than mothers, reflecting their suggested 'burst-of-energy' interaction style (Benders et al., 2021; but see Fernald et al., 1989).

For our second aim, we assessed whether any of the acoustic measures that were significantly different between the two registers would have predicted infants' word comprehension. Our assumption was that the prosodic and segmental quality of input that the infant receives from the main caregiver will be related to her early word representations. All acoustic measures were operationalized both as the between-register adaptation in IDS vs ADS, and as the acoustic input in IDS *per se*, and infants' word comprehension was indexed by two measures: indirectly, using parental reports, and directly, assessing infants' performance in an intermodal preferential looking (IPL) task using eye-tracking (see Method for details). Based on previous literature, we expected that increased pitch, pitch range, pitch change, vowel duration and vowel space expansion, and decreased articulation rate, would have a positive effect on infants' word comprehension (Han et al., 2023; Kalashnikova & Burnham, 2018; Porritt et al., 2014; Rosslund et al., 2022; Song et al., 2010). By contrast, we expected that increased vowel variability and decreased vowel distinctiveness would have a negative effect on infants' word comprehension (Rosslund et al., 2022). We expected these hypotheses to hold for both measures of parental speech (IDS vs. ADS adaptation and IDS input) and both measures of word comprehension (direct and indirect).

Method

Participants

Forty-five parent-infant dyads living in Oslo, Norway, participated in the current study. The following criteria were used for participant inclusion: (1) the infant was born full term (gestational weeks >37); (2) the infant was exposed to 90% Norwegian or more at home; (3) both parents spoke Norwegian to the infant; and (4) the infant had no developmental

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delays and no history of chronic ear infections. Two additional dyads were excluded from the final sample due to noisy speech recording in IDS (n = 1), and less than 90% exposure to Norwegian (n = 1).

All parents (24 mothers, 21 fathers) were native speakers of Norwegian, and the majority (n = 37) spoke the Eastern Norwegian dialect; the other 8 parents spoke the Central (n = 2), Western (n = 3) and Northern (n = 3) dialects. We encouraged the 'main caregiver' (could be the infants' mother or father) at the time of testing to come to the lab.[2] All parents cohabited with their infant and the infants' other parent, and reported to provide, on average, 56.5% of language input to their infant as compared to the other parent (*SD* = 12.0, range = 25–80). Infants (21 girls, 24 boys, *M* age = 8.22 months, *SD* = 0.48, range = 7.24–8.98) were exposed, on average, to 99.5% of Norwegian (*SD* = 1.21). Socioeconomic status (SES), reported as the parents' highest education level, ranged from 1 (secondary school) to 5 (doctoral degree), with the median being 3 (bachelor's degree) for both mothers and fathers.

The current study was conducted according to the guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from the child's parent or guardian before data collection. The study has been approved by the Norwegian Centre for Research Data (NSD/Sikt, ref. 56312), and the local ethical committee at the Department of Psychology, University of Oslo. The pre-registration, data, stimuli and analysis script for the study are openly available at the Open Science Framework (OSF) project's page (https://osf.io/wyasm/).

Stimuli

Visual stimuli to record parental IDS and ADS

For the speech recordings, to rigorously control for the quantity and the quality of the linguistic material across registers and speakers (Steinlen & Bohn, 1999; Wang et al., 2015), we designed a child-friendly 5-page book with colourful pictures, that contained five short stories describing the pictures, one story per page (also used in Rosslund et al., 2022). The main characters in each of them were a bear, a cow, the moon, a spoon, and a mouse, respectively. The picture book was written in Norwegian Bokmål[3] and contained 39 sentences (327 words in total). In the current study, we analysed the production of nine Norwegian long (acoustically more salient than short) vowels /ɑ:/, /e:/, /i:/, /u:/, /ʉ:/, /y:/, /æ:/, /ø:/, and /ɔ:/. Note that previous research found no formant differences between the Norwegian long and short vowels (Englund & Behne, 2006). In a difference to previous studies that used one word per vowel (e.g., sheep, shark, shoe for /i/, /ɑ/, /u/), in the current study, we assessed vowel production across five phonetic contexts, all in a stressed syllable, exemplified by five different words repeated twice over the course of the book. Words were counterbalanced in terms of their position within a sentence, so that each target vowel was present in at minimum one start-, mid- and end-sentence word. Such an approach promised to represent vowel production more comparable to what is encountered in natural speech. See Appendix 1 for an overview of the target vowels and words.

[2]In Norway, parental leave constitutes either 49 weeks of leave with 100% salary, or 59 weeks of leave with 80% salary, out of which mothers and fathers are entitled to an equal amount (Brandth & Kvande, 2020).

[3]Dialects are not used in written text; hence, this is one of two official, dialect-neutral, written forms of Norwegian, mapping closest onto the Eastern Norwegian dialect.

Word comprehension task

In the eye-tracking task, we used eight picture pairs depicting familiar objects taken from a recent study on word comprehension in 6–9-month-old Norwegian infants (for details see Kartushina & Mayor, 2019, or the OSF project page, https://osf.io/gj8u9). The eight picture-pairs were laid out on a light-grey background of 51 cm by 28 cm, i.e., the size of the experimental screen used for the study (as shown in Figure 1). An additional set of eight picture-pairs was created by switching the side of the objects within each pair to counterbalance the side of object presentation, resulting in 16 picture pairs in total.

To prompt infants' gaze at the target, we used four types of sentences: 'Can you find the <target>?', 'Where is the <target>?', 'Do you see the <target>?' and 'Look at the <target>!', where the target is one of the 16 labels of the items depicted in the pictures (described in Kartushina & Mayor, 2019). The sentences were produced by a native female speaker of Eastern Norwegian dialect, who was recorded while reading them in a child-directed fashion. The same sentence-frame was used for the two words within a pair (e.g., 'Look at the apple!' and 'Look at the foot!'). Therefore, each type of sentence was paired with two picture pairs. The audio (sentence) files were combined with the picture pairs to create 32 video files to run the stimuli in our setup with a Tobii TX300 eye-tracker. The side of picture presentation was counterbalanced.

Procedure

Data collection took place in the BabyLing lab at the Department of Psychology, University of Oslo. After receiving postal invitations, parents, who agreed to participate with their infant in the study, signed an informed consent form, and no sooner than one week prior to their visit to the lab answered a web questionnaire that included general demographic questions and questions about their infants' linguistic environment. The online questionnaire also included a Norwegian adaptation of the MacArthur-Bates CDI–Words and Gestures form (Simonsen et al., 2014).

Upon arrival to the lab, parents and their infants were familiarised with the lab environment and experimenter and received information about the course of their visit. Next, infants and parents were accompanied to the dimly lit experimental room to perform the eye-tracking task. The IDS and ADS recordings took place after the eye-tracking task (see below).

During the eye-tracking task, the infant was sitting in their parents' lap, facing the experimental computer screen fitted with an eye-tracker base. Parents wore sound-attenuating headphones through which they heard masking noise (a mix of music and intelligible speech). The experimenter was sitting in the same room, behind the parent.

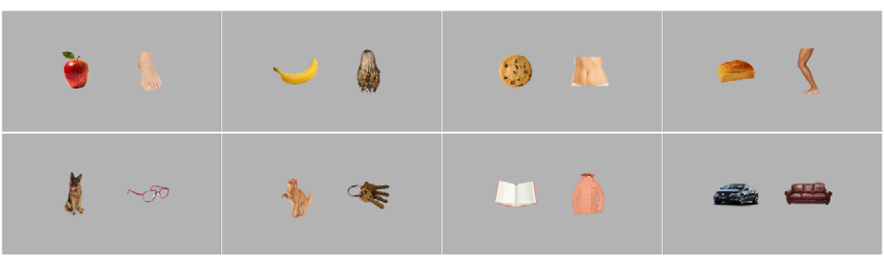

Figure 1. Picture-pairs used in the word comprehension task.

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Therefore, neither the infant nor the parent was able to see the experimenter. We collected infants' gaze using a Tobii TX300 eye-tracker, with a sampling rate (binocular mode) of 60 Hz and a screen resolution of 1920 x 1080 pixels. The auditory stimuli were presented at the average amplitude of 65 dB through two speakers, positioned at the left and right sides of the screen. The experimenter was able to monitor the infants' looking behaviour via the Tobii Live Viewer tool operating on the control screen. The experiment started with a five-point calibration procedure, which was followed by the test trials (see below).

On each test trial, infants saw two pictures displayed on the right and left sides of the screen and heard, after 1.5 s, a target sentence prompting them to look at either of the two pictures. The pictures remained on the screen for 3.5 s after the target-word onset; hence, trials ended 3.5 s after the target word onset. Due to differences in length of prompts and target words, length of the trials varied from 5.4 to 6.2 s ($M = 5.7$); yet, the analysis window was fixed (see Data Processing). The task stopped after all 32 trials had been presented to the infant. Infants heard each target word twice: Once when the target picture was on the left side and once when the target picture was on the right side of the screen. Infants were randomly assigned to one of four presentation order lists, with the restriction that there were at least two different picture pairs between two similar picture pairs (e.g., 'apple-foot', 'hair-banana', 'bread-leg', 'foot-apple').

After finishing the eye-tracking task, the infant and the parent were accompanied back to the reception room to record parental IDS and ADS. During the IDS recording, the parent read the picture book to their infant either sitting on their lap or next to them. Parents were instructed to read and interact with their infant as they would typically do when reading a book at home. During the ADS recording, parents read the same picture book to the experimenter (a native speaker of Norwegian), with no further instructions but to read the book naturally as if reading to an adult. During the ADS recording, for approximately half of the sample, the second parent took care of the child in an adjacent room. For sessions where the second parent did not join the visit to the lab, the infant was in the same room, occupied with toys, outside the parents' field of vision. The order of the recordings was counterbalanced. All sessions were recorded with a Sony ICD-MX20 handheld recorder in 16-bit/22.05 kHz.

At the end of their visit, parents were able to choose a small gift for their infant (e.g., a toy) and were reimbursed for travel costs.

Data processing and dependent measures

Processing of IDS and ADS recordings

The processing of IDS and ADS recordings and the computation of the acoustic measures followed that detailed in Rosslund et al.' study (2022). In short, we manually segmented 3910 phrases (Appendix 2) and 7094 target vowels (Figure 2 and Appendix 3) from the speech recordings using Praat (Boersma & Weenink, 2020). Phrases were defined as a portion of continuous speech with intact pitch tracks, without interruptions (e.g., interference from the child), enclosed by approximately 500 ms of silence, typically a pause where the parent would draw breath. Only audible target vowels, with a minimum length of 30 ms, with no noise and with visually trackable first (F1) and second (F2) formants were segmented. Vowel-level data were used to compute the following measures: vowel duration, vowel space areas (a corner version using /i/-/æ/-/u/, and a full version using all border vowels), vowel variability and vowel distinctiveness. Phrase-level data were used to compute the following measures: pitch, pitch range, pitch change and

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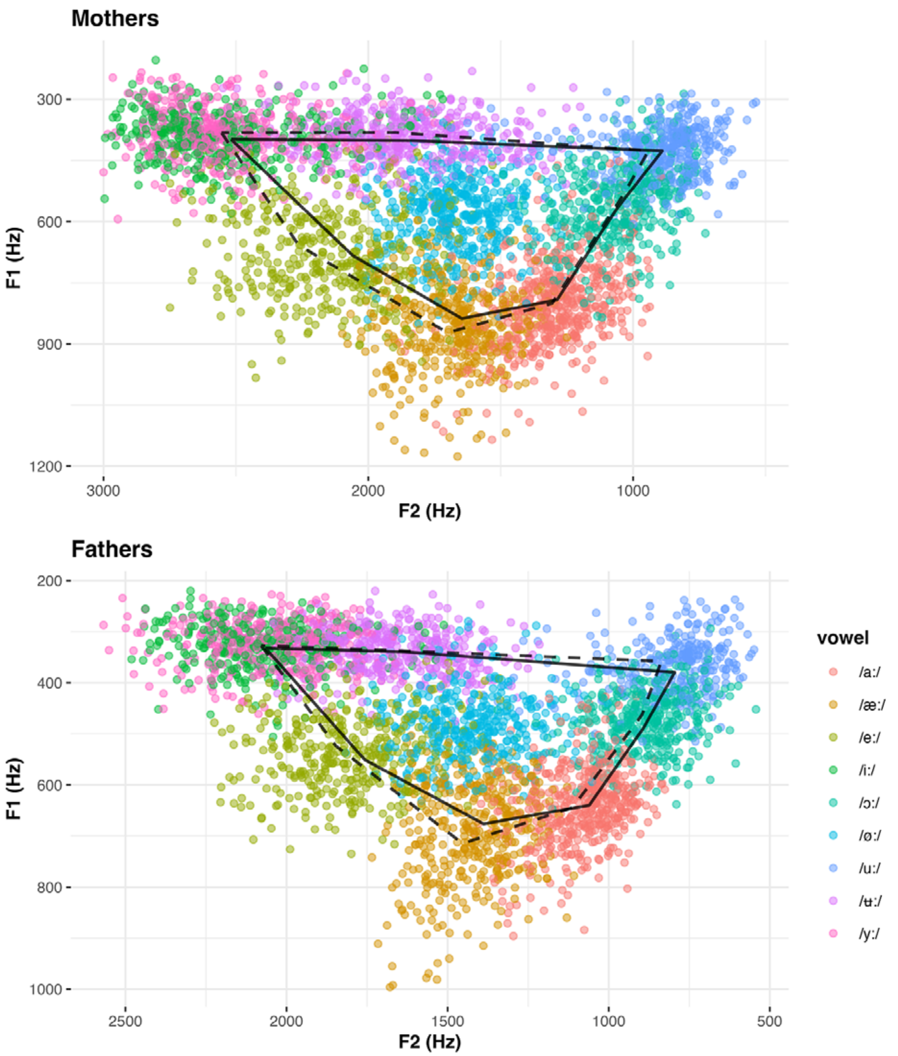

Figure 2. Mothers' and fathers' vowel tokens in F1-F2 space (solid line = ADS, dashed line = IDS).
Note. The polygons depict the mean vowel space areas for each register by drawing a line between the mean F1-F2 values of all border vowels (/iː/, /eː/, /æː/, /ɑː/, /ɔː/, /oː/, /uː/, and /ʉː/).

articulation rate. Measures are described below, and readers are invited to consult Rosslund et al. (2022) for a more detailed description.

Vowel duration is the full duration of a target vowel (in ms).

Vowel space areas are the overall size of the F1-F2 vowel space (in Hz^2), for each participant and register, computed by the average F1 and F2 (in Hz) for each vowel category using the following formula (exemplified with three vowels, where 'ABS' is the absolute value): $ABS\ \frac{1}{2} \times [(F1/vowel_1/ \times (F2/vowel_2/ - F2/vowel_3/) + F1/vowel_2/ \times (F2/vowel_3/ - F2/vowel_1/) + F1/vowel_3/ \times (F2/vowel_1/ - F2/vowel_2/)]$ and so forth.

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VOWEL VARIABILITY is an index of the within-category precision in vowel production, measured by fitting F1 and F2 of all vowel tokens, exemplifying the category, to a customised MatLab script which calculated the area of an ellipse (Hz^2), adjusting for its position in the acoustic space, for each vowel category, participant, and register, with the formula: $\sigma F1 \times \sigma F2 \times \pi$, where σF1 is 1 standard deviation of the mean of F1, and σF2 is 1 standard deviation of the mean of F2.

VOWEL DISTINCTIVENESS is an index of the proportion of variance in F1 and F2 explained by vowel category identity, computed as the between-vowel category Sum of Squares (the squared distances of category cluster centroids from the overall vowel space centroid) divided by the total Sum of Squares (squared distances of individual vowel tokens from the overall vowel space centroid), for each participant and register, for eight vowel categories (we omitted the category /y/, as it fully overlaps with the Norwegian /i/ in the F1-F2 space).

PITCH is the mean pitch in a phrase (in semitones, converted from Hz using the formula $semitones = 12 * log^2 (F0/constant)$.

PITCH RANGE is the difference between the highest and lowest pitch (in semitones) in a phrase.

PITCH CHANGE is the absolute change in mean pitch (in semitones) between two subsequent phrases, i.e., indexing any sudden 'bursts' of pitch variability that would not be captured by the (within-phrase measure) pitch range. To the best of our knowledge, this measure has been first described in IDS research by Benders et al. (2021) as utterance-to-utterance pitch change.

ARTICULATION RATE is the number of syllables in a single phrase divided by phonation time of the phrase – that is, the duration of the phrase after excluding any silences. In other words, the measure captures the speed at which syllables are articulated within a phrase, while considering the duration of the phrase itself, without including pauses or breaks. To acquire this measure, we used version 3 of the Praat script by de Jong and Wempe (2009), which automatically detects syllables, based on peaks, and preceding and subsequent dips, in intensity. A similar approach to IDS data was used by Cox et al. (2023).

Processing of vocabulary scores

Individual raw CDI scores, in comprehension (the number of words that parents reported their child to understand, $M = 20.6$, $SD = 20.0$, range = 0–90) were converted to daily percentiles using the normative Norwegian data from Wordbank (Frank et al., 2017; for the conversion procedure, see Kartushina et al., 2022); the mean percentile was 52.6 ($SD = 30.0$, range = 8–96). Note that one of the parents did not fill in the CDI; hence, the above descriptive statistics do not include one child (n = 44). From here on, we refer to the CDI percentile as the receptive vocabulary measure.

Processing of eye-tracking data

The processing of the eye-tracking data (including data exclusion), and the computation of the looking time measure, follows that of Kartushina and Mayor (2019). For brevity, we direct the reader to the detailed descriptions found there. In short, two naming windows were identified on each trial (following Bergelson & Swingley, 2012): a pre-naming (from the start of the trial to the target word onset, around 2000 ms, depending on the prompt's length, see Stimuli) and a post-naming (367–3500 ms after target onset) window. Our

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dependent measure - *proportion looks to target* - was computed by subtracting the proportion of time that infants looked at the target vs the distractor picture during the pre-naming window from the proportion of looking time at the target vs distractor picture during the post-naming window, and then averaging the measure across valid trials for each infant. We excluded trials where parents reported to never have used the target or the distractor word in the infant's presence, trials with no looking data at either of the pictures in the pre-naming window, trials with < 0.5 s looking to either picture in the post-naming window, and infants with < 20% valid trials. After applying these criteria, 27 infants (15 girls, 12 boys) were retained for the analyses, with a mean proportion looks to the target of 0.50 (SD = 0.05, range = 0.40–0.61). Note that a one sample t-test showed no significant difference in proportion looking against chance performance, $t(26) = 0.11$, $p = 0.91$; Hedge's g = 0.02, 95% CI [-0.35, 0.39], $BF_{10} = 0.21$, thus suggesting no word comprehension on a group level. Further, proportion looks to the target were not correlated with infants' receptive vocabulary as indexed by CDI percentiles, $r_s(25) = .01$, $p = .960$, $BF_{10} = 0.43$.

Results

The results are structured according to the two main aims of the current study: (1) to examine whether there are differences in the acoustic properties between parental IDS and ADS, and if these are comparable between mothers and fathers, and (2) to assess whether properties of IDS (as adaptation and as input) predict infants' word comprehension, as reported by parents and indexed by an eye-tracking task. All analyses were pre-registered (https://osf.io/wyasm/) and conducted in R (R Core Team, 2022), with libraries and their versions listed in Appendix 4.

Differences between IDS and ADS

Between-register differences in the acoustic measures were assessed with a linear mixed-effect model separately for each acoustic measure. The fixed structure was similar for all models and included register, parent gender and their interaction; the random structure included participant as well as register, and story (which of the five stories in the stimuli) or vowel category for some models (see Table 1 for details on the random structure). Models were fitted with the *lme4* package (Bates et al., 2015) and the model assumptions, including normality and homogeneity of residuals, were visually inspected on diagnostic plots derived from the check_model() function from the *performance* package (Lüdecke et al., 2021). Fixed effects were computed via the Anova() function from the *car* package (Fox & Weisberg, 2018) with the p-values obtained from the *lmerTest* package, using Satterthwaite approximation (Kuznetsova et al., 2017).

All model outputs are shown in Table 1, and significant results of register and interactions between register and parent gender for each acoustic measure are enumerated below. Main effects of parent gender are not outlined (e.g., mothers having overall higher pitch than fathers collapsed across registers), but for a numerical comparison between mothers and fathers, descriptive statistics, and the effect sizes with 95% confidence intervals are broken down by parents' gender and reported in Table 2. Averaged by-participant, between-register differences are visualised in Figure 3.

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Table 1. Model outputs on acoustic differences between the IDS and ADS registers (n = 45)

Model	Parameter	χ^2	*df*	*p*
Pitch ~	Register	26.35	1	<.001***
Register * Gender +	Gender	418.7	1	<.001***
(1 + Register | Participant) + (1 + Register | Story)	Register * Gender	0.041	1	.840
Pitch range ~	Register	12.43	1	<.001***
Register * Gender +	Gender	0.897	1	.344
(1 + Register | Participant) + (1 + Register | Story)	Register * Gender	0.036	1	.850
Pitch change ~	Register	73.93	1	<.001***
Register * Gender +	Gender	1.366	1	.243
(1 + Register | Participant) + (1 + Register | Story)	Register * Gender	0.042	1	.837
Articulation rate ~	Register	14.68	1	<.001***
Register * Gender +	Gender	9.142	1	.002**
(1 + Register | Participant) + (1 + Register | Story)	Register * Gender	0.504	1	.478
Vowel duration ~	Register	66.21	1	<.001***
Register * Gender +	Gender	0.016	1	.900
(1 + Register | Participant) + (1 + Register | Vowel)	Register * Gender	0.035	1	.853
Vowel space corners[4] ~	Register	17.02	1	<.001***
Register * Gender +	Gender	72.91	1	<.001***
(1 | Participant)	Register * Gender	0.006	1	.939
Vowel space full[4] ~	Register	35.50	1	<.001***
Register * Gender +	Gender	77.43	1	<.001***
(1 | Participant)	Register * Gender	6.131	1	.013*
Vowel variability ~	Register	42.96	1	<.001***
Register * Gender +	Gender	87.49	1	<.001***
(1 | Participant) + (1 + Register | Vowel)	Register * Gender	2.257	1	.133
Vowel distinctiveness ~	Register	27.02	1	<.001***
Register * Gender +	Gender	11.58	1	<.001***
(1 | Participant)	Register * Gender	4.127	1	.042*

Note. Pitch change, vowel duration and vowel variability was log-transformed to meet the assumption of normality of residuals. *$p < .05$, **$p < .01$, ***$p < .001$

Pitch

There was a significant effect of register and parent gender on pitch. As expected, parents had a higher mean pitch (reported in semitones) in IDS ($M = 50.4$, $SD = 5.19$) than in ADS ($M = 49.0$, $SD = 5.09$), Hedges $g = 1.00$. Mothers had an overall higher pitch than fathers (cf. Table 2 for details).

Pitch range

There was a significant effect of register on pitch range. As expected, parents had a wider pitch range within phrases (reported in semitones) in IDS ($M = 13.2$, $SD = 2.19$) than in ADS ($M = 12.0$, $SD = 1.90$), Hedges $g = 0.55$.

[4]Computing the vowel space areas on log-transformed formant frequencies did not change the significance of the main effects in our models; hence, we report the results of raw frequencies in line with Rosslund et al. (2022).

Table 2. Mean, SD and absolute effect sizes with 95% CI on mothers' and fathers' acoustic differences between the IDS and ADS registers (n = 45)

	Mothers						Fathers					
	ADS		IDS				ADS		IDS			
	M	*SD*	*M*	*SD*	Hedges *g*	$CI_{95\%}$	*M*	*SD*	*M*	*SD*	Hedges *g*	$CI_{95\%}$
Pitch	53.5	1.95	55.0	2.94	1.18	0.66, 1.69	43.9	2.32	45.6	3.50	0.85	0.35, 1.33
Pitch range	12.2	3.33	13.5	4.08	0.61	0.18, 1.02	11.7	3.77	13.2	5.83	0.47	0.03, 0.90
Pitch change	1.50	1.29	2.37	2.02	1.44	0.86, 1.99	1.66	1.43	2.57	2.29	0.97	0.46, 1.47
Articulation rate	3.95	0.75	3.74	0.84	0.65	0.21, 1.07	3.75	0.76	3.59	0.87	0.51	0.06, 0.94
Vowel duration	113	39.5	129	56.3	1.38	0.82, 1.92	127	50.1	111	37.0	0.95	0.44, 1.45
Vowel space corners	344	53.3	378	70.6	0.55	0.13, 0.96	200	52.0	235	72.8	0.66	0.19, 1.11
Vowel space full	432	67.0	500	89.5	1.10	0.60, 1.60	269	63.4	296	76.0	0.53	0.08, 0.97
Vowel variability	244	156	352	176	1.25	0.71, 1.77	130	84.9	173	99.9	1.09	0.55, 1.61
Vowel distinctiveness	0.91	0.03	0.87	0.03	1.07	0.57, 1.56	0.92	0.02	0.91	0.03	0.41	−0.02, 0.84

Note. Pitch, pitch range and pitch change are in semitones, articulation rate in syllables per seconds phonation time, vowel duration in milliseconds, vowel space areas and vowel variability in kHz^2, and vowel distinctiveness in quotients.

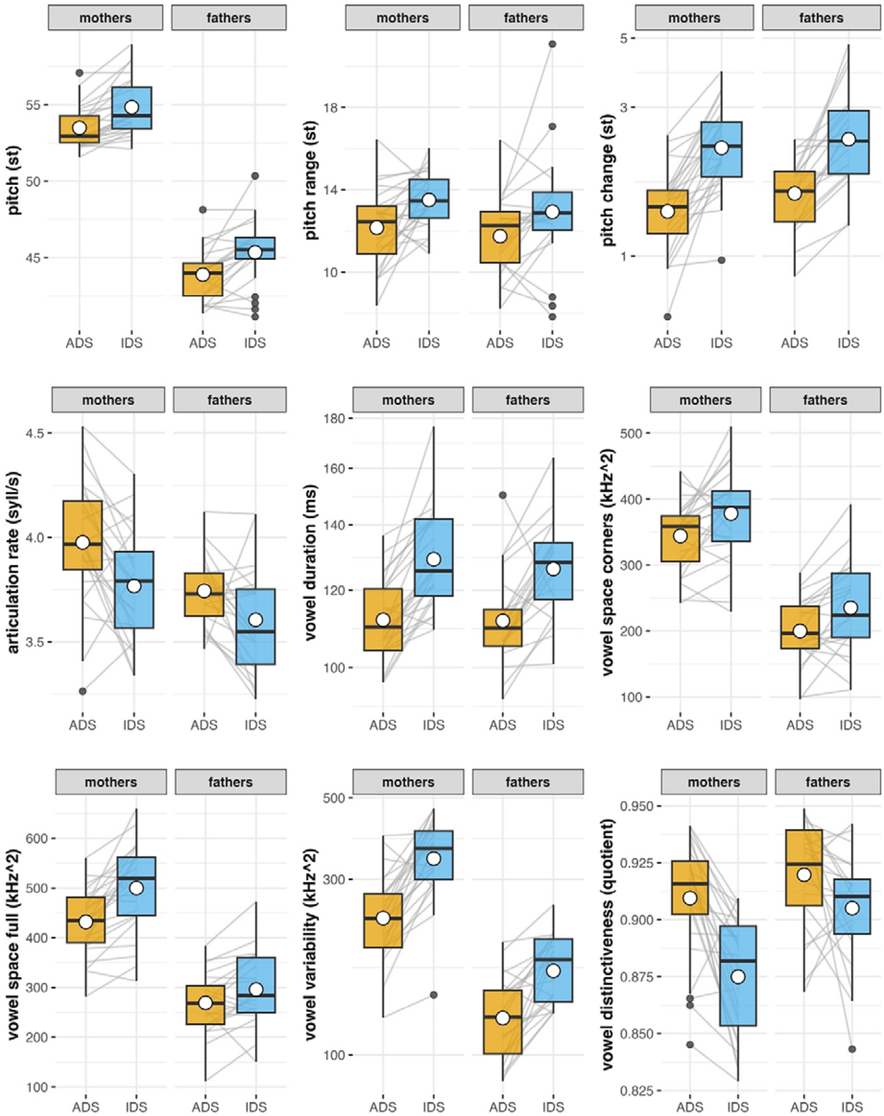

Figure 3. Boxplots of by-participant acoustic measures in IDS and ADS (n = 45).
Note. White dots represent the sample mean. Grey lines represent by-participant means across registers. Pitch, pitch range and pitch change are in semitones, articulation rate in syllables per seconds phonation time, vowel duration in milliseconds, vowel spaces and vowel variability kHz^2, and vowel distinctiveness in quotients. For pitch change, vowel duration and vowel variability, y-axis ticks indicate the scale in the original units, but data are plotted with log-transformed units as this was used in our models.

Pitch change

There was a significant effect of register on pitch change. As expected, parents had a more prominent pitch change between subsequent phrases (reported in semitones) in IDS (M = 2.42, SD = 0.83) than in ADS (M = 1.54, SD = 0.44), Hedges g = 1.19.

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Articulation rate

There was a significant effect of register and parent gender on articulation rate. As expected, parents had a slower articulation rate (reported in syllables per second phonation time) in IDS (M = 3.69, SD = 0.73) than in ADS (M = 3.87, SD = 0.28), Hedges g = -0.60. Mothers had an overall slower articulation rate than fathers (cf. Table 2 for details).

Vowel duration

There was a significant effect of register on vowel duration. As expected, parents had longer vowel duration (reported in ms) in IDS (M = 129, SD = 15.3) than in ADS (M = 112, SD = 11.9), Hedges g = 1.18.

Vowel space areas

There was a significant effect of register and parent gender on vowel space area (both the corner and full version). As expected, parents expanded their vowel space area (reported in kHz^2) in IDS (corner: M = 312, SD = 101; full: M = 405, SD = 132) as compared to ADS (corner: M = 277, SD = 894; full: M = 356, SD = 105), Hedges g = 0.61 and 0.83, for corner and full spaces, respectively. Mothers had overall more expanded vowel spaces than fathers (cf. Table 2 for details). The interaction between parent gender and vowel space area was significant for the full space measure. As can be seen in the follow-up analyses using *lsmeans* (Lenth, 2016), mothers expanded their vowel space to a greater degree in IDS (M = 500, SD = 89.5) as compared to ADS (M = 432, SD = 67.0, t(43) = -6.04, p = <.001, Hedges g = 1.10), than fathers (IDS: M = 296, SD = 76.0, ADS: M = 269, SD = 63.4, t (43) = -2.26, p = .03, Hedges g = 0.53).

Vowel variability

There was a significant effect of register and parent gender on vowel variability. As expected, parents had more variable vowel categories (reported in kHz^2) in IDS (M = 268, SD = 110) than in ADS (M = 191, SD = 78.1), Hedges g = 1.04. Mothers had overall more variable vowel categories than fathers (cf. Table 2 for details).

Vowel distinctiveness

There was a significant effect of register, parent gender and their interaction on vowel distinctiveness. As expected, parents had less distinct vowel categories (reported in quotients) in IDS (M = 0.89, SD = 0.03) than in ADS (M = 0.91, SD = 0.03), Hedges g = -0.74. Mothers had overall less distinct vowel categories than fathers. As can be seen in the follow-up analyses of the interaction using *lsmeans* (Lenth, 2016), mothers had overall less distinct vowel categories in IDS (M = 0.87, SD = 0.03) as compared to ADS (M = 0.91, SD = 0.03, t(16.3) = -7.39, p = <.001, Hedges g = 1.07), than fathers (IDS: M = 0.91, SD = 0.03, ADS: M = 0.92, SD = 0.02, t(19.5) = -2.79, p = .01, Hedges g = 0.41). Note that the 95% confidence intervals for the effect size in fathers cross zero (Table 2) and should be interpreted with caution.

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Summary of results on acoustic measures

In sum, the results support our hypotheses on the differences between IDS and ADS for all the acoustic measures examined in the current study, in both mothers' and fathers' speech, and the expected numerically larger effect sizes in mothers compared to fathers for most acoustic measures (cf. Table 2). Contrary to our expectations, mothers' effect sizes were numerically larger also for pitch range and pitch change.

As this study used the same procedure and analytical approach as that of Rosslund et al. (2022) – but with younger infants and with parents speaking a different dialect – effect sizes from the two studies are visualised in Figure 4 for a numerical comparison only. Finally, as a complementary analysis, in Appendix 5 and 6, we provide correlation matrices between the acoustic measures and the percentage of input that each parent reported to provide to their infant – indicating no significant associations between input exposure and acoustic measures.

Relationship between IDS and infants' word comprehension

Role of adaptation in IDS

To assess whether the adaptations parents do in IDS as compared to ADS predict infants' word comprehension, we computed, first, the ratio between the registers for all the acoustic measures we examined, by dividing, for each parent, the average IDS measure by the respective average ADS measure (for the vowel space measures, there was only one measure per register; hence, we did not compute the average). A score above 1 indicated a higher value of a specific acoustic measure in IDS – that is, a HYPER-feature in IDS (e.g., for pitch) – and a score below 1 indicated a lower value of a specific acoustic measure in IDS –

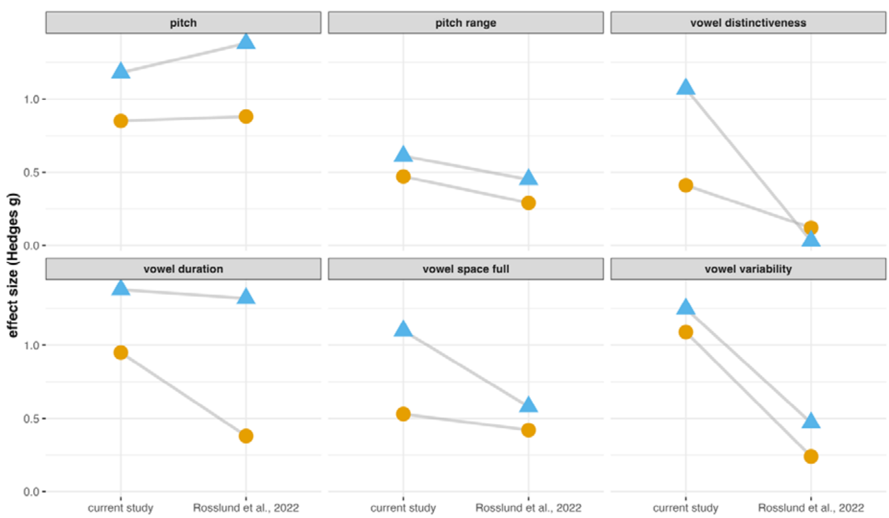

Figure 4. Absolute effect sizes for the differences in the acoustic measures between IDS and ADS revealed in the current study with 8-month-old infants and the equivalent effect sizes computed for the data in Rosslund et al., 2022 with 18-month-old infants (blue triangles = mothers, orange dots = fathers).
Note. Only 5 fathers were included in Rosslund et al. (2022); hence, the effect sizes reported for the fathers should be interpreted with caution. Vowel distinctiveness was not significantly different between IDS and ADS in Rosslund et al. (2022).

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that is, a HYPO-feature in IDS (e.g., for articulation rate). To facilitate model convergence, we z-transformed these ratios for each acoustic measure, separately for mothers and fathers, given that there are physiological differences in the vocal tract morphology between males and females impacting the acoustics of speech, and separately for the full sample (n = 44) and the sub-sample with valid eye-tracking data (n = 27). Next, we fitted two separate beta-regression models with logit link functions using the *glmmTMB* package (Brooks et al., 2017), with the outcome measure being infants' receptive vocabulary (percentiles divided by 100, as required for the beta distributions), and infants' proportion looks to target in the eye-tracking task[5], respectively. As in Rosslund et al. (2022), we assessed multi-collinearity of predictors using the variance inflation factor (VIF, see footnotes). The final model parameters were:

Receptive vocabulary ~ Pitch + Pitch range + Pitch change + Articulation rate + Vowel duration + Vowel space_corners + Vowel space full + Vowel variability + Vowel distinctiveness

Proportion looks ~ Pitch + Pitch range + Articulation rate + Vowel duration + Vowel space full + Vowel variability + Vowel distinctiveness[6]

Finally, in order to evaluate whether any of the predictor variables had an effect on the outcome while avoiding the potential issue of multiple testing, we performed a full-null model comparison (Forstmeier & Schielzeth, 2011), where we compared the above models to their respective null model that contained only the intercept. The results of the full-null comparisons, based on the likelihood ratio tests, revealed no significant difference between the two models for receptive vocabulary ($\chi^2 = 10.5$, $df = 11$, $p = .309$) or for the proportion of looks to target ($\chi^2 = 4.87$, $df = 9$, $p = .675$), suggesting that none of the acoustic predictors significantly improved the fit of the intercept-only models. For completeness, model estimates, produced by the *summary* function on the model are reported in Appendix 7 and 8.

Role of acoustic input in IDS

To assess whether the acoustic properties of parental input in IDS predicted infants' word comprehension, independently of any differences between the IDS and ADS registers, we z-transformed mean values of all our acoustic measures in IDS, again separately for mothers and fathers, and for the full and valid eye-tracking samples. As before, we fitted two separate beta-regression models with infants' receptive vocabulary (percentiles divided by 100), and proportion looks to target in the eye-tracking task, as our outcome measures. The model parameters were:

Receptive vocabulary ~ Pitch + Pitch range + Pitch change + Articulation rate + Vowel duration + Vowel space full + Vowel variability[7]

[5]This is a deviation from the pre-registration, where we specified a linear model to predict proportion looks, but as proportions are bound between 0 and 1, a beta distribution is more fitting.

[6]Due to high VIFs we removed two predictors (vowel space corners and pitch change), resulting in VIFs < 2.6 for the remaining predictors.

[7]Due to high VIFs, we removed two predictors (vowel space corners and vowel distinctiveness), resulting in VIFs < 1.9 for the remaining predictors.

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Proportion looks ~ Pitch + Pitch range + Pitch change + Articulation rate + Vowel duration + Vowel space full + Vowel variability + Vowel distinctiveness[8]

Again, to avoid the potential issue of multiple testing, we performed a full-null model comparison for each model, where the null model contained only the intercept. The results of the full-null comparisons revealed no significant differences between the two models for receptive vocabulary ($\chi^2 = 10.1$, $df = 9$, $p = .181$) or for the proportion of looks to target ($\chi^2 = 8.53$, $df = 10$, $p = .384$), suggesting that none of the acoustic predictors significantly improved the fit of the intercept-only models. Model estimates are reported in Appendix 9 and 10.

Discussion

The current pre-registered study aimed to address the issue of the so-called 'maternal template' in IDS research (Ferjan Ramírez, 2022), and examined a wide range of prosodic and segmental properties of Norwegian IDS and ADS in both mothers and fathers addressing their 8-month-old infants, and how these IDS properties might be associated with infants' language outcomes. Given conflicting evidence on the facilitating role of IDS on infants' language development, we assessed this relationship using two measures of IDS and two measures of language outcomes. That is, we examined parents' IDS as an adaptation in comparison to ADS, and as acoustic input per se, in relation to infants' word comprehension as indexed directly by infants' performance in an eye-tracking task, and indirectly from parental reports of vocabulary.

Properties of mothers' and fathers' IDS

Our results echo previous findings on the acoustic features of IDS reported in other languages (Cox et al., 2022), as well as in a different Norwegian dialect (Rosslund et al., 2022), and support our first hypothesis that IDS, as compared to ADS, is characterized by higher mean pitch, wider pitch range within phrases, more prominent pitch change between phrases, slower articulation rate, and longer vowel duration. Further, our results revealed that parents expanded their vowel space in IDS, both when measuring the full vowel space, and with the three most extreme corner vowels in Norwegian (/i/-/æ/-/u/), and that their vowel categories were more variable and less distinct in IDS than ADS. Hence, while IDS certainly features more exaggerated prosody and might function as a 'perceptual hook', vowel categories were more variable when compared to ADS (see also Cox et al., 2023; Cristia & Seidl, 2014; Miyazawa et al., 2017; Rosslund et al., 2022), and hence may not provide a 'cleaner' acoustic input to the child.

Crucially, all of the above differences between the registers were evident in both fathers and mothers, aligning with the broader findings in the literature to date (Ferjan Ramírez, 2022). The interaction between register and parents' gender was only significant for the vowel space and vowel distinctiveness, indicating that mothers expanded their vowel space more (Gergely et al., 2017), but that their categories were also less distinct (in IDS vs ADS), as compared to fathers (Rosslund et al., 2022). Overall, the effect sizes for the differences in the acoustic features between the two registers were numerically smaller in

[8]Due to high VIFs, we removed one predictor (vowel space corners), resulting in VIFs < 2.3 for the remaining predictors.

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fathers than in mothers. We originally hypothesised that we would observe larger difference between the registers in mothers since they typically spend more time with their infants compared to fathers. Yet, the acoustic features were not correlated with the amount of parent reported input provided to their infant. Alternatively, socio-cultural norms and expectations regarding gendered parenting styles (Yaffe, 2020) might play a role in shaping mothers' IDS and leading it to be more exaggerated, perhaps as a vehicle to convey affect (Benders, 2013). It is also possible that fathers are more restrained in their IDS to make the home and other communicative environments alike, in line with the father-bridge hypothesis, which suggest that fathers are providing communicative challenges for their children as a preparation for the "outside world" (Gleason, 1975). Contrary to our predictions, fathers' 'burst-of-energy' interaction style (Benders et al., 2021; Feldman, 2003) was not reflected by significant interactions between the register and the parents' gender for the measures of pitch range (within phrases) and pitch change (between phrases); unexpectedly, the between-register effect sizes for these measures were larger in mothers (in line with Fernald et al., 1989). It is possible that the 'burst-of-energy' interaction style is not adopted by Norwegian fathers to 8-month-olds, or, alternatively, that our study design limited the opportunity to register this type of interaction, perhaps because the picture book reading context was less favourable for such differences between mothers and fathers to arise.

If we compare our effect sizes to those that have previously been reported in a study with Norwegian 18-month-old toddlers, that used the same method and statistical analyses (Rosslund et al., 2022), it is apparent that vowel variability is one of the acoustic features that becomes markedly less exaggerated with the child's increasing age for both mothers and fathers, while other features remain more comparable between the two studies (see Figure 4). We propose that later in development, when infants start to produce words, parents may be particularly careful with their own production, and realise the need for providing clear and precise examples with little variability, a hypothesis that is supported by the reported association between vowel categories' low variability and toddlers' higher expressive vocabulary in Rosslund et al., (2022). A comparison of the two studies on Norwegian IDS reveals that Norwegian parents' pitch, pitch range, and vowel duration (for mothers) are hyper-featured to the same extent in both infancy and early toddlerhood, which is somewhat unexpected, given the results of a recent meta-analysis suggesting that at least pitch and vowel duration in IDS become more similar to ADS with age (Cox et al., 2022). However, these two Norwegian studies differ not only in the age of the participants, but also in the dialect that parents speak to their children. Northern Norwegian (Rosslund et al., 2022) and Eastern Norwegian (current study) differ in both lexicons, phonemic realisation, and pitch accent patterns. These dialectal differences between the two studies make their direct comparison not straightforward. Longitudinal studies comparing the acoustic features of IDS within the same participants are needed in order to assess more precisely any developmental changes in parental speech, which is currently assessed in a separate study in our lab.

Relationship between parents' IDS and infants' word comprehension

Contrary to our expectations, our study did not reveal an association between parents' IDS and infants' word comprehension, indexed by either direct or indirect measures. As the evidence for this association in the literature is mixed, and studies also vary in their approaches as to how they measure the acoustic features in IDS and word comprehension,

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the current work aimed to characterize IDS from two perspectives, and to assess infants' word comprehension using both direct and indirect measures, to collect the most comprehensive data possible. IDS was measured as the within-parent adaptations in IDS as compared to ADS (e.g., Kalashnikova & Carreiras, 2021), and as the input in IDS *per se* (e.g., Liu et al., 2003; Porritt et al., 2014). While the first has the benefit of using participants' own ADS as their baseline, the latter captures the speech input perceived by infants more closely. Infants' word comprehension was measured directly using an eye-tracking IPL task (e.g., Suttora et al., 2017), and indirectly through parental reports of receptive vocabulary (e.g., Hartman et al., 2017), each with their own strengths and limitations (Frank et al., 2021; Tomasello & Mervis, 1994). Yet, none of the association between IDS and language outcomes was significant.

We suggest that the main reason for the lack of an association between IDS and word comprehension in the current study is the still immature word comprehension in our sample of 8-month-old infants. At the group level, infants showed no word comprehension in the IPL task. Although word comprehension as indexed by the IPL task has been reported already at 6 months of age in infants learning American English (Bergelson & Swingley, 2012), Norwegian infants might need more time to form robust representations (Kartushina & Mayor, 2019, 2022). As such, any association between individual differences in word comprehension and the acoustic features of parents' speech might be limited in 8-month-old Norwegian infants, and may only appear at later ages, as revealed in older infants and in other languages (see Introduction for a review of studies showing such a relationship). At 8-months, perhaps the primary function of IDS is not a didactic one, but to foster social-emotional bonding and convey affect (Benders, 2013; Kalashnikova et al., 2017). Still, we do not claim that IDS has no facilitating role in concurrent language development at 8-months of age; yet, the absence of word comprehension at a group level and the potential difficulty for parents to report infants' word comprehension at this age (Tomasello & Mervis, 1994; but see also Syrnyk & Meints, 2017) limit the interpretation of the current null results and should not be equated to the evidence-of-absence. Yet, perhaps any association between IDS and language outcomes at this age is more likely to be evident for phonological, pre-lexical skills such as speech sound discrimination (Liu et al., 2003) or vocalisations and babbling (Spinelli et al., 2017), rather than for word comprehension, that might be still immature and fragile to be assessed reliably at 8 months of age. The above-listed potential relationships are currently being investigated in our lab.

Notably, in the current study, we adapted a full-null model comparison to minimise the likelihood of type-I errors due to multiple testing (Forstmeier & Schielzeth, 2011). To the best of our knowledge, this is rarely done in the developmental literature and should be adopted in future research to minimise type-I errors, in addition to other recommended practices, i.e., adapting different workflows, that could improve the quality of research output (Havron et al., 2020).

Limitations and future directions

The current study has several limitations that need to be addressed in future research. First, we cannot rule out that parents' IDS and ADS may have been impacted by the lab environment or task demands as compared to more ecological settings (e.g., home), although a meta-analysis suggests comparable effect sizes across tasks and environment for most acoustic measures (Cox et al., 2022). Further, we note that properties of parents'

IDS, and their impact on infants' language outcomes, might depend on parents' accumulated experience as the main caregiver. Here we reported parents' own indication of proportion of language input given to their infant, a measure we expect to be reliable (Orena et al., 2020), and find no significant relationship between this measure and the acoustic measures. Still, future studies should incorporate more fine-grained measures of time spent with the infant, and/or the parental leave status of the parents. Although mothers and fathers in Norway are entitled to an equal amount of parental leave (Brandth & Kvande, 2020), this does not always happen in practice (Norwegian Labour and Welfare Administration, 2022). Next, our eye-tracking task used female-voice stimuli only, and future studies that investigate the facilitating role of fathers' IDS on direct measures of word comprehension could increase their ecological validity by incorporating male-voice stimuli. Finally, although the properties of Norwegian IDS and its impact on language outcomes have now been investigated in both early (this study) and late infancy (Rosslund et al., 2022), these two studies provide cross-sectional evidence on Norwegian IDS and its role in infants' language development, with samples from different dialectal regions; longitudinal investigations are needed to assess the developmental trajectories of both input and outcomes.

Conclusion

To conclude, this study reveals similar prosodic and segmental features in Norwegian mothers' and fathers' speech addressed to 8-month-old infants. That is, for both genders, their IDS is characterised by increased pitch, pitch range (within phrases), pitch change (between phrases) and vowel duration, decreased articulation rate and expanded vowel spaces, but also more variable and less distinct vowel categories, as compared to ADS. These findings are in line with previous reports of Norwegian IDS to older 18-month-old toddlers (Rosslund et al., 2022). Further, our study found no relationship between these acoustic features – either operationalized as the adaptation in IDS from ADS, or as IDS input *per se* – and direct and indirect measures of infants' early word comprehension. We suggest that, at 8-months of age, Norwegian infants' word comprehension is still fragile, and that any facilitating effect of IDS might not be evident until comprehension is more robust.

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