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Does prosody make the difference? A meta-analysis on relations between prosodic aspects of infant-directed speech and infant outcomes

Maria Spinelli [a,*], Mirco Fasolo [b], Judi Mesman [c]

[a] Department of Psychology, University of Milano-Bicocca, Milan, Italy
[b] Department of Neurosciences, Imaging and Clinical Sciences, University "G. D'Annunzio" Chieti-Pescara, Chieti, Italy
[c] Centre for Child and Family Studies, Leiden University, Leiden, The Netherlands

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ABSTRACT

Infant-directed speech (IDS) is the particular voice register observed in the majority of parents in interaction with their infants and differs from natural speech used in conversations with adults by showing exaggerated prosodic features. These prosodic features are supposed to have effects on regulating infant arousal and attention, fostering infant pre-linguistic and linguistic competences and enhancing the expression of positive affect. The present set of meta-analyses was conducted to test these associations and the role of moderators during the first two years of infant life. The results confirmed an overall association between IDS prosody and infant outcomes with prosodic values typical of IDS associated with better outcomes. This association was confirmed for attentional, pre-linguistic and linguistic outcomes with a greater effect on pre-linguistic than linguistic outcomes. An insufficient number of studies was found to test the association with infant emotion expression.

Many limitations in the existing body of literature were found, such as a lack of empirical papers exploring IDS prosody in relation to infant outcomes using natural observations. The results and limitations were discussed in light of the necessity to examine the interplay between the quality of IDS prosody and other aspects of parental communicative and caregiving competences. To do so, the contribution of scholars from different fields is needed with the aim to fully understand the multidimensional determinants and influential mechanisms of IDS.

Introduction

Baby-talk, motherese, or infant- or child-directed speech (IDS or CDS) are all terms used to indicate the particular voice register observed in the majority of parents in interaction with their infants (Saxton, 2008). IDS is preferred by infants compared to adult-directed speech (ADS) (e.g. Cooper, Abraham, Berman, & Staska, 1997; Fernald, 1985; see Dunst, Gorman, & Hamby, 2012 for a meta-analysis) and differs from natural speech used in conversations with adults by specific prosodic, lexical, syntactic and functional characteristics (e.g. Fernald & Simon, 1984; see Soderstrom, 2007 and Saint-Georges et al., 2013 for reviews).

* Corresponding author at: Department of Psychology, University of Milano-Bicocca, Piazza dell'Ateneo Nuovo, 1, 20126 Milan, Italy.
E-mail addresses: maria.spinelli@unimib.it (M. Spinelli), mirco.fasolo@unich.it (M. Fasolo), mesmanj@fsw.leidenuniv.nl (J. Mesman).

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The characteristics of IDS and its importance both for parent-infant interaction and for infant development have been studied extensively during the last decades. Since the pioneering studies by Ferguson and Snow (Ferguson, 1964; Snow & Ferguson, 1977), the role of IDS linguistic features as a potentially helpful tool for language learners has been well documented (see Cristia, 2013 and Soderstrom, 2007 for reviews). However, concerning the role of the prosodic aspects of IDS for child development, various hypotheses have been put forward (Fernald & Simon, 1984). IDS presents exaggerated and stereotyped vocal patterns that are believed to play an important role in many infant competences such as regulating infant arousal and attention, making linguistic input more apparent and salient to infants and helping infant interpretation of the emotional signals of adult speakers (Fernald, 1989; Fernald, 1992; Saint-Georges et al., 2013). However, the empirical literature on the topic is wide and not consistent. Many studies coming from different fields of developmental psychology[1] explored the associations of IDS prosody with infant outcomes. This distribution across different fields has led to high variability between the variables used, both as predictors and as outcomes, and the contextual aspects taken into consideration. There is, for example, a great variability between the prosodic variables considered, the measures of infant outcomes, the infant and parental variables taken into account, and study designs. Moreover, there are inconsistencies in the findings, with some studies reporting associations between IDS prosody and infant outcomes and others not finding significant associations. While these results have been summarized in several reviews (Golinkoff, Can, Soderstrom, & Hirsh-Pasek, 2015; Saint-Georges et al., 2013; Soderstrom, 2007) that provide insightful and helpful integrations of the literature, a statistical integration of findings, as can be done only with a meta-analysis, is missing. The present study aims to fill this gap.

In the current paper we present a series of meta-analyses exploring IDS prosodic aspects in relation to infant development during the first two years of infant life (both concurrently and longitudinally), testing the associations of IDS prosody with infant attentional, pre-linguistic, linguistic and affective outcomes and the role of moderators (e.g., sample and procedural characteristics, predictor and outcome evaluation).

Infant-directed speech characteristics

The linguistic and prosodic characteristics of IDS were mainly defined by scholars by comparing the particular speech register of mothers, fathers and other caregivers while speaking with infants and children to the voice they use in interaction with other adults. Numerous studies have described the specific linguistic characteristics of IDS (see Soderstrom, 2007, for a review) reporting that utterances are shorter, articulated clauses are rare and parents use a lower proportion of different verbs, function and content words and more diminutives, subject pronouns, and onomatopoeic sounds (Newport, Gleitman, & Gleitman, 1977; Papoušek, Papoušek, & Haekel, 1987).

Concerning the prosodic and acoustic features of IDS, several parameters distinguish IDS from ADS such as intensity, duration, velocity and prosody, but among these, the parameters that seem to better draw infant interest relate to the fundamental frequency (F0) of the voice (Fernald & Kuhl, 1987). The F0 represents the rate of vibrations of the vocal cords within the larynx and is acoustically perceived as the pitch of the voice. The different aspects of the pitch characteristics of the voice may be grouped into three categories: the mean of F0 (F0 mean) that represents the rate of vibrations of the vocal cords within the larynx, and reflects pitch variations of the voice; the width of F0 variations and excursions within and between utterances (F0 variability); and F0 contours that represent the overall shape of the F0 variations over time and are operationalized as the direction (rising when the F0 increases, falling when it decreases and flat when no perceived change in F0 is present) and number of these variations (F0 contours). A summary of these variables and their definitions is presented in Table 1.

There is a broad agreement on the F0-related characteristics more commonly observed in IDS. F0 mean values are higher in IDS than in ADS (e.g. Fernald & Simon, 1984; Grieser & Kuhl, 1988), indicating that parents tend to use a voice that is generally perceived with higher pitch. F0 variations are much wider and smoother in typical IDS and play a special role in giving IDS its typical exaggerated modulation (e.g. Fernald & Mazzie, 1991; Fernald & Simon, 1984). The prosodic contours that convey speaker communicative intent even in adult speech (e.g., rising contours to express questions) are used more clearly and with an exaggerated emphasis in IDS that thus results in more communicative speech than ADS (Katz, Cohn, & Moore, 1996). Moreover, varied F0 contours, such as those that are rising, falling and sinusoidal-bell shaped, which imply one or more significant variations in the pitch within the production, are used more commonly in IDS, whereas flat productions, without variations in the intonation and therefore perceived as monotone speech, are more frequent and prevalent in ADS (e.g. Fernald & Simon, 1984; Knoll & Costall, 2015).

Thus, a full range of modifications that may be summarized with higher F0 mean values, wider F0 variability and a predominance of varied (non flat) F0 contours constitute the prototypical prosodic patterns demonstrated in caregivers' speech directed to infants and children, with only slight differences across languages and cultures (Fernald & Simon, 1984; Fernald et al., 1989).

It is this prototypical IDS that results in more attractive speech for infants and children in comparison with ADS (Dunst et al., 2012; Fernald, 1985). This preference for IDS is crucial because it makes infants more focused on adults who address them with IDS and consequently facilitates more effective interactions (Schachner & Hannon, 2011). Saint-Georges et al. (2013) suggested that it is through these social interactions that, in turn, IDS stimulates infant socio-cognitive development. This is consistent with several empirical studies reporting that prototypical IDS prosodic values are associated with more

[1] See for example how the role of IDS in enhancing linguistic development is a major focus of linguistic researchers (see D'Odorico and Jacob, 2006) while the association of IDS and affective competences is a concern of researchers more interested in socio-affective development (see Stern, Spieker, & MacKain, 1982).

Table 1
Prosodic F0-related variables and definitions.

Prosodic feature	Definition	Variables
F0 mean	It represents the rate of vibrations of the vocal cords within the larynx, and reflects pitch variations of the voice Acoustically, F0 is defined as the lowest periodic cycle component of the acoustic waveform, and it is extracted by computerized tracking algorithms Measured in Hz	F0 mean
F0 variability	It refers to the width of pitch changes, the difference between the maximum and the minimum F0 peaks, over the entire utterance. Measured in Hz or in semitones	F0 SD = F0 maximum – F0 minimum (between the productions) F0 range or ΔF0 = F0 maximum – F0 minimum (within the production) F0 minimum and maximum value Magnitude of final contour = F0 maximum – F0 minimum (of the last movement in the production) Jitter = fast variations in F0
F0 contours	Overall shape of a production in terms of its pitch (F0) variation over time	Number of movements Classification of contours on the basis of the direction and slope of movements: Flat/Unitonal (no perceived changes in F0), Rising (F0 increases), Falling (F0 decreases), Bell-shaped (F0 increases and then decreases), U-shaped (F0 decreases and then increases), Sinusoidal, Complex (more than two F0 variations)

infant attention (e.g. Roberts et al., 2013), infant engagement (e.g. Gratier & Devouche, 2011), linguistic acquisition (e.g. Vosoughi, Roy, Frank, & Roy, 2010), and enrichment in affect transmission and sharing (e.g. Stern et al., 1982).

Infant-directed speech and infant outcomes

Infant attention

Starting from the preference of infants and children for IDS over ADS, one of the main functions we may expect this particular register to have is to evoke and stimulate infant attention. Prototypical IDS with its prosodic modifications is perceived by infants as a signal of communication more than ADS and hence, attracts the attention towards the caregiver. Indeed, infants look at adults that address them using IDS longer (Cohen et al., 2013; Kaplan, Bachorowski, Smoski, Hudenko, & Zarlengo-Strouse, 1995). Consistent with this notion, infants have also been found to show a higher cerebral activation during exposure to IDS than to ADS (Naoi et al., 2012; Zangl & Mills, 2007).

Adults also intentionally use the different aspects of speech to engage and maintain infant attention. For example mothers increase their F0 variability to obtain infant attention when infants do not respond immediately to their vocal stimuli (Masataka, 1992b) and Stern et al. (1982) found that rising and bell-shaped contours were consistently used by the mother to catch and maintain infant attention, respectively.

However, findings are less consistent regarding the association between prototypical IDS and infant attentional outcomes. Some authors found that IDS with higher F0 mean and wider F0 variability was associated with an increase in attention both for newborns (Butler, O'Sullivan, Shah, & Berthier, 2014) and 6- to 8-month-old infants (Phillips, 1995). Other studies found opposite associations, with 3-month-old infants paying more attention to utterances classified as comforting, with a lower F0 mean and F0 variability, than approving sentences with higher F0 features, while 6 and 9-month-olds did not show a preference (Kitamura & Lam, 2009). Similar contrasting findings have been found for F0 contours; while 6-month-old infants listened longer to bell shaped IDS (very typical of IDS), 10-month-olds preferred flat contours typical of a monotonic speech (Kitamura & Notley, 2009).

This role of IDS in guiding child attention to maternal speech impacts the infant learning processes. Kaplan and colleagues reported, in several studies, the implications of IDS for associative learning using a conditioned-attention paradigm. While 4- and 9-month-old infants exposed to prototypical IDS were able to learn a sound-face association, infants who were exposed to IDS of depressed parents, a consistently low modulated IDS (Kaplan, Bachorowski, Smoski, & Zinser, 2001), showed a reliable impairment in learning tasks in response to parental IDS (Kaplan, Bachorowski, Smoski, & Hudenko, 2002; Kaplan, Bachorowski, & Zarlengo-Strouse, 1999; Kaplan, Sliter, & Burgess, 2007). However, while IDS F0-related measures significantly predicted infant associative learning in the first study (Kaplan et al., 1999), a lack of association was found in other studies both for IDS from mothers and fathers (Kaplan, Burgess, Sliter, & Moreno, 2009; Kaplan et al., 2007).

In addition, IDS is also perceived as a social cue that guides infant attention towards referential targets. At 6 months, infants are more likely to follow an adult gaze towards an object when the adult addressed the object with IDS compared to ADS (Senju & Csibra, 2008). This potential of IDS to facilitate engagement in a topic-sharing task was also considered by Roberts et al. (2013) as the main cause of their reported association between maternal F0 variability at 6 months and

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infant joint attention skills at 12 months and as a confirmation of the long-term effects of IDS attention-gating effects. However, to our knowledge, this is the only study that explored IDS effects on infant attention longitudinally.

In sum, even if the hypothesis that prototypical IDS drives and influences the attentional competences of infants is widely shared based on the consistent preference infants show to IDS over ADS, the empirical findings on the associations between IDS F0 features and attentional outcomes are incongruous. The majority of the studies explored the effect while also measuring infant looking time, but many differences were found, for example, at different ages and across different characteristics of prototypical IDS that may, more or less, play a role in the process.

Infant pre-linguistic outcomes

From the first weeks after birth neonates vocally respond more when parents are present and when they talk to them (Cassel et al., 2013), and mothers adjust their speech to elicit infant responsiveness using, for example, higher F0 mean and more rising contours when interacting with a less frequently responding child (Niwano & Sugai, 2003a). Therefore, it was hypothesized that a primary effect of IDS is to increase infant vocal response to caregiver's vocal stimulation even before language development. Consequently, some studies explored whether prosodic features of IDS were associated with a higher rate of infant pre-linguistic vocal responses. Findings revealed an association between IDS prosody and infant responses but with age-related changes. A predominance of responses to falling contours was found at 3 and 5 months and to rising contours at 9 months (Niwano & Sugai, 2002a, 2002b).

Together with the rate of responses, the quality of these responses came under scrutiny since the first studies on the topic. In particular, the ability of infants to imitate the prosodic characteristics of parental speech was explored, as prosodic imitation, similar to general imitation, may have an important role for communication development by being a precursor to language acquisition (Papoušek et al., 1987). While some studies have demonstrated the ability of infants to imitate the prosody of parental speech, for instance, by adapting their F0 features to match that of the parents (Ko, Seidl, Cristia, Reimchen, & Soderstrom, 2015; Papoušek & Papoušek, 1989), other studies have failed to find this association both with maternal and paternal speech (McRoberts & Best, 1997; Siegel, Cooper, Morgan, & Brenneise-Sarshad, 1990). Furthermore, other authors specifically analysed if some prosodic aspects of IDS were more effective in eliciting infant imitation of caregiver's speech. Both Papoušek and Papoušek (1989) and, more recently, Gratier and Devouche (2011) found that 3-month-old infants consistently imitate maternal prototypical IDS F0 contours as rising, falling, bell-shaped and sinusoidal contours during vocal interactions while they do not imitate maternal unitonal/flat productions. Rising contours were also more imitated by infants at 3–4 months in a Masataka (1992b) study, a further confirmation that contours typical of more exaggerated parental speech are better in eliciting infant imitation compared to flat productions.

Therefore, the prototypical prosodic modifications of IDS are associated with higher rates of vocal responses and imitation that, in turn, may be considered important indexes of a greater active participation in social exchanges between infants and caregivers. This active participation, increased by IDS, is the key element in the language acquisition process (Golinkoff et al., 2015).

Infant linguistic outcomes

Higher exposure to IDS in daily life at 12 months was associated with a larger 2-year productive vocabulary (Ramirez-Esparza, Garcia-Sierra, & Kuhl, 2014). The prosodic aspects of IDS may play a crucial role in this process and may help pre-linguistic and linguistic development in several ways (Morgan, 1996). Parents regularly use exaggerated prosody (higher F0 mean, peaks and variability) to mark focus (Fernald & Mazzie, 1991), as well as new and relevant words (Albin & Echols, 1996; Bortfeld & Morgan, 2010; Fisher & Tokura, 1995; Lyakso, Frolova, & Grigorev, 2014). These characteristics of prototypical IDS seem to be a fundamental cue in understanding word boundaries and discriminating words from part-words (Soderstrom, Blossom, Foygel, & Morgan, 2008; Thiessen, Hill, & Saffran, 2005) and may assist in word recognition and facilitate word comprehension and learning of children (Fernald & Mazzie, 1991; Herold, Nygaard, & Namy, 2012; Singh, Nestor, Parikh, & Yull, 2009). Indeed, a wider F0 variability of IDS at 3 months was associated with a larger infant productive vocabulary at 12 months (Porritt, Zinser, Bachorowski, & Kaplan, 2014). However, D'Odorico and Jacob (2006) found that IDS F0 variability was not a discriminant characteristic between mothers of late-talkers and children with a normal language development at 20 months. On the contrary, in their study, a higher presence of flat and less varied F0 contours was associated with a language delay in children. Regarding word recognition abilities, different findings are reported according to infant age. While Song, Demuth, and Morgan (2010) failed to find a role of F0 variability in improving the ability of infants to recognize familiar words at 19 months, Ma, Golinkoff, Houston, and Hirsh-Pasek (2011) found that 21-month-old children learn new words if addressed with prototypical IDS and not with ADS, but such difference was not present later at 27 months.

Even if the hypothesis of the role of prosodic features of IDS in child language development is widely shared, the empirical findings are not consistent. In particular it seems that the association is not consistent over the first two years.

Infant expression of emotions

Emotional arousal is known to influence and to be shown in vocal expressions. In fact, several studies have demonstrated a direct link between different prosodic voice parameters and emotion (Juslin & Laukka, 2001; Scherer, 2003). For instance, high-intensity positive emotions, such as joy, have been consistently described as expressed with increased F0 mean and variability (Scherer, 2003). While similar prosodic values have been found in prototypical IDS, a common hypothesis is that caregivers use such exaggerations to communicate positive emotions to infants and children (Fernald & Kuhl, 1987; Stern et al., 1982). Indeed, IDS is rated as expressing more emotions than standard ADS (Kitamura & Burnham, 2003) and has shown prosodic features similar to emotional ADS (Trainor, Austin, & Desjardins, 2000). Therefore, emotional expression, which is typically constrained in normal ADS, seems to be a primary determinant of IDS, and the exaggeration of pitch levels and pitch variability typical of IDS may be perceived as more attractive because it communicates positive affect, thus contributing to the creation and maintenance of an emotional bond between caregivers and their infants. Singh, Morgan, and Best (2002) confirmed this hypothesis, showing that the only condition in which infants prefer IDS compared to ADS is when IDS was rated positive and ADS neutral. No preference was present when both the stimuli were happy, showing a general preference of infants for positive emotions in speech. The authors suggested that previous studies were exploring the preference for positive versus neutral emotions more than between the two registers. Indeed, maternal IDS with higher F0 mean was rated as expressing a more positive affect (Kitamura & Burnham, 2003), and a reduction in F0 mean and variability with a general lack of emotional expression in the voice was found, for example, in depressed mothers, who have difficulties expressing and communicating positive emotions and whose IDS was, indeed, less attractive to infants (Bettes, 1988; Kaplan et al., 2009; Porritt et al., 2014). High prosodic features are also used by mothers to mirror infant positive emotions; for instance, high pitches are present in conjunction with infant spontaneous surprise exclamations (Reissland, Shepherd, & Cowie, 2002). In contrast, when trying to comfort a crying infant, mothers were found to use a lower F0 mean and fewer rising contours (Moore, Cohn, & Katz, 1994; Papoušek, Papoušek, & Symmes, 1991; Spence & Moore, 2002).

On the basis of these findings we may expect that prototypical IDS also has the function to elicit and regulate infant positive emotions. Infants indeed show a pattern of frontal brain electrical activity when listening to emotional IDS that is consistent with that observed in adults during the processing of emotions (Santesso, Schmidt, & Trainor, 2007). Moreover, some prosodic features characteristic of prototypical IDS are more relevant in stimulating infant positive affect. Stern et al. (1982) found that a preponderance of sinusoidal-bell contours was more associated with infant smile and gaze directed to the mother. Fernald (1993) showed that infants responded with more positive affect to approval vocalizations, characterized by exaggerated F0 mean and variability and rise-fall F0 contours, than to low modulated prohibition vocalizations, to which they tend to respond with more negative affect. However, this difference was present for English, their own language, and for German and Italian sentences but not for Japanese productions. Also Phillips (1995) found cultural differences in the association between more exaggerated IDS prosody and greater infant positive affect responses. Whereas African American mothers' speech with a greater jitter elicited more infant positive affect in 6-to 8-months-old infants, for European American infants the wider F0 variability of maternal speech was more relevant.

If IDS is a vehicle to express emotions to the infant, we may therefore expect to find a consistent association between prototypical IDS and infant expression of positive emotions. Nonetheless the picture is not clear; there are only a few studies that have explored these associations and the characteristics of the prototypical IDS that better elicit positive affect are not consistent.

Moderators

As illustrated in the previous paragraphs, a great variability with respect to sample and procedural characteristics exists among studies that explore the association between IDS prosody and infant outcomes. It is therefore relevant to test the moderation effect of these variables in the meta-analyses. Relevant sample characteristics include infant age, type of caregiver, language and parental socio-economic status (SES), and the procedural characteristics of interest are the study design (concurrent or longitudinal), the predictor evaluation (during free-play or structured interactions) and the outcome evaluation (with observations, questionnaires or experiments).

Starting with the characteristics of the sample, studies exploring IDS and its effects have included many different age groups from early infancy to late toddlerhood. Even though patterns of IDS have been observed from infancy onwards (Kitamura & Burnham, 2003; McRoberts & Best, 1997), infant reactions to IDS seem to vary with an increase in preference for IDS over the first months of life (Dunst et al., 2012) and a reduction thereafter (Hayashi, Tamekawa, & Kiritani, 2001; Newman & Hussain, 2006; Panneton, Kitamura, Mattock, & Burnham, 2006). Similarly, findings are not consistent concerning which prosodic feature is associated at the different ages with infant vocal responses (Niwano & Sugai, 2002b), infant attention (Kitamura & Burnham, 2003; Kitamura & Lam, 2009; Kitamura & Notley, 2009) and infant language development (D'Odorico and Jacob, 2006; Porritt et al., 2014). We may therefore expect that the association of prosody with infant outcomes may be stronger for younger infants, who may be more sensitive to the prosodic features of the voice due to their limited attentional and language comprehension abilities (Matsuda et al., 2014; Stern, Spieker, Barnett, & MacKain, 1983).

Parental characteristics may also influence the investigated relation; consequently the type of caregiver, language and SES will be considered as moderators. Fernald et al. (1989) found that both mothers and fathers modify their intonation while speaking with infants, but slight differences were present. A comparison between different caregivers would clarify if these differences have an impact on infant outcomes. Niwano and Sugai (2003b) showed similarities between maternal and paternal IDS prosody but infants vocally responded more to their mothers than to their fathers. It would be interesting to see if

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this means that the association between prototypical IDS prosody and infant pre-linguistic responses is predominantly present for mothers in general.

Several studies have explored IDS prosodic characteristics in different linguistic contexts and they found that mostly all caregivers modify their speech when interacting with infants and children with exaggerating the prosodic patterns of the voice (Broesch & Bryant, 2015; Ferguson, 1964; Fernald et al., 1989; Grieser & Kuhl, 1988; Kitamura, Thanavishuth, Burnham, & Luksaneeyanawin, 2002; Kuhl et al., 1997). Even though the majority of studies on the topic have been conducted in the American English linguistic context, a language that has been demonstrated to be much more exaggerated in IDS compared to other languages (Fernald et al., 1989), the associations between prototypical IDS and infant outcomes have also been found in other languages (Gratier & Devouche, 2011; Masataka, 1992a; Niwano & Sugai, 2002b). To our knowledge, there are no studies that have compared the degree of these associations in different linguistic contexts; based on the literature, we may expect that this relation is universal and not language-specific.

To our knowledge there are no specific studies that explore the relationship between IDS prosody and SES, but the few studies on IDS linguistic features suggest that low-SES parents use a linguistically less complex stimulating speech that in turn negatively influences infant language development (Hoff, 2003; Rowe, 2008). We aimed to test if this moderation effect of SES is also present with IDS prosody.

Other questions at which the present meta-analyses aimed to answer were if the associations between IDS prosody and infant outcomes are stronger concurrently or longitudinally and if the outcome is observed or measured within structured experiments.

Moreover, we examined whether the strength of the associations was affected by the type of assessment, i.e., whether IDS prosody was assessed during a free-play, structured or semi-structured parent-infant interaction.

Lastly, the studies reported in the introduction of this paper used different F0-related-variables as predictors of the association between IDS prosody and infant outcomes. Consequently, our last moderation analyses aimed to test if, among these F0 patterns (F0 mean, F0 variability and F0 contours), some are more strongly related to infant outcomes and are therefore worthier of further study.

The current study

A great number of studies have explored the effect of IDS prosody using non-natural and spontaneous parental speech reproduced in the laboratory. However, specific prosodic features of natural parental speech are not exactly reproduced in a laboratory context with simulated IDS produced by students and actresses (Knoll & Costall, 2015). In addition, when compared to synthesized IDS, infants prefer natural recordings of IDS (Cooper & Aslin, 1994; Dunst et al., 2012). We therefore argue that the use of synthetized and not spontaneous IDS or IDS pronounced by actors or non-parental adults does not exactly correspond to the IDS heard by infants in social verbal exchanges with parents. Hence, to select the studies to include in the meta-analyses, we decided to focus on findings related to natural caregiver speech recorded during caregiver-infant interactions.

Based on the literature discussed above, we formulated several hypotheses about the potential beneficial effects of IDS prosodic features on the behaviors and development of infants to be tested in our meta-analyses. We expected that prototypical IDS, defined as IDS with a higher F0 mean, wider F0 variability and the presence of varied (with a perceived change of F0 within the utterance) F0 contours, would be associated with (1) more infant attention, (2) better pre-linguistic and linguistic abilities and (3) more expression of positive affect. We also examined several samples and procedural moderators and expected that the hypothesized associations were (1) stronger in younger infants, (2) stronger for mothers than for fathers, (3) equally strong in different linguistic contexts; (4) stronger for families with high SES, (5) equally strong concurrently and longitudinally, (6) stronger when IDS was measured during free-play interactions, (7) stronger when the outcome was measured during infant observation, and (8) equally strong for the different variables used as prosodic predictors.

Method

Literature search and inclusion criteria

Two research methods were used to identify relevant studies. First we searched the electronic databases Web of Science, Psychinfo and PubMed by using the keywords 'motherese', 'infant-directed speech', 'child-directed speech', 'baby talk', 'm aternal/paternal/parental speech', 'mother/father speech', 'maternal/paternal/parental language', 'mother/father language', 'maternal/paternal/parental talk', 'mother/father talk', with the inclusion criteria 'age = 0–24 months', 'publication date between January 1965 – September 2015', 'human subjects' and 'English' as journal language. The search was finalized in September 2015. Second, the complete reference lists of the reviews by Saint-Georges et al. (2013), Soderstrom (2007), Cristia (2013), Golinkoff et al. (2015) and Morgan (1996), and from the meta-analysis by Dunst et al. (2012) were included in the database. A total of 1612 papers was found (see Fig. 1).

The 1612 papers were then screened according to five inclusion criteria, selecting only studies including: (1) assessments of prosodic aspects of IDS related to F0 variables, excluding those assessing only linguistic, temporal, intensity, phonological, or phonetic features; (2) observations of naturalistic IDS during interaction with the infant (not singing); (3) measures of IDS

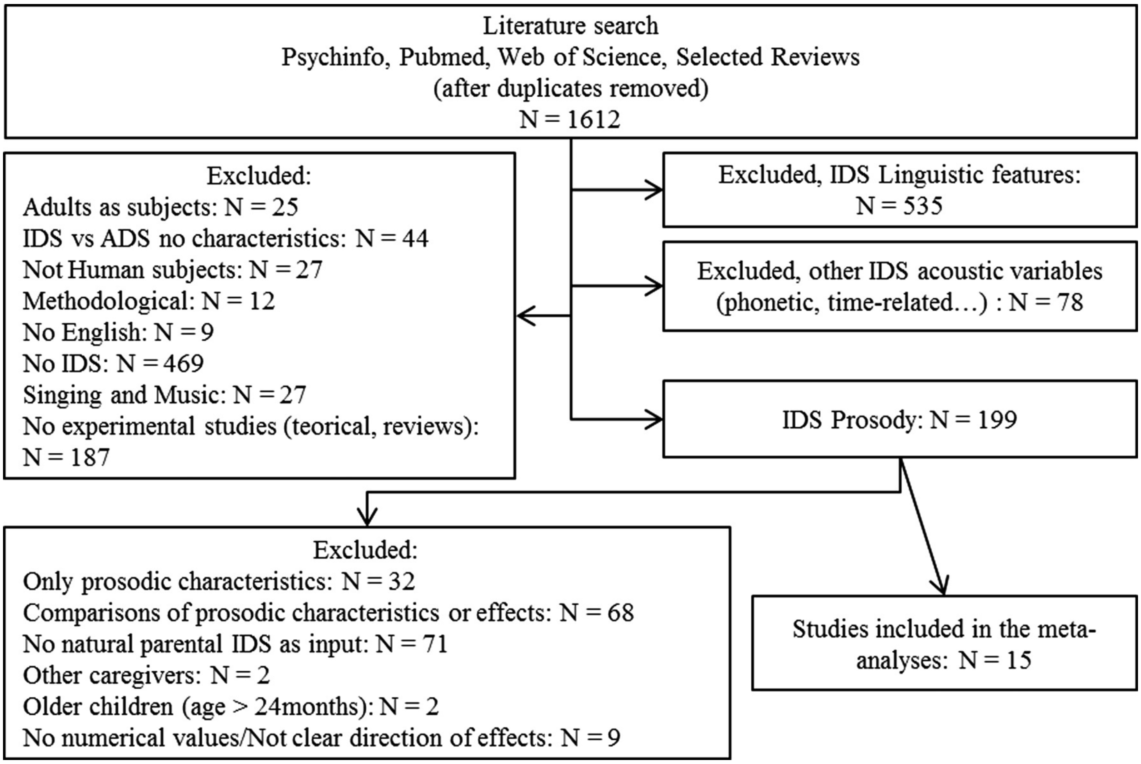

Fig. 1. Flow chart of literature search and selection.

of mothers, fathers or other primary caregivers; (4) numerical or categorical variables of a clear characteristic of the prosody of speech that indicates ordinal levels of IDS prosody (i.e. no categories as good vs poor IDS); (5) statistical analyses testing the relation between IDS and an infant outcome (with higher scores reflecting better outcome.[2])

If no adequate statistics were reported in the article, the authors were contacted for additional details. Conference abstracts and papers whose statistics were not found were excluded. Dissertations published in the ProQuest database were included.

To make sure that the inclusion criteria could be interpreted unambiguously, all the included and ambiguous articles were discussed by two authors and 100 articles were assessed for eligibility by two coders and screened of abstracts and full-texts. The mean intercoder agreement was 96 % suggesting a high level of reliability of the inclusion-exclusion process. In case of disagreement, the coders discussed and reconsidered the criterion to get to a full consensus on the in/or exclusion of these articles.

We found 15 studies with 16 samples that met our search criteria (see Fig. 1). All the included papers' references were checked for other missing studies, but no additional studies were found. Sample sizes ranged from 1 to 223, and infant age at the moment of predictor measurement ranged from 3 weeks to 20 months (see Table 2). One study, Phillips (1995) included 2 different samples and measured 2 different outcomes for each sample, so four effect sizes from this paper were included in the analyses. One other study, Stern et al. (1982), measured two different outcomes on the same sample so two effects were included in the meta-analysis. A total of 19 effect sizes, that corresponds to the number of the associations evaluated by the included studies, was therefore included in the meta-analytic database.

Moderators

We coded four types of moderators: type of outcome, sample characteristics, prosodic predictors and procedural moderators (see Table 3).

Outcomes were grouped in three principal categories: attentional, communicative and affective outcomes. Attentional outcomes included global measures of attention, joint attention and conditional attention. Communicative outcomes included pre-linguistic and linguistic outcomes. Pre-linguistic outcomes included the rate of response and the imitation of parental intonation of voice. Linguistic outcomes included lexical, syntactic and vocabulary production and

[2] Studies that explored the correlation between prosodic values of the parents and prosodic values of the infants (i.e. Ko et al., 2015) were excluded because the prosodic characteristics of infant voice can't be clearly considered a competence.

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Table 2
Studies included in the meta-analyses.

Study	*n*	T.O.[b]	Outcome	Outcome measure[c]	Infant age in months	T2 age[d]	Linguistic context	SES[e]	Study design[f]	Predictor observation[g]	Prosodic predictor[h]
Butler, O'Sullivan, Shah, and Berthier (2014)	24	At	Sucking behavior	E	0.56		English	Mx	Co	F-I	Var
D'Odorico and Jacob (2006)	18	L	Vocabulary production	Q	20.00		Italian	Mx	Co	F-I	Var, Contour
Gratier and Devouche (2011)	28	P	Imitation of contours	O	2.68		French	Mx	Co	F-I	Contour
Kaplan et al. (2009)	45	At	Conditioned attention/learning	E	9.70		English	Nr	Co	Semi	Mean, Var
Kaplan et al. (2007)	32	At	Conditioned attention/learning	E	9.25		English	Nr	Co	Semi	Var
Lyakso et al. (2014)	10	L	Various linguistics	O	7.50	1–7 y	Russian	Nr	L	F-I	Mean, Var
Masataka (1992a)	10	P	Peak location of production	O	2.00		Japanese	Nr	Co	Semi	Contour
Niwano and Sugai (2002a)	50	P	Rate of response	O	9.00		Japanese	Mx	Co	F-I	Contour
Niwano and Sugai (2002b)	40	P	Rate of response	O	3.00		Japanese	Mx	Co	F-I	Mean
Phillips (1995) AA[a]	20	At, Af	Global attention, Affect	O	6.60		English	Nr	Co	F-I	Mean, Var
Phillips (1995) EA[a]	20	At, Af	Global attention, Affect	O	6.70		English	Nr	Co	F-I	Mean, Var
Porritt et al. (2014)	138	L	Vocabulary production	Q	9.03		English	Nr	Co	Semi	Var
Roberts et al. (2013)	223	At	Joint attention	O	6.60	12.8 m	English	Mx	L	Semi	Mean, Var
Stern et al. (1982)	6	At, Af	Looking, Smile	O	2.00		English	Nr	Co	F-I	Contour
Vosoughi et al. (2010)	1	L	Word acquisition	O	9.00		English	Nr	Co	F-I	Var
Walker (2013)	4	L	Word production, Word comprehension	Q	10.00	25.6 m	English	Nr	L	F-I	Var

Note: n = total number of participants.
[a] AA = African-American, EA = European-American.
[b] T.O. = Type of Outcome, P = Prelinguistic, L = Linguistic, At = Attentional, Af = Affect .
[c] O = Observation, Q = Questionnaire, E = Experimental.
[d] T2 age = time point measure for outcomes in longitudinal studies, y = years, m = months.
[e] SES = Socio-Economic Status, Mx = Mixed, Nr = Not reported/Not determinable.
[f] Co = Concurrent study, L = Longitudinal study.
[g] F-I = Free-play interaction, Semi = Semi-structured observation.
[h] Mean = F0 mean related predictors, Var = F0 variability related predictors, Contour = F0 contours related predictors.

comprehension, age of acquisition of words, and reading competence. Infant affect included response to the parent with positive affect and smiles and global positive affect during the interaction. Only 3 studies were included in this last category, not enough to run a meta-analysis on the association between IDS prosody and infant affect. A meta-analysis may be run only if the number of studies is more than four and the contrast effect of a moderator may be tested only when at least two of the subsets consisted of at least four studies (Bakermans-Kranenburg, Van IJzendoorn, & Juffer, 2003). Positive effect sizes indicate that the meta-analytic effect (based on results reported in the papers) reflected the directions of the hypotheses (prototypical IDS prosody associated with better infant outcomes), whereas negative effect sizes indicate effects opposite of the hypothesized direction.

We also coded the way the infant outcome was measured; if it was measured with observation of infant behaviors, questionnaires (e.g., using the MacArthur Communicative Development Inventories, Fenson et al., 1993, completed by the caregiver to assess infant vocabulary) or experimental procedures (e.g., in a conditioned-attention paradigm). Due to the limited number of studies (k) where the outcome was measured with questionnaires ($k = 3$) and studies that used an experimental outcome measure ($k = 3$), this moderator factor could not be tested. Even when merging observations with questionnaires (as they both assess spontaneous infant outcomes), the number of studies in the comparable category using experimental outcome was not sufficient.

Regarding the sample characteristics moderators, we coded infant age at the time when IDS was recorded, infant gender, infant population, the identity of the caregiver, linguistic context, and SES. Age was divided into three categories on the basis of their frequencies to have similarly represented categories (0–6 months, 6–9 months and older than 9 months; see Table 3). Concerning the infant population, all studies referred to typically developing children except Butler, O'Sullivan, Shah, and Berthier (2014), which included premature infants. The caregiver was the mother in all but two

Table 3
Coding System for Studies on Prosody on Infant Competences.

Variable	Coding system	Notes
Sample characteristics		
Infant age in months	1 = < 6 months	
	2 = 6–9 months	
	3 = > 9 months	
Gender	1 = Predominantly female infants (>75%)	
	2 = Predominantly male infants (>75%)	
	3 = Mixed	
	4 = Not reported	
Infant population	1 = Typically development	
	2 = Premature infants	
	3 = Impaired children	
	4 = Other	
Caregiver	1 = Mother	
	2 = Father	
	3 = Mixed	
Linguistic context	1 = English	
	2 = Romance languages	i.e. French, Italian, Spanish
	3 = Asiatic languages	i.e. Japanese
	4 = Other languages	
SES	1 = Predominantly low SES (> 75% low)	
	2 = Other	
	3 = Not reported/Not determinable	
Procedural		
Study design	1 = Concurrent	
	2 = Longitudinal	
Predictor observation	1 = Free-play interaction	
	2 = Semi-structured interaction	
	3 = Structured interaction	
Analyses	1 = Univariate	i.e. Simple correlations or mean contrasts
	2 = Bivariate	i.e. Regressions
Prosodic predictor		
Prosodic predictor	1 = F0 mean	
	2 = F0 variability	
	3 = F0 contours	
Type of outcome		
Outcome	1 = Pre-linguistic	
	2 = Linguistic	
	3 = Attentional	
	4 = Affective	
Outcome evaluation	1 = Observation	
	2 = Not-observation	Questionnaire and Experiment

studies. Kaplan et al. (2007) was the only study that explored the IDS of fathers, and Vosoughi et al. (2010) recorded the speech of both parents. Thus, due to an insufficient number of studies per subset, i.e., less than four (Bakermans-Kranenburg et al., 2003), the infant population and caregiver identity could not be used as moderators in the analyses. Due to the limited number of studies conducted in non-English contexts, the linguistic context was reduced to two categories: English (including 1 British English and 8 American English studies) and other languages (non-English; including Italian, French, Russian and Japanese studies).

The procedural moderators included study design, type of predictor observation and type of analyses. In the study design category, studies that measured IDS prosody and infant outcomes at the same time point were coded as concurrent and studies that measured infant outcomes at a time point after the assessment of prosody were coded as longitudinal. Two studies measured IDS prosody and infant outcomes both concurrently and longitudinally. However, Masataka (1992b) merged the measures from all ages in the analyses, and Vosoughi et al. (2010) used the means of the IDS prosodic values across age for correlations; for these reasons both can be considered more concurrent than longitudinal and were included in the concurrent category. Finally, only three studies were included in the longitudinal category; therefore, this moderator was not further considered. None of the included studies used a structured procedure to evaluate IDS prosody, so the moderation effect of the predictor observation was computed for the contrast between free-play interaction and semi-structured interaction procedures. Moreover, only Walker (2013) used a regression analysis in his study; all of the other studies reported univariate analyses, so the type of analysis predictor was not further tested as a moderator.

To assess intercoder reliability, ten randomly selected studies were coded by two coders. The agreement between the coders across the moderator variables was 100%.

Prosodic predictors as moderator

Many of the studies selected in this set of meta-analyses, as well as the majority of the studies present in the literature, tested several prosodic characteristics of parental speech as predictors of infant outcome. The predictors of each selected study are listed in Table 2, and their definitions are present in Table 1.

The variables used in the studies can be grouped into 3 categories (see Table 1). The first category included mean values of fundamental frequency (F0 mean) throughout the caregiver production or the utterance. The second category included measures of the amplitude of variations of the fundamental frequency between and within vocal productions (F0 variability). In addition, the last category included measures of the direction and number of variations of the fundamental frequency (F0 contours). For studies that explored F0 contours we considered IDS flat contours (no relevant changes in the F0) as non-prototypical. The association of the presence of this contour with positive infant outcomes is therefore expected to be negative or absent. The presence of the other varied F0 contours (one of more relevant changes in F0; e.g., rising, falling, bell-shaped, sinusoidal) were expected to be positively related to positive child outcomes. We made this decision on the basis of previous findings that described flat F0 contours as typical of ADS and very infrequent in IDS, while the other contours, expression of expanded variations of the voice, are very frequent in prototypical IDS.

To test a potential moderator effect of the type of F0 variable we went back to the effect sizes of the selected papers and calculated different cumulative effect sizes for each paper considering the 3 categories of predictors separately. Thus, effect sizes from the same sample were included in the different levels of the moderator (F0 mean, F0 variability and F0 contours). For example, D'Odorico and Jacob (2006) explored the association of both F0-variability-related (F0 minimum, F0 maximum and F0 variability) and F0-contour-related (% of flat contours, number of movements) predictors; therefore, we considered this paper to have two different effect sizes calculated from each group of predictors. The 24 effect sizes obtained were included in the last meta-analyses to test the moderation effect of the type of prosodic predictor.

Meta-analytic procedures

The meta-analyses were performed using the Comprehensive Meta-Analysis (CMA) program Version 2 (Borenstein, Hedges, Higgins, & Rothstein, 2009; ; Borenstein, Rothstein, & Cohen, 2005). For each study, an effect size based on correlations and with a 95% confidence interval (*CI*) was calculated. Positive effect sizes indicate that the association reflected the directions of the hypotheses (prototypical IDS prosody-better infant outcome), whereas negative effect sizes indicate association opposite to the hypothesized direction. For papers that reported more than one result on the same sample combined effect sizes were computed. For studies that reported a non-significant finding without providing the exact statistics, a conservative non-significant zero effect size was used (Mullen, 1989) ($p = 0.50$). The program converted the correlations in Fisher's z scale and used these values for analyses and transformed them back again in correlations to give final results. For studies computing relations based on a sample of speech productions, effect sizes were calculated with the number of productions as sample size and Fisher's z and standard errors were reported as final statistics.

Meta-analyses were conducted with random effects models. Under the random effects model the true effects in the studies are assumed to vary between studies and the summary effect is the weighted average of the effects reported in the different studies (Borenstein et al., 2009).

To test the homogeneity of the overall and specific sets of effect sizes, we computed *Q*-statistics (Borenstein et al., 2005). *Q*-statistics and their *p*-values were also computed to assess differences between combined effect sizes for specific subsets of study effect sizes grouped by moderators. Contrasts were only tested when at least two of the subsets consisted of at least four studies (Bakermans-Kranenburg et al., 2003).

Funnel plots were examined in order to detect possible publication bias (only for analyses with number of studies $\geqslant 10$). A funnel plot is a plot of each study's effect size against its standard error (usually plotted as 1/SE, or precision). It is expected that this plot has the shape of a funnel, because studies with smaller sample sizes have increasingly large variation in estimates of their effect size as random variation becomes increasingly influential, whereas studies with larger sample sizes have smaller variation in effect sizes (Duval & Tweedie, 2000). However, smaller studies with nonsignificant results or with effect sizes in the non-hypothesized direction are less likely to be published. Therefore, a funnel plot may be asymmetrical around its base. The degree of asymmetry in the funnel plot was examined by estimating the number of studies which have no symmetric counterpart on the other side of the funnel. The 'trim and fill' method was used to test the influence of possible adjustments of the sets of studies for publication bias (Duval & Tweedie, 2000).

No outliers (standardized z-values smaller than -3.29 or larger than 3.29) were found for study effect sizes (Tabachnick & Fidell, 2001).

Results

Infant outcomes

A meta-analysis was conducted with the 19 effect sizes to test the relation between IDS prosody and infant outcomes (see Table 4). The results showed an overall significant relationship between prototypical IDS prosody and infant outcomes

Table 4
Meta-analytic results of prosodic associations with infant outcomes.

	k	n	*r*	95% *CI*	Q^a	*p*
Total set			.17***	(0.08–0.25)		
Infant outcomes					.94	.623
Attentional outcomes	7	370	.20*	(0.03–0.35)		
Communicative related outcomes					5.59	.018
Pre-linguistic	4	128	.39***	(0.22–0.53)		
Linguistic	5	171	.17***	(0.12–0.32)		

Note: *k* = number of studies' effect sizes; n = sample size; and *CI* = confidence interval.
[a] Q statistic for moderator stands for effect of contrasts (df = number of subgroups − 1).
* $p < 0.05$.
*** $p < 0.001$.

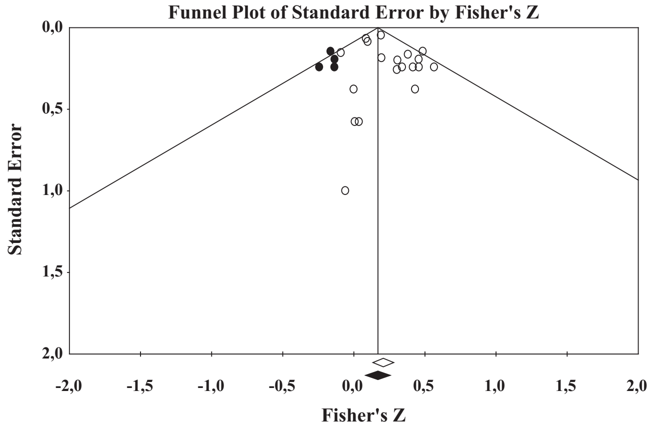

Fig. 2. Funnel plot of the studies included in the meta-analyses of the association between IDS prosody and infants outcomes. The effect size Fisher's z of each study (x-axis) is plotted against its standard error (y-axis). The vertical line represents the mean weighted effect size and the diagonal lines the 95% confidence interval.

($r = 0.20$, 95% $CI = 0.13–0.27$, $p < 0.001$). Using the trim and fill method (Duval & Tweedie, 2000), asymmetry was found in the funnel plot (see Fig. 2). Four missing studies were identified to the left of the mean. The adjusted value for the effect size was considered, but it was still significant ($r = 0.17$, 95% $CI = 0.08–0.25$, $p < 0.001$). The fail-safe number for this set of studies was 160. A fail-safe number is the number of studies that would be needed to change a significant combined effect size into a nonsignificant outcome and publication bias is generally regarded as a concern if the fail-safe number is less than $5k + 10$ (Rosenthal, 1995). Thus, our finding indicated that a high number of null studies would be required to cancel out this significant combined effect size, and we conclude that our results are unlikely to be heavily influenced by publication biases.

We tested whether the type of infant outcome (attentional, communicative and affective) was associated with the effect size (see Table 4).The contrast was not significant ($Q_{(2)} = 0.95$, $p = 0.623$). This result indicates that IDS prosody is equally strongly related to the three infant outcomes considered (see Table 4).

To further explore in detail the relation of IDS prosody with infant outcomes, we further conducted different meta-analyses for each outcome or group of outcomes (see Table 4). The first was to test the association of IDS prosody with infant attention. The combined effect sizes for the 7 included studies was significant and in the positive direction ($r = 0.20$, 95% $CI = 0.03–0.35$, $p = 0.024$). The direction of the effect indicates that prototypical IDS prosody is associated with more attention in infants.

With a subsequent meta-analysis, we aimed to test the association of IDS prosody with communicative-related outcomes that included pre-linguistic and linguistic outcomes. The 9 samples measuring those outcomes were included, and the type of outcome (two levels: pre-linguistic and linguistic) was used as a moderator. The contrast was significant ($Q_{(1)} = 5.59$, $p = 0.018$). The studies focusing on the association of IDS prosody with pre-linguistic outcomes showed the largest combined effect ($r = 0.39$). The combined association of IDS prosody with linguistic outcomes was smaller but also significant and in the positive direction ($r = 0.17$). Prototypical IDS prosody has a significant association both with linguistic and pre-linguistic outcomes, but the association with pre-linguistic outcomes is stronger.

Due to the limited number of studies that explored the relationship between IDS prosody and positive affect in infants ($k = 3$), we were not able to run a meta-analysis on these studies.

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Table 5
Meta-analytic results of moderator effects.

	k	*n*	*r*	95% *CI*	Q[a]	*p*
Infant age					5.47	.065
0–6 months	6	108	.35***	(0.17–0.51)		
6–9 months	7	324	.31**	(0.13–0.47)		
Older than 9 months	6	237	.16***	(0.08–0.23)		
Linguistic context					5.03	.025
English	13	513	.17**	(0.17–0.09)		
Non-English	6	156	.36***	(0.21–0.50)		
Predictor Evaluation					8.11	.004
Free-play interaction	14	221	.25***	(0.18–0.32)		
Semi-structured	5	448	.09	(−0.01 to 0.18)		

Note: *k* = number of studies' effect sizes; n = sample size; and *CI* = confidence interval.
[a] Q statistic for moderator stands for effect of contrasts (df = number of subgroups – 1).
** $p < 0.01$.
*** $p < 0.001$.

Table 6
Meta-analytic results for the separated effect sizes of prosodic predictors.

	k	n	*r*	95% *CI*	Q[a]	*p*
Type of predictor					20.25	<0.001
F0 contours	6	152	.44***	(0.29–0.57)		
F0 mean	7	483	.04	(−0.05 to 0.13)		
F0 variability	11	535	.19***	(0.12–0.25)		

Note: *k* = number of studies' effect sizes; n = sample size; and *CI* = confidence interval.
[a] Q statistic for moderator stands for effect of contrasts (df = number of subgroups – 1).
*** $p < 0.001$.

Moderators

A further set of meta-analyses was conducted to test if the moderators considered (infant age at the moment of predictor recording, linguistic context, study design, predictor's evaluation, and outcome evaluation) were associated with the 19 effect sizes. The results of the moderators' comparisons are reported in Table 5. Infant age was a marginally significant moderator ($Q_{(2)} = 5.47$, $p = 0.065$). IDS prosody was more strongly related to infant outcomes for infants younger than 6-months, and between 6 and 9 months ($r = 0.35$ and $r = 0.31$ respectively) than for infants older than 9 months ($r = 0.16$). We further tested the moderator effect of age comparing younger than 9 months *versus* older than 9 months infants. The contrast effect was significant ($Q_{(1)} = 4.03$, $p = 0.045$); the association of prototypical IDS prosody with infant outcomes was stronger for younger than 9 months infants ($r = 0.29$) than for older infants ($r = 0.16$). The contrast effect of the linguistic context was significant ($Q_{(1)} = 5.03$, $p = 0.025$). The relationship with prototypical prosodic values of IDS was stronger in studies conducted in countries where English is not the speaking language of the parent ($r = 0.36$) than in English contexts ($r = 0.17$). In the other language studies category, we grouped together a wide variety of languages (Italian, French, Russian and Japanese) and the cultural contexts of these languages are very different from one another, also the English category summed British with American English studies, two different cultural contexts; therefore, this result needs to be interpreted carefully (see Discussion section). The procedure used to evaluate the parental voice was also a significant moderator ($Q_{(1)} = 8.11$, $p = 0.004$). The association was higher in studies where IDS was evaluated in free-play parent-infant interactions ($r = 0.25$). The association was small and not significant when IDS was recorded in semi-structured parent-infant interactions ($r = 0.09$).

Prosodic predictors as moderator

The last aim of the present study was to explore if some prosodic aspects of prototypical IDS would be more strongly associated with positive infant outcomes than others. A meta-analysis was conducted on the 24 effect sizes, obtained combining the results according to the type of predictor considered (F0 mean, F0 variability, F0 contour), with the type of predictor as the moderator (see Table 6). The contrast effect of the type of predictor was significant ($Q_{(2)} = 20.25$, $p < 0.001$). Both prototypical IDS F0 contours and F0 variability were positively and significantly associated with infant outcomes ($r = 0.44$ and $r = 0.19$ respectively), but the association between F0 contours and infant outcomes was significantly higher. The combined effect of the F0 mean was smaller and not significant ($r = 0.04$).

Discussion

With the present study, we meta-analytically tested the association of prosodic aspects of natural parental IDS with infant outcomes while summarizing the findings of the empirical studies to give a complete and clear picture of the phenomenon. Overall, the current meta-analyses showed that prototypical prosodic features of IDS are related to more positive infant outcomes, confirming previous hypotheses on the role and functions of IDS prosody (Fernald & Simon, 1984; Garnica, 1977; Papoušek, 1992). In particular, prototypical IDS prosody is associated with more infant attention and better pre-linguistic and linguistic skills, while the association with infant positive affect was not tested due to the insufficient number of studies. In addition, these relationships were significantly stronger for younger infants, weaker in studies conducted in English linguistic contexts and stronger when IDS was measured in free-play interactions. F0 contours and F0 variability were the prosodic variables most strongly associated with infant outcomes.

IDS and infant outcomes

The first hypothesis on the association of prototypical IDS prosody with more infant attention was confirmed. This supports the notion that the exaggerated prosodic characteristics of IDS have the function to maintain infant arousal and attention and may explain why previous studies have found a high preference for IDS compared to ADS (Fernald, 1985; Fernald & Kuhl, 1987).

Unfortunately, among the 6 studies included in our meta-analyses, only one measured the association of prosody with infant attention longitudinally (Roberts et al., 2013). All of the others were concurrent and measured IDS characteristics and infant outcomes at the same moment. This leaves open the question of if our result simply demonstrates that the prosodic characteristics of the voice attract more infant attention or also facilitates the development of attentive competences in the long term as suggested by the Roberts et al. (2013) study. More longitudinal studies would help answer this question.

The results further confirmed the second hypothesis on the association of IDS prosody with better infant pre-linguistic and linguistic skills (Fernald, 1991; Golinkoff et al., 2015). Hence, prototypical IDS prosody corresponded with greater infant vocal response and imitation (Golinkoff et al., 2015) and better vocabulary comprehension and production (Fernald & Mazzie, 1991; Fisher & Tokura, 1995), with the first showing a greater effect size. The significant association between prototypical IDS and infant language outcome when IDS is recorded in natural parent-infant interactions may explain why other studies that used recorded speech found contrasting findings on the role of IDS prosodic features in improving, for example, the ability of infants to recognize words (Ma et al., 2011; Song et al., 2010). Moreover, as many studies have demonstrated the importance of other acoustic and phonological factors in the language development process (Liu, Kuhl, & Tsao, 2003; Song et al., 2010; Uther, Knoll, & Burnham, 2007), a meta-analysis that compares the effects of prosodic, linguistic, phonological and acoustic variables in improving language development would be helpful for understanding what are, and to what extent, the characteristics of IDS that assist infant language development.

Notably, none of the considered studies explored both pre-linguistic and linguistic associations. While infant communicative engagement has been shown to be a precursor of and crucial for language development, we may hypothesize that prototypical IDS prosody facilitates the development of pre-linguistic communicative abilities, such as vocal imitation and responses, and that these in turn facilitate language acquisition (Golinkoff et al., 2015). This provides an interesting suggestion for future studies that may test the mediating role of pre-linguistic skills longitudinally, with different time point measures, in the relationship between IDS prosody and linguistic development. A larger number of studies would also help to test if IDS prosody is more relevant for pre-linguistic competences when infants are younger, when the affective role of IDS may be prevalent by promoting infant engagement (Burnham, Kitamura, & Vollmer-Conna, 2002), than for linguistic competences later, as hypothesized by other scholars (Fernald, 1989; Stern et al., 1983). Lastly, as all the studies exploring the effect of prototypical IDS on infant pre-linguistic outcomes measured only the F0 contours properties of IDS, more studies are needed to see if this association also applies to other IDS prosodic features.

Our last hypothesis focused on the similarities between emotional prosody and IDS prosody that led the authors to assume that parents adjust the prosodic features of the input in order to communicate positive emotions to the child (Trainor et al., 2000). This positive affective communication should consequently stimulate a greater production of positive affect in infants and children. Only two studies explored this association, not sufficient to conduct a meta-analysis. Stern et al. (1982) found an association between bell-sinusoidal maternal production (productions with more varied F0 contours) and infant smiles; and Phillips (1995) found that infants of both African-American and European-American mothers tend to show more positive affect when IDS was characterized by wider and faster prosodic excursions of the voice. These findings seem to corroborate the hypothesis, but further research is needed.

Importantly, the lack of an effect of infant outcome as a moderator demonstrated that IDS prosody is equally associated with attentional, communicative and affective outcomes, confirming the multidimensional roles of IDS prosody (Saint-Georges et al., 2013; Soderstrom, 2007).

Moderators

Consistent with our expectations, the association of IDS prosody with infant outcomes was stronger for younger infants than for older children and toddlers. It has previously been hypothesized that in the pre-verbal stage the prosody of the voice is more salient for infants than the linguistic aspects and this may explain the stronger effect it has on improving the outcomes of infants at this age (Stern et al., 1983). At the end of the first year, on the other hand, children start to rely less on prosodic properties, as has been shown by studies on infant and child preferences at different ages (Hayashi et al., 2001; Kitamura & Notley, 2009). This may be due to the growing importance of structural aspects of speech, such as phonetic and phonotactic features, in driving infant attention as a function of the specific language experience, according to the main role that the structural aspects of speech have in language comprehension and production development (Song, Demuth, & Morgan, 2010; Zangl & Mills, 2007).

We found a stronger relationship between prototypical IDS prosody and infant outcomes in non-English samples. However, the non-English studies category was composed of both Asiatic and Romance languages that have very different acoustic and prosodic features and can barely be considered comparable. Similarly, the English category included one British English study collapsed with the American English studies, two very different cultural contexts. Moreover, four out of the six non-English studies used F0 contours as the predictor, and this predictor also showed the strongest association with infant outcomes. The effect of the linguistic context could therefore be a spurious effect, more determined by the type of predictor than by the language of the country where the study was conducted.

Consistent with the decision to include only studies that used natural spontaneous parental IDS in the meta-analyses, we found that the prototypical IDS prosody during free-play parent-infant interaction has a stronger association with infant outcomes than IDS prosody measured during semi-structured interactions. Apparently, it is the natural parental speech that makes the difference for infants, and experimental studies that provide specific directions about what to say and in which circumstances risk obscuring the positive effect of IDS prosody. This result further emphasizes the importance of measuring parental input in natural observational studies (Knoll & Costall, 2015).

A very interesting finding is represented by the evidence for the main role of F0 contours and F0 variability compared to the F0 mean, a variable that was not significantly associated with infant outcomes. This confirmed the hypothesis by Fernald and Kuhl (1987) that, between all the prosodic characteristics of IDS, the more salient aspects of IDS are related to the modulation of the voice, and not simply to average pitch levels. Indeed, it is the F0 variability of the voice, not the F0 mean, that has been found to be the main factor that differentiates the prototypical IDS of mothers with the IDS of depressed mothers (Kaplan et al., 2001). Our finding may thus explain why infants of depressed mothers show developmental impairments in attentional (Kaplan et al., 2002), affective (Murray, Marwick, & Arteche, 2010) and cognitive abilities (Murray, Kempton, Woolgar, & Hooper, 1993). As prosody can be measured with many F0-related variables, causing confusion between studies and making many findings difficult to compare, this result provides an interesting direction for future studies on the main variables that are more interesting to focus on when exploring the effects of parental IDS prosody on infant outcomes. Such a focused approach would facilitate the interpretation of the IDS-outcome associations.

Due to the insufficient number of studies we could not investigate the effects of all of the moderator variables we were interested in nor the effects of the moderators within each infant outcome category. This leaves many questions open and further underlines the need for more studies. For instance, testing the moderator effect of the type of predictor separately on each infant outcome would have allowed us to explore if some prototypical IDS prosodic features were more or less strongly associated with the different outcomes. Not only were the data insufficient to make these comparisons but the different F0 patterns were also not uniformly represented in each outcome. For example, all studies exploring the association of IDS prosody with pre-linguistic abilities used F0 contours as the prosodic variable. Further studies should test if the high and consistent association between IDS prosody and pre-linguistic infant outcomes is present also when measuring other prosodic patterns (as F0 variability) and whether and to what extent other variables could be more or less strongly associated with each infant outcome.

Limitations and directions for future research

In interpreting our results, some attention should be focused on the methodological issues relevant to the studies included in our meta-analyses. Our meta-analyses showed that prototypical IDS prosody is associated with better infant outcomes. However, the meaning of prototypical IDS prosody is not equivocal. It is well known that the prosody of IDS is exaggerated in comparison with ADS, but high vocal prosodic values could be associated not only with positive emotions but also with high negative arousal emotions, such as anger and fear, which are expressed with very high F0 mean variability and wide F0 variability (Juslin & Laukka, 2001; Scherer, 2003). Therefore, speaking to infants with a prosodically exaggerated voice may also represent an intrusive and negative parental behavior.

Additionally, some prosodic features that are considered by most authors to be positive and prototypical, such as falling F0 final contours (Gratier & Devouche, 2011; Masataka, 1992a; Niwano & Sugai, 2002a), may be considered negative and an indication of monotonous speech if they represent the majority of maternal productions, as was in the Murray et al. (2010) study on depressed mothers.

On the other hand, our finding may be interpreted as showing that prototypical IDS is better than low modulated IDS in enhancing infant outcomes. In addition, this is in line with the idea that low modulated prosodic features, previously reported in IDS of depressed mothers (see for example Marwick & Murray, 2009) and mothers with a highly controlling childrearing experience (Spinelli et al., 2016), can be interpreted as indicating a less affective and positive speech due to mother's impairment in adjusting and attuning with infant needs. However, it is well known that these mothers demonstrated a general under-stimulating interaction style that is composed by many interactive modalities other than the voice and that may contribute to affecting infant outcomes. The effect on infant outcome may therefore be due to the combination of these modalities, some of which may play a more or less important role in interaction with others.

To our knowledge, there are no studies that have explored the effect of IDS prosody taking into consideration or controlling for other parental variables, such as maternal involvement, intrusiveness and expression of affect. This represents an important gap in the literature on mother-infant communication and leaves many questions open. Some associations have been found; for example, Kaplan et al. (2009) found that highly hostile mothers used a lower F0 variability and that maternal sensitivity predicted infant associative learning (attentional competence). However, they did not explore if the IDS prosody of mothers with different sensitivity levels influenced infant competences in a different way.

Thus, the beneficial effects of prototypical IDS have to be considered while also taking into account that IDS is part of a multimodal communicative modality composed of facial expressions, gestures, touch, etc., which together form the complexity of the parent-infant interaction (Saint-Georges et al., 2013). Future studies should explore the effects of IDS on infant development without ignoring its interactions with the other aspects of the parental communication system.

Another critical aspect of our work was that we decided to consider the absence of flat F0 contours prototypical IDS prosody, because IDS is expected to be more melodic and more characterized by variations in F0 contours, while flat productions are more present in ADS (Knoll & Costall, 2015). Nonetheless, there is no unanimous way to characterize F0 contours, and the studies used different ways to define the limit at which a production is considered flat making the results less comparable (i.e., for Gratier & Devouche, 2011, it was flat if F0 max − F0 min < 50 Hz, for Stern et al., 1982, if F0 max − F0 min < 128 Hz). Similarly, there is not a clear and agreed-upon rule about which contours are relevant and which ones are not. The use of a shared coding system with defined cut-off at which one F0 contour has to be considered flat, with common definitions of the different F0 contours would be helpful for solving this issue.

Our literature research yielded a large number of studies. Of these, 199 explored IDS prosody. However, only 15 of these studies actually reported on naturally occurring prosody in relation to infant outcomes and were thus suitable for the meta-analyses. In light of how extensively IDS has been studied over the last 30 years we expected to find more relevant studies. The list of excluded studies (see Fig. 1) showed that, except for the expected large number of works that investigated linguistic aspects of IDS, the majority of the studies on IDS prosody explored differences in prosodic characteristics of IDS, comparing it with ADS or within different populations (i.e., depressed versus non-depressed mothers), and those addressing IDS in relation to infant outcomes did so using prevalently artificial voices and experimental situations. We contend that because IDS is part of the parent-infant interactive and communicative process, its effects should be tested in a naturalistic observational context. Furthermore, intervention studies with randomized control trial designs can elucidate the potential causal effects of IDS prosody in enhancing infant linguistic, attentional, and social development.

Conclusions

The current set of meta-analyses provides evidence for the role of IDS in child development. When mothers and fathers talk to their infants with prosodic exaggerated voices, they facilitate infants attention and foster their communicative skills. Importantly, the meta-analyses also highlighted several crucial limitations in the existing body of literature, which evidenced a lack of empirical papers exploring IDS prosody in relation to infant outcomes using natural observations, particularly such studies addressing infant positive affect. Furthermore, there is a lack of multivariate explorations of potentially confounding factors in the associations between IDS prosody and infant outcomes, which leaves open the possibility that these are spurious relations. Thus, our meta-analytic study shows that IDS is certainly a worthwhile phenomenon to study to uncover mechanisms that stimulate infant development in different domains of functioning, not only given the significant associations we found but also because so many questions regarding IDS and infant development are left unanswered due to a lack of studies. For this field to move forward and become integrated with the wider infancy literature, it would also be crucial to examine the interplay between the quality of IDS prosody and other aspects of parental communicative and caregiving competences. Relevant parental skills include vocabulary, empathy, and sensitive responsiveness, and each could provide avenues for interventions that may also be relevant for the enhancement of IDS. In conclusion, the effects of IDS on infant development represent a multidimensional topic that requires a unified contribution from scholars from different fields to fully understand its contextual determinants and influential mechanisms.

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