Infants' preference for speech is stable across the first year of life: Meta-analytic evidence

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Our data is fully available in the corresponding OSF repository: http://tidy.ws/bqjc4U

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Abstract

Previous work suggested that humans' sophisticated speech perception abilities stem from an early capacity to pay attention to speech in the auditory environment. Previous studies have therefore tested if infants prefer speech to other sounds at a variety of ages, but provided contrasted results. In this paper, we make the hypothesis that speech is initially encoded similarly to other natural or vocal sounds, and that infants tune to speech during the first year of life as they acquire their native language. To test this hypothesis, we conducted a meta-analysis of experiments testing speech preference in infants, sorting experiments by whether they used native or foreign speech on the one hand, and vocal or non-vocal, natural or artificial sound on the other hand. Synthesizing data from 775 infants across 38 experiments, we found a medium effect size, confirming at the scale of the literature that infants reliably prefer speech over other sounds. However, this preference was not significantly moderated by the language used, nor vocal quality, or naturalness of the competitor. Strinkingly, we found no effect of age: infants showed the same strength of preference throughout the first year of life. Speech therefore appears to be preferred from birth, even to other natural or vocal sounds. These results suggest that speech is processed in a specific way by an innate dedicated system, dictinct from other sounds processing.

Keywords: Meta-analysis, Infants, Speech preference, Conspecific detection, Developmental tuning

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Significance

- Infants reliably prefer natural speech over other types of sounds
- Preference is stable from birth to the end of the first year of life
- Speech is preferred over both artificial and other natural sounds
- Speech is preferred over both non-vocal and other vocal sounds
- The language used for the speech sounds made no significant difference

Introduction

Humans acquire their communication skills from early infancy, with specialized speech perception abilities well before they produce their first word. These perceptual capacities manifest in an early preference for speech over other types of sound (Ecklund-Flores & Turkewitz, 1996; Vouloumanos, Hauser, Werker, & Martin, 2010; Vouloumanos & Werker, 2007). However, how this preference develops is debated: some studies show a broad preference for speech and other related sounds (e.g. monkey calls) at birth that narrows to speech in the first months of life (Vouloumanos et al., 2010), whereas others have found a preference for speech from birth (Ecklund-Flores & Turkewitz, 1996). These contrastive results raise questions about the mechanisms that support speech perception in infants: does the auditory system process all sounds similarly, or are there dedicated mechanisms for speech? Does the auditory system have properties that match particularly well with the acoustics of speech, as well as sounds with close acoustical properties (e.g. other natural or vocal sounds)? Or does the auditory system encode all sounds equally well, the preference coming from high-level linguistic processing (i.e. specific to the language learned)? Drawing a developmental curve is crucial to tackle these questions: if speech is processed in a specific way as compared to other sounds, then from birth, infants should show a preference for speech as compared to other sounds. If speech benefits from properties that also apply to other sounds, then infants should first have a general preference for acoustically close sounds that match these properties (among them speech), and then gradually tune to speech as they are exposed to speech. Finally, if speech processing relies on the same auditory-general mechanisms as any other sound, then speech preference should emerge during the first year of life with language acquisition and depend on the language learned.

Here, to test these hypotheses, we synthesize the available empirical data on infants' preferences for speech over non-speech sounds from birth to the end of the first year of life, and use a meta-analytic approach to test if the factors cited above explain the variability found in the literature.

A first possibility to explain infants' preference for speech is that the auditory system is tailored for the acoustic properties of speech, as well as sounds with close acoustical properties (e.g. other natural or vocal sounds). This idea has been pervasive in the field of auditory neuroscience, relying on the hypothesis that the auditory system has been shaped by evolutionary pressure to efficiently encode ecologically important sounds, typically environmental sounds signalling a threat, or conspecific vocalizations, and more generally natural sounds such as wind, rain, or the sound of a river, as well as those produced by biological systems, such as heart beats, step sounds, or animal vocalizations, and speech. Following this hypothesis, numerous studies have shown that natural sounds are processed more efficiently by the auditory system, from the cochlea (Smith & Lewicki, 2006) to the auditory cortex (see Mizrahi, Shalev, & Nelken, 2014 for a review). If this mechanism (partially) explains infants' speech preference, then we should observe an initial preference at birth for speech over artificial competitors, but no preference at birth when contrasting speech against another natural sounds. Infants would then gradually tune to speech as they acquire language during the first year of life.

A second possibility is that auditory coding is tailored to vocal sounds more specifically.

Vocal sounds have acoustic signatures, since they are characterized by modulations introduced by the vocal tract, with harmonically related energy peaks. Animal vocalizations (among them speech) are characterized by low temporal and spectral modulations, therefore form a separate acoustic category within natural sounds (Singh & Theunissen, 2003). As a result, it is possible that infants initially have a broad category of vocal sounds, including the vocalizations of other species that also use oral communication (e.g. other primates and birds), and later tune to speech as they acquire their native language and build specialized linguistic abilities. This view is supported by studies that found that newborns showed no preference for speech compared to monkey calls, but three month-olds did (Vouloumanos et al., 2010). If this mechanism explains at least partially speech preferences, then we should observe at birth a preference for speech over non-vocal competitors, but no preference when contrasting speech against other vocal sounds. This initial preference for vocal sounds would then tune to speech specifically during the first year of life as infants acquire language.

A third possibility would be that the brain encodes all sounds equally well. In this case, speech would not be preferred to any other sound at birth, natural or artificial, vocal or not. Speech preference would solely reflect top-downs influences of language acquisition. Any preference would emerge during the first year of life, and speech preference would be restricted to the infant's native language. Previous results about language preference make this explanation plausible: Newborns prefer their native speech as compared to prosodically distinct foreign speech (e.g., Mehler et al., 1988; Moon, Cooper, & Fifer, 1993). If this mechanism is at play in speech preference, infants should show no preference at all at birth, and after a few months a stronger preference for speech over other sounds when tested with their native language, and a weaker or no preference when tested with a foreign language.

Finally, if there are dedicated perceptual mechanisms for speech, then speech should be preferred to any other sounds from birth, even to other vocal or natural sounds. Previous studies provided evidence for this hypothesis: newborns respond more to natural speech than to heartbeat, high-pass or band-ass filtered speech (Ecklund-Flores & Turkewitz, 1996). Newborn and one-month-old infants even prefer natural to low-pass filtered speech, that mimics what's heard in the womb [Ecklund-Flores and Turkewitz (1996);cooper_developmental_1994]. If perceptual mechanisms specific to speech are at play, then we should observe a preference for speech to any other sound from birth, at the scale of the literature. This preference should strengthen with language acquisition, and become stronger during the first year of life when infants are tested with their native language.

A meta-analytic approach

In sum, previous results on infants' preference for speech are broadly compatible with a preference for natural over artificial, vocal over non-vocal, and/or familiar over unfamiliar sounds, potentially interacting with infants' age. In this paper, we seek to directly test these potential mechanisms by employing a meta-analytic approach.

A meta-analysis can integrate data from experiments that vary in their methodology, as well as test the effect of factors of theoretical importance, by redescribing the stimuli used as a function of those factors. For instance, a study measuring preference for native speech over white noise provides data on a natural versus artificial contrast, as well as a vocal versus non-vocal contrast.

Also, we can draw a developmental timeline across the age range covered by the literature, beyond age groups tested within papers. This is particularly useful in developmental psychology, which relies on age-related differences that need to be tested statistically (Gelman & Stern, 2006). Meta-analyses offer a powerful statistical approach to directly test for interactions with age across the whole age-range covered by the literature. To give an example from a previous developmental meta-analysis, it had been proposed that infants' preference for novel or familiar items related to infants' age such that, all things equal, younger infants showed familiarity preferences whereas older infants exhibited novelty preferences (Hunter & Ames, 1988). However, stable familiarity preferences across the first two years have been found for word segmentation in natural speech (Bergmann & Cristia, 2016); and a stable novelty effect ensues for artificial grammars implemented in synthesized speech, whereas those implemented in natural speech led to stable familiarity preferences (Black & Bergmann, 2017). Meta-analyses are therefore important to statistically and systematically test the theoretical predictions proposed in qualitative reviews, and show subtle effects that are difficult to see when reading the literature with a human eye.

Single experiments tell us about what a specific group of participants, presented with a specific set of stimuli, at a specific point in time has done. Meta-analyses are the following step because they provide a principled statistical approach to integrate those individual and specific results into a larger picture. By aggregating the numerous individual studies of a literature, meta-analyses gain statistical power. As a result, meta-analyses can reveal small effects that are difficult to show in individual experiments. By integrating data across different laboratories, they provide evidence for the generalizability of effects, and facilitate comparisons between experimental results.

Finally, meta-analyses offer tools to detect publication bias in the literature. By aggregating all the available evidence for a phenomenon, we can see if the distribution of effect sizes has an unexpected shape, typically with an excess of positive results due to the difficulty to publish null or negative results. We can further integrate this information, and derive a new estimate of the overall effect size.

The present study

Meta-analyses provide a unique vantage point on a body of work as a whole. We therefore first check for how strong infants' preference for speech over other types of sounds is according to the public body of literature. We additionally assess this body of data for evidence of publication bias.

We then turn to our key interest, namely shedding light on the potential mechanisms underlying infants' speech preferences. Meta-regressions assess whether the proposed mechanisms of naturalness, vocal quality, and familiarity drive this preference, and how the preference develops over the first year of life. Assuming all three mechanisms are at play, and further assuming that the definition of the preferred stimulus narrows with age, we predicted that infants will show (see Figure 2):

1. a greater preference for speech over other natural sounds as a function of age, but a preference for speech over artificial sounds that is stable over development;
2. a greater preference for speech over other vocal sounds as a function of age, but a stable preference for speech over non-vocal sounds over development;
3. a greater preference for native speech over non-speech as a function of age, but a smaller preference for foreign speech over non-speech with age.

Methods

This meta-analysis was carried out following PRISMA recommendations (Moher, Liberati, Tetzlaff, Altman, & Group, 2009). In addition, we provide information on all steps (including PRISMA checklist, data, and code) for full transparency and accountability via online supplementary materials; https://osf.io/4stz9/?view_only=d0696591ebf34bfc8430f848cd945ca8.

Literature search

We composed the initial list of papers with suggestions by experts (authors of this work); one google scholar search (*("speech preference" OR "own-species vocalization") AND* *infant* - *"infant-directed"*), the same search in PubMed and PsycInfo (last searched on 2019-09-24); and a google alert. We also inspected the reference lists of all included papers. Finally, we emailed a major mailing list to ask for missing data. We received two replies, one of which revealed a formerly undiscovered published study, and communicated unpublished data (Santolin, Zettersten, & Saffran, 2020).

Inclusion criteria

After a first screening based on titles and abstracts using more liberal inclusion criteria, we decided on final inclusion based on full paper reading. We included experiments that tested human infants from birth to one year of age, and contrasted speech sounds with any other type of sound, measuring behavioral preferences to the sounds (e.g., looking times). If a paper reported results from neurotypical and at-risk infants, we included only the data from the neurotypical group.

Given our key interest in the preference for speech over other sounds, we excluded studies that contrasted two different speech sounds (e.g., foreign vs. native language, or adult vs. child-directed speech, or mother vs. stranger's voice); or two different non-speech sounds (e.g., backward speech vs. animal vocalizations). In addition, we excluded experiments where the contrast presented to the infants could not be coded according to our three mechanistic explanations. This meant the exclusion of experiments where speech was presented in the mother's voice (which thus confounds between speech and individual voice recognition for our familiarity factor). Finally, we excluded neuroimaging experiments to avoid mixing results from different brain regions with different response profiles. We included published (i.e., journal articles) as well as unpublished works (i.e., doctoral dissertations) as long as sufficient information was provided.

A PRISMA flow chart summarizes the literature review and selection process (Figure

3). The full list of the papers that were inspected together with final inclusion decisions are available in a decision spreadsheet (see the online supplementary materials; https://osf.io/4stz9/?view_only=d0696591ebf34bfc8430f848cd945ca8).

Coding

Data were coded by the first author. In addition, 20% of the papers were randomly selected to be coded by the last author independently, with disagreements resolved by discussion. There were 10 disagreements out of a total of 260 fields filled in, and they were indicative of the coders not following the codebook, which led to a revision of all data in four variables.

The critical variables for our purpose are key stimuli characteristics, infant age, and testing method (central fixation, high amplitude sucking, head-turn preference procedure). As for key stimuli characteristics, we coded familiarity, naturalness, and vocal quality, as follows.

For **naturalness**, the competitor sound was coded as natural if it was produced by a biological organism without any further acoustic manipulation. Natural competitors included animal calls, environmental sounds (e.g. wind or water sounds), heartbeat, bird song, non-speech vocalizations (e.g. laughter or coughs). If the authors applied acoustic manipulations, the competitor was coded as artificial. Artificial competitors included sine-wave speech, filtered speech[1], white noise, instrumental music, and speech with altered rhythmic structure. The only exception was for newborn experiments presenting low-pass filtered speech mimicking the filtering applied by the womb. Given the recency of the

[1] In the case of filtered speech, the modulations introduced by the vocal tract are still present at the retained frequencies, and formant transitions are consistent with vocal production constraints. For this reason, filtered speech can be considered as vocal but not natural. Because the womb acts as a low-pass filter, newborn infants are familiar with low-pass filtered speech, but this familiarity fades after birth.

intra-uterine environment to newborns (about 2 days), we coded these as natural.

For **vocal quality**, the competitor sound was considered as vocal if it was produced by an animal vocal tract (human or not), either original or modified. Vocal competitors included non-speech vocalizations, animal calls, bird songs, and filtered speech. Non-vocal competitors included backward speech (that has abrupt closures that cannot be produced by the vocal tract), white-noise, environmental sounds, instrumental music, heartbeat, and sine-wave speech (that lacks the harmonic structure introduced by the natural resonance of the vocal tract).

For **familiarity**, we considered the language in which the speech sounds were recorded (native or foreign).

We coded all the statistical information reported in the included papers. If reported, we coded the mean score and the standard deviation for speech, and the other sound separately. When infant-level data was provided, we recomputed the respective mean scores and standard deviations based on the reported individual scores. If reported, we also coded the t-statistic between the two sound conditions, or an F-statistic provided this was a two-way comparison. If effect sizes were directly reported as a Cohen's d or a Hedges' g, we also coded this.

Effect sizes

Once the data were coded, we extracted effect sizes, along with their respective variance. Effect sizes were standardized differences (Cohen's d) between response to speech vs. the competitor. If effect sizes were not directly reported in the papers, we computed them using the respective means and SDs (Lipsey & Wilson, 2001), or a t- or F-statistic (Dunlap, Cortina, Vaslow, & Burke, 1996). As our effect sizes came from within-subject comparisons (e.g., looking time of the same infant during speech and monkey calls), we needed to take into account the correlation between the two measurements in effect sizes and effect size variances computations. We computed this correlation based on the t-statistic, the respective means, and SDs (Lipsey & Wilson, 2001) if they were all reported; or imputed this correlation randomly if not. We finally calculated the variance of each effect size (Lipsey & Wilson, 2001). Cohen's d were transformed to Hedges' g by multiplying d by a correction for small sample sizes based on the degree of freedom (Borenstein, Hedges, Higgins, & Rothstein, 2011).

We did not center age because our hypotheses included a developmental progression from birth to the end of the first year of life. We were therefore interested in the intercept at age 0 (i.e., birth).

Analyses use the R (R Core Team, 2018) package Robumeta (Hedges, Tipton, & Johnson, 2010), which allows us to fit meta-analytic regressions that take into account the correlated structure of the data when repeated measures are obtained from the same infant groups within papers.

Results

Database description

We found a total of 18 publications (labeled with an asterisk in the reference list) reporting 38 experiments, for a total of 775 infants, and 54 (not mutually independent) effect sizes, see Figure 6. 15 papers have been submitted to or published in peer-reviewed journals (Colombo & Bundy, 1981; Cooper & Aslin, 1994; Curtin & Vouloumanos, 2013; Ecklund-Flores & Turkewitz, 1996; Santolin, Russo, Calignano, Saffran, & Valenza, 2019; Segal & Kishon-Rabin, 2011; Shultz & Vouloumanos, 2010; Sorcinelli, Ference, Curtin, & Vouloumanos, 2019; Spence & DeCasper, 1987; Vanden Bosch der Nederlanden & Vouloumanos, 2020; Vouloumanos & Curtin, 2014; Vouloumanos, Druhen, Hauser, &

Huizink, 2009; Vouloumanos et al., 2010, 2010; Vouloumanos & Werker, 2004, 2007; Yamashiro, Curtin, & Vouloumanos, 2019). The remaining 1 publication contributing 8 effect size was a thesis (Ference, 2018). 6 more effect sizes were contributed by authors of unpublished work (Santolin et al., 2020).

Experiments tended to have small sample sizes, with a median N of 16 children (Range = [60, 4], M = 19.83), which is close to the field standard (Bergmann et al., 2018), but much lower than current recommendations (Oakes, 2017). Infants ranged from 0 to 12 months (1.50 to 380.50 days), although the majority were under 6 months of age (63.16% of the experiments). Individual samples comprised 46% of female participants on average. Infants were native of 6 different languages across the whole database (English, French, Russian, Yiddish, Hebrew, Italian). Experiments were performed in 10 different laboratories from 4 different countries (United States, Canada, Israel, Italy). 3 experimental methods were used: 30 experiments used Central Fixation (CF) (also called sequential looking preference procedure) (Colombo & Bundy, 1981; Cooper & Aslin, 1994; Curtin & Vouloumanos, 2013; Ference, 2018; Santolin et al., 2019, 2020; Segal & Kishon-Rabin, 2011; Shultz & Vouloumanos, 2010; Sorcinelli et al., 2019; Vanden Bosch der Nederlanden & Vouloumanos, 2020; Vouloumanos & Curtin, 2014; Vouloumanos et al., 2009, 2010; Vouloumanos & Werker, 2004; Yamashiro et al., 2019); 3 used High-Amplitude Sucking (HAS) (Spence & DeCasper, 1987; Vouloumanos et al., 2010; Vouloumanos & Werker, 2007); and 5 used Head-turn Preference Procedure (HPP) (Ecklund-Flores & Turkewitz, 1996). Trial length was fixed in 8 experiments, and infant-controlled in 29 experiments.

Speech sounds were spoken by a female in 36 out of 38 experiments, with an infant-directed prosody in 21 out of the 38 experiments. Speech was presented in isolated segments (i.e. words or syllables) in 5 experiments, and full sentences or passages in 19 experiments. Speech stimuli were recorded in the infant native language in 63.16% of the experiments. Strikingly, experiments using the infants' native language tested infants from 0 to 12 months of age, whereas experiments using a foreign language only tested infants from 3 to 9 months of age (see Figure 10). The competitor sound was vocal in 47.37% of the experiments. The competitor sound was natural 47.37% of the experiments. The stimuli characteristics are summarized on Figures 4 and 5.

Average effect size

We integrated all effect sizes in a meta-analytic regression without any moderator, and found an average effect size g of 0.35 (SE = 0.06, CI = [0.22 , 0.48]) (Table 1, and Figure 6, diamond), corresponding to a medium effect size. Heterogeneity among effect sizes was estimated at $\tau^2 = 0.13$ ($I^2 = 77.08\%$), which was significant ($Q = 202.15$, $p < 0.01$) despite the removal of outliers before running the model. This strongly suggest differences across experiments, and invites analyses using moderators.

Publication bias

We checked for the presence of a potential publication bias in the body of literature by studying the relationship between standard errors of effect sizes as a function of Hedges' g (see funnel plot in Figure 7)[2]. A regression test on these data was significant ($z = 7.83$, $p < 0.01$), as was the Kendall's tau rank correlation test for funnel plot asymmetry (Kendall's tau = 0.49, $p < 0.01$), consistent with a publication bias in the literature.

To check whether this bias fully explains infants' speech preference, we symmetrized the funnel plot with the "trim and fill" method (Duval & Tweedie, 2000). To symmetrize the

[2] If the literature is not biased, effect sizes should be evenly distributed around the mean effect size, with increasing standard error as they go away from the mean effect size (both in the positive and negative directions, white triangle in the funnel plot). This is reflected by a symmetrical funnel plot, with no linear relationship between effect sizes and standard errors.

funnel plot, 12 (SE = 4.71) missing experiments were needed on the left side of the plot. The corrected effect size was estimated at 0.22 (SE = 0.07) after filling in the 12 missing experiments, which is still significantly different from zero. Thus, even correcting for a potential publication bias, we still find statistical evidence for infants' preferring speech over competitors.

Moderator analyses

We then tested if heterogeneity could be accounted for by the mechanistic explanations described in our introduction. Following our hypotheses, we fit a meta-analytic model with the following moderators:

- mean age of children;
- naturalness of the competitor sound (coded as yes if it was natural and no otherwise);
- vocal quality of the competitor sound (coded as yes if it was vocal and no otherwise);
- familiarity with the language used (native or foreign).

These moderators were specified without interactions to avoid overfitting.

None of the moderators was significant (see Table 2).

We also tested each of our three hypotheses by three separate models for each moderator and its interaction with age. There was no significant main effect or interaction (see Figures 8, 9, and 10 ; and Tables 3, 4, and 5).

Discussion

Our meta-analysis synthesizes the available literature on infants' preference for speech sounds. When all experiments were considered together with no moderators, we found a sizable intercept (g=0.35, g=0.22 when taking the publication bias into account), which was still significant after correcting for the publication bias. Our meta-analysis shows that this preferential processing of speech sounds is observable from birth on. We had hypothesized age to play a major role, because it may correlate with a reshaping of the category definition for speech itself. Indeed, experiments comparing the preference for human speech against human non-speech as well as animal vocalizations more generally (McDonald et al., 2019; Vouloumanos et al., 2010) often discuss age-related differences in categorization of these sounds. Surprisingly, age did not significantly moderate the overall preference for speech, as shown by the null estimate of this moderator (Table 2), nor did it interacted with any other moderators (Table 5, 3, and 4). This result was replicated in a separate model for age only, which showed a significant intercept, similar to the intercept found in the meta-regression with no moderator (Supplementary results S1). Crucially, age was not centered. This intercept therefore provides an estimate of the effect size at age 0, i.e. at birth. Moreover, the scatterplot of effect sizes as a function of age reveals clearly no change with age even when plotted without other moderators (Supplementary figure S2). This null effect of age, combined with the sizable intercept, confirms that infants reliably prefer speech over other types of sounds from birth.

The significant heterogeneity we found among the literature suggests that underlying factors modulate this effect. We had predicted infants' speech preference to be larger when the competitor was an artificial sound than when it was a natural one; when the competitor was non-vocal; and when the speech was in the infants' native language. In fact, we were unable to disprove the null hypothesis of no difference for all three factors. Our meta-analysis revealed uneven distributions of experiments across age and stimulus dimensions, and that the distribution of effect sizes in the literature is consistent with publication bias. It is possible that the effect of our three moderators would emerge if the publication biased was solved. However, by aggregating the numerous individual studies of a literature, meta-analyses gain statistical power as compared to individual experiments. As such, meta-analytic results have more cumulative explanatory value than single studies. Moreover, distributions of effect sizes for experiments varying along the three dimensions widely overlap. Our findings therefore suggest that none of these parameters fully explain infants' preference for speech sounds. Our dataset can be community-augmented, and we invite researchers investigating this phenomenon to complement it with any data they would have (https://osf.io/4stz9/?view_only=d0696591ebf34bfc8430f848cd945ca8), whatever the results and publication status, to solve the publication bias and confirm our findings.

This clearly points to the value of meta-analysis: to take stock of a field and inspire follow-up studies. In particular, future experiments should test infants from 1 to 3 months, and older than 9 months. Language production gains in complexity at about 9 months (Oller, Eilers, Neal, & Schwartz, 1999), which could affect infants' speech preference. Experiments using natural vocal stimuli as competitor, and foreign speech as target, would contribute to fill in the gap in the litterature that our meta-analysis revealed.

Our results suggest that, from birth on, infants show a preference for speech, which cannot be accounted by the three explanations tested here: naturalness, vocalness, or familiarity with the native language. It is possible that infants prefer speech because of its complex acoustic structure and fast transitions (Rosen & Iverson, 2007). Spectral or temporal modulations taken separately are not sufficient to elicit neural responses similar to the ones elicited by speech (Minagawa-Kawai, Cristià, Vendelin, Cabrol, & Dupoux, 2011). However, speech is characterized by joint spectrotemporal modulations at specific rates (Singh & Theunissen, 2003). It is possible that infants are sensitive to this specific spectro-temporal structure (though see Norman-Haignere & McDermott, 2018 showing that they only explain neural responses in primary auditory cortex, suggesting that other factors contribute to the behavioral response in later processing stages). Testing this explanation would require to compute the modulation spectra of the actual stimuli used in the experiments. Thus, we recommend interested researchers to deposit their stimuli in a public archive such as the Open Science Framework (Foster & Deardorff, 2017).

A capacity to preferentially listen to speech sounds from birth suggests that infants are born with the capacity to recognize their conspecifics' communication signals. This parallels what has been proposed for faces: Infants are born with the capacity to orient their attention toward them, even without any prior exposure to faces (Morton & Johnson, 1991; Turati, 2004). This would stem from basic perceptual abilities present at birth, namely that the visual system would be tuned to a spatial structure that correspond to those of faces (Morton & Johnson, 1991; Turati, 2004). As newborns have never been exposed to such visual stimuli before, it would reflect general properties (i.e. filters) of the visual system. Similarly, the auditory system could be tuned to a spectro-temporal structure that speech presents. The combination of this non-specific bias with the systematic variations of the auditory environment (i.e. the fact that an acoustical structure characterizes speech but not other sounds of the environment) would result in preferential responses to speech from birth. However, contrary to faces, fetuses are exposed to speech as low-pass filtered by the womb throughout the last trimester of gestation (Lecanuet & Granier-Deferre, 1993; Querleu, Renard, Versyp, Paris-Delrue, & Crèpin, 1988). It is therefore possible that prenatal experience with low-pass filtered speech helps infants to form a representation of speech, by tuning the response properties of the auditory system to speech. The fact that familiarity with the language used in the experiment did not modulate infants' preference suggests that this effect is not triggered by familiarity with the sounds of the native language. Infants would therefore form a representation that is specific enough to discriminate speech from other natural or vocal sounds, but general enough to be independent of the language spoken.

The human species is a gregarious one. Detecting speech signals allows to integrate it with other sensory percepts, such as faces, to form multisensory representations of conspecifics. Five-months old infants were capable to match human faces to speech, as well as monkey faces to monkey vocalizations (Vouloumanos et al., 2009). This provides evidence that human infants make correspondences between faces and vocalizations, and that they distinguish their conspecifics from other species. This lays the groundwork for social cognition. Finally, the preference itself may also be a meaningful index of processing that can be used to identify children at risk (Sorcinelli et al., 2019). Understanding this phenomenon is therefore crucial for both theoretical and clinical advances.

Ultimately, preferential processing of speech may support higher level cognitive tasks. Identifying speech signals and paying attention to them would allow infants to form complex representations of the sensory world, that they can manipulate cognitively. Consistently, infants could categorize visual stimuli (i.e., associate a label to a category of objects) when they were associated to speech, but not pure tones or backward speech (Ferry, Hespos, & Waxman, 2010, 2013; Fulkerson & Waxman, 2007). Interestingly, infants categorized visual stimuli when presented with speech, melodies, monkey (Fulkerson & Haaf, 2003), or lemur vocalizations (Ferry et al., 2013). These results support the idea that infants' cognition is set up to respond to, and manipulate complex sounds (i.e. modulated in time and frequency), especially those of critical ecological importance such as communicative vocalizations.

With a sample size of 775 infants, covering the wide age range of all individual experiments available, our meta-analysis provides evidence for a specialized processing of speech from birth. This parallels infants' attention to faces from birth (Morton & Johnson, 1991; Turati, 2004), and suggests that human cognition is set up to pay attention to signals from conspecifics specifically. Such systems may be the precursors of humans' advanced social cognition skills.

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Table 1

Statistical results of meta-regression without any moderator.

	estimate	SE	t	confidence interval
average effect size	0.35	0.06	5.52	0.22 - 0.48

Table 2

Statistical results of meta-regression with all moderators. The intercept corresponds to the effect size when the competitor is natural, and vocal, and speech is in a foreign language, at age 0. The moderator estimates correspond to changes in the intercept when the target stimuli are in the native language (familiarity); the competitor is artificial (naturalness); and the competitor is non-vocal (vocal quality).

	estimate	SE	t	confidence interval
intercept	0.23	0.14	1.63	-0.07 - 0.53
naturalness	0.26	0.12	2.22	0.01 - 0.51
vocal quality	-0.09	0.15	-0.61	-0.41 - 0.23
language	0.00	0.12	0.03	-0.25 - 0.26
age	0.00	0.00	0.41	0 - 0

Table 3

Statistical results of meta-regression with naturalness and its interaction with age as moderators. The intercept corresponds to the effect size when the competitor is natural, at age 0. The moderator estimates correspond to changes in the intercept when the competitor is artificial (naturalness).

	estimate	SE	t	confidence interval
intercept	0.33	0.22	1.50	-0.21 - 0.87
naturalness	0.05	0.24	0.19	-0.47 - 0.57
naturalness*age	0.00	0.00	0.71	0 - 0

Table 4

Statistical results of meta-regression with vocal quality and its interaction with age as moderators. The intercept corresponds to the effect size when the competitor is vocal, at age 0. The moderator estimates correspond to changes in the intercept when the competitor is non-vocal (vocal quality).

	estimate	SE	t	confidence interval
intercept	0.47	0.16	2.94	0.1 - 0.84
vocal quality	-0.35	0.20	-1.72	-0.77 - 0.08
vocal quality*age	0.00	0.00	2.22	0 - 0.01

Table 5

Statistical results of meta-regression with language of the speech sounds and interaction with age. The intercept corresponds to the effect size when speech is in a foreign language at age 0. The moderator estimate correspond to changes in the intercept when the target stimuli are in the native language.

	estimate	SE	t	confidence interval
intercept	0.67	0.29	2.33	0 - 1.34
language	-0.42	0.31	-1.37	-1.1 - 0.26
language * age	0.00	0.00	2.01	0 - 0.01

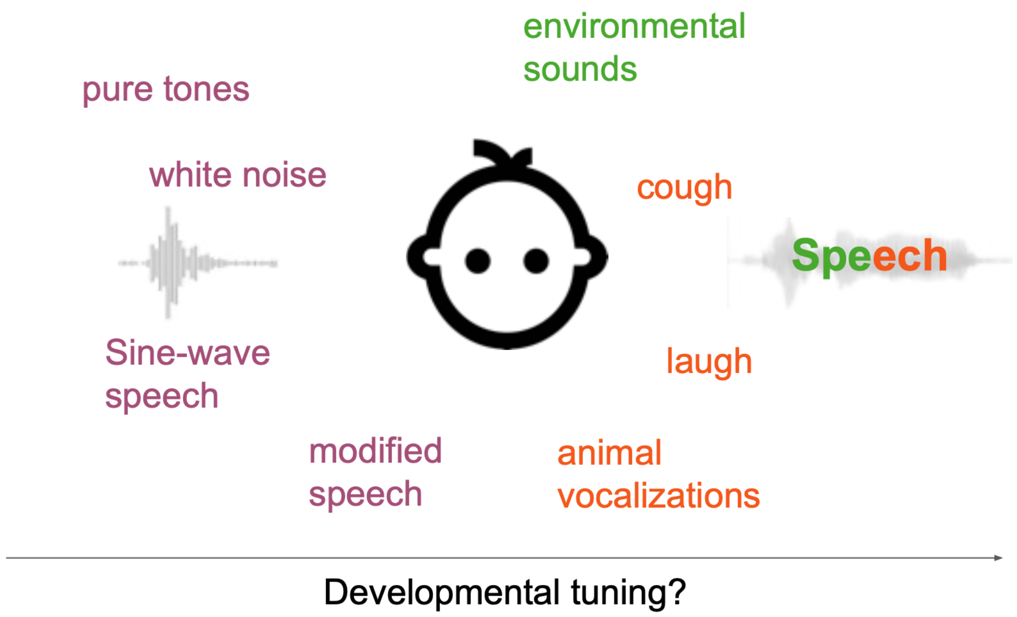


Figure 1. Developmental tuning for speech in the first year of life: infant would first discriminate artificial (purple) and natural (green) sounds, then vocal sounds (orange) within natural sounds, and ultimately speech as a separate category within natural and vocal sounds.

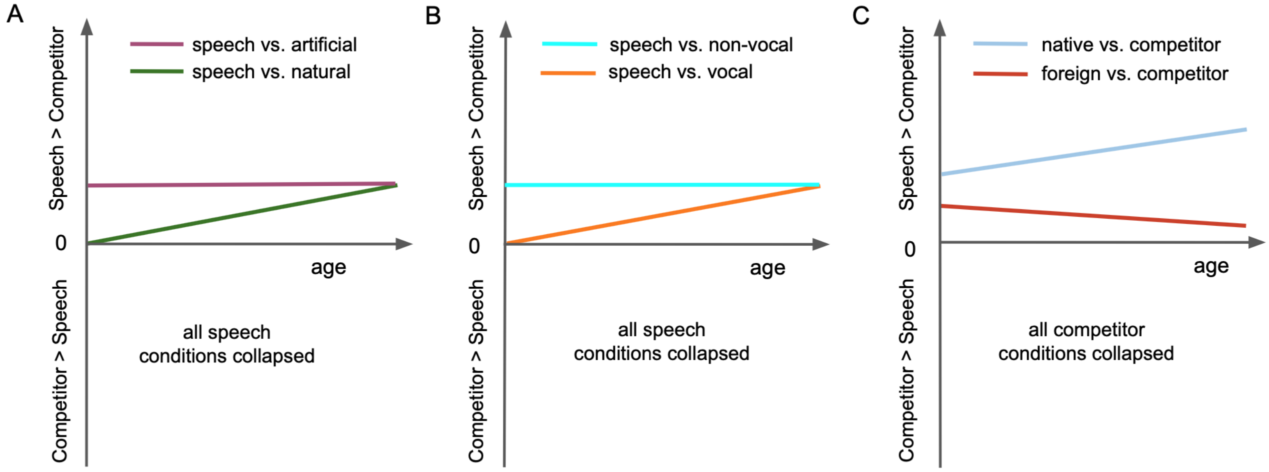


Figure 2. Hypothesized pattern of preference: the x axis shows age, the y axis represents the effect size derived from the contrast between a speech condition and a competitor condition (preference for speech over the competitor is plotted up; the lower quadrants are empty because we do not predict a preference for the competitor over speech). A: Speech contrasted to natural (green) or artificial (purple) competitors. B: Speech contrasted to vocal (orange) or non-vocal (cyan) competitors. C: Collapsing across competitors, separating speech in a foreign language (red); speech in the native language (blue).

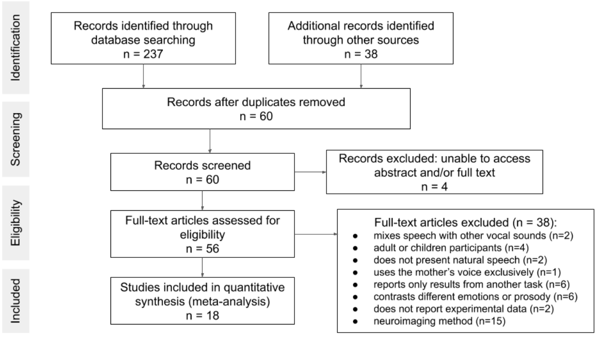

Identification
Screening
Eligibility
Included
Records identified through database searching n = 237
Additional records identified through other sources n = 38
Records after duplicates removed n = 60
Records screened n = 60
Records excluded: unable to access abstract and/or full text n = 4
Full-text articles assessed for eligibility n = 56
Full-text articles excluded (n = 38):
● mixes speech with other vocal sounds (n=2)
● adult or children participants (n=4)
● does not present natural speech (n=2)
● uses the mother's voice exclusively (n=1)
● reports only results from another task (n=6)
● contrasts different emotions or prosody (n=6)
● does not report experimental data (n=2)
● neuroimaging method (n=15)
Studies included in quantitative synthesis (meta-analysis) n = 18

Figure 3. PRISMA flowchart summarizing the literature review and selection process.

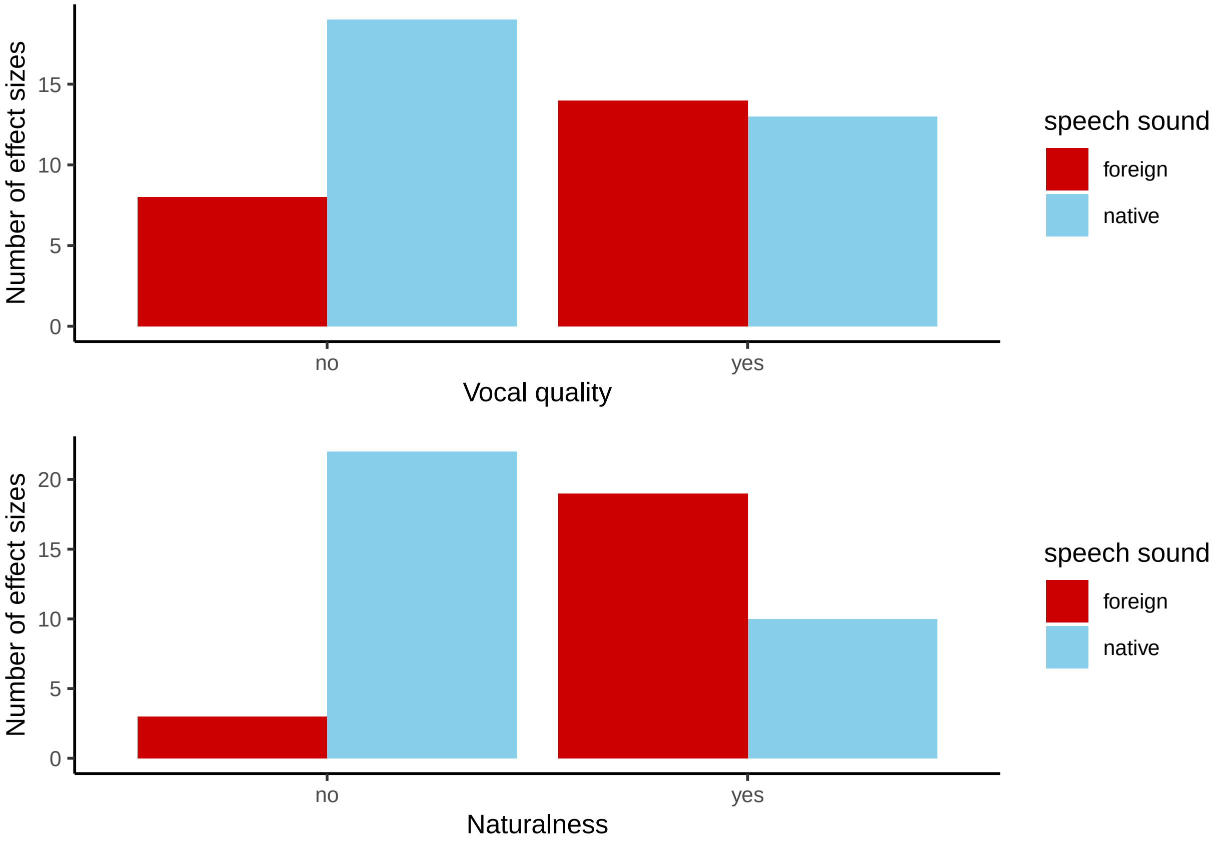


Figure 4. Histograms of the number of effect sizes for each language and moderator status.

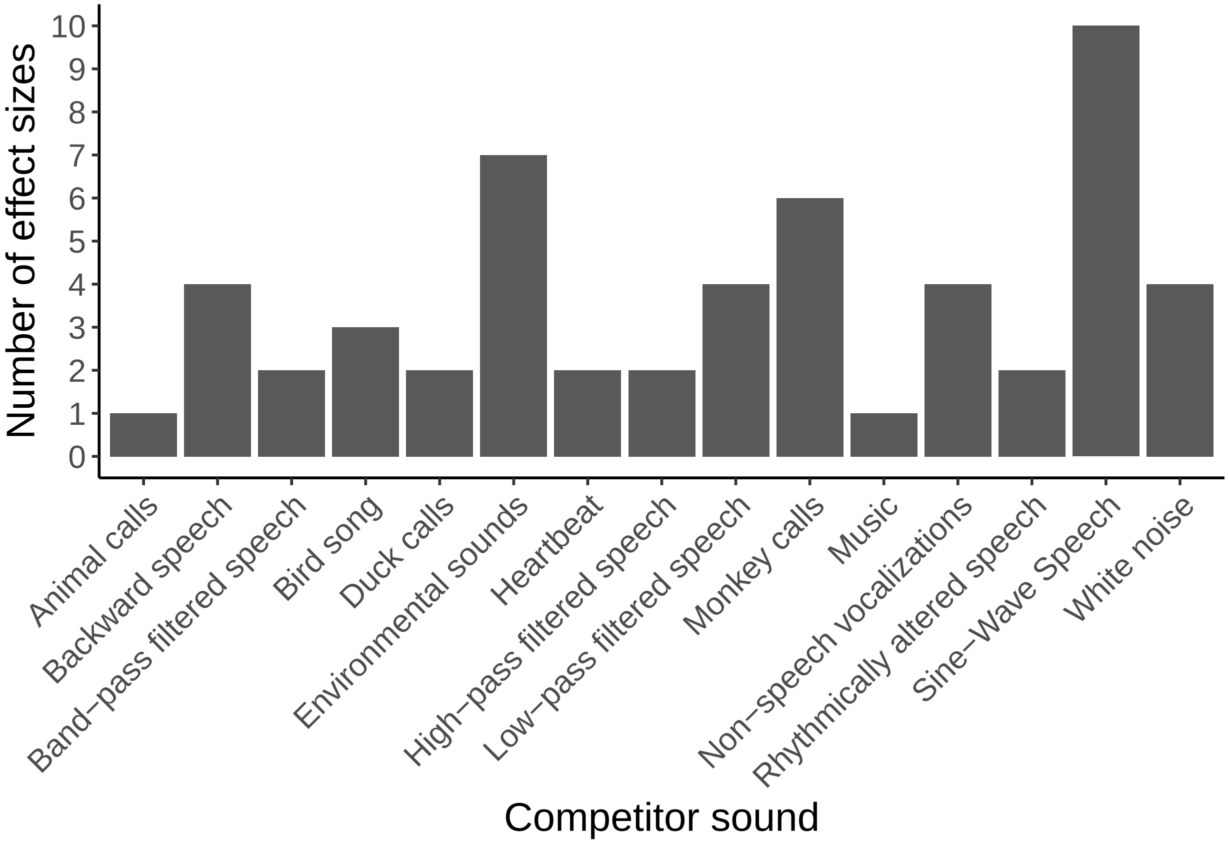
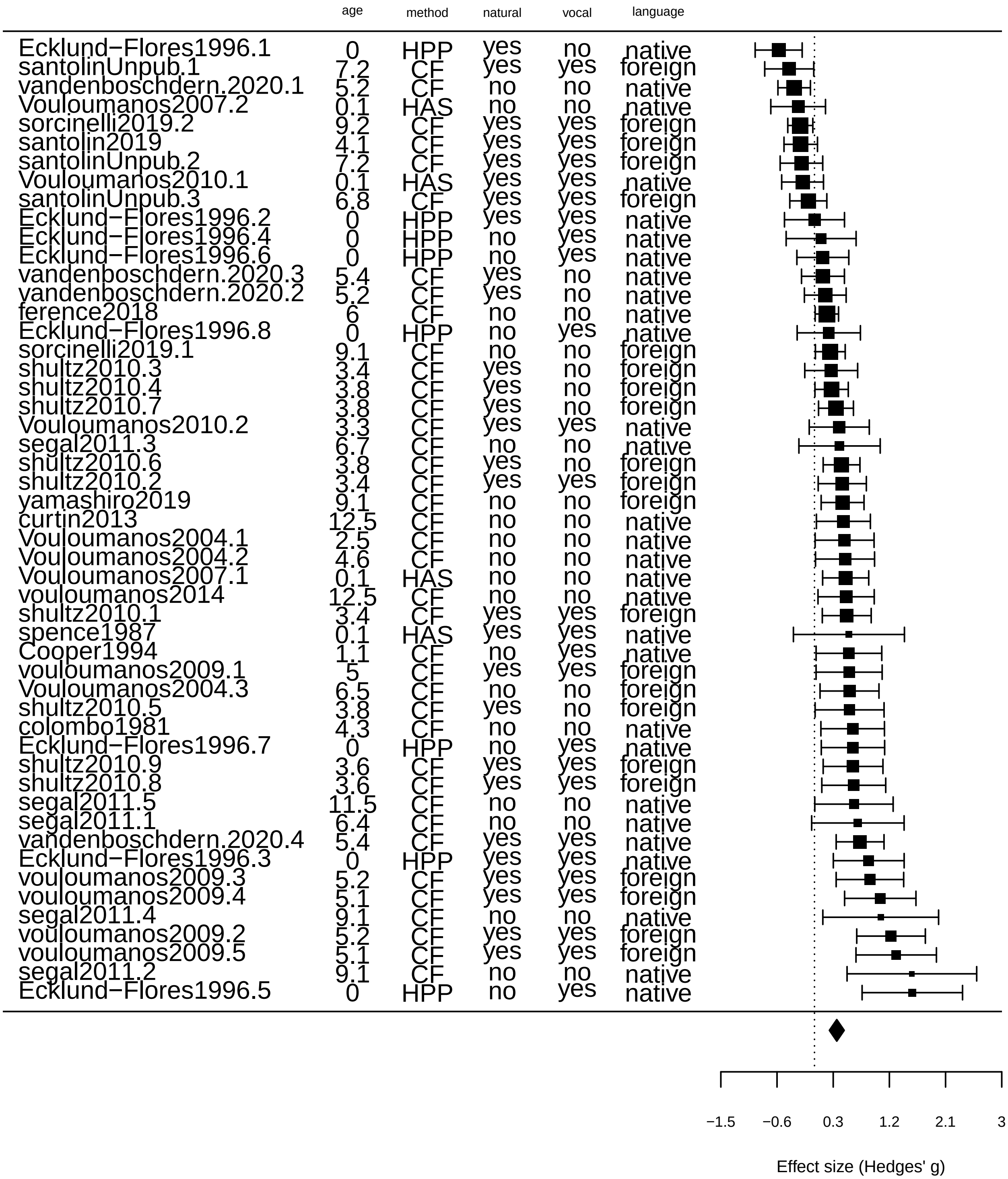


Figure 5. Histogram of the number of effect sizes for each competitor.



	age	method	natural	vocal	language
Ecklund−Flores1996.1	0	HPP	yes	no	native
santolinUnpub.1	7.2	CF	yes	yes	foreign
vandenboschdern.2020.1	5.2	CF	no	no	native
Vouloumanos2007.2	0.1	HAS	no	no	native
sorcinelli2019.2	9.2	CF	yes	yes	foreign
santolin2019	4.1	CF	yes	yes	foreign
santolinUnpub.2	7.2	CF	yes	yes	foreign
Vouloumanos2010.1	0.1	HAS	yes	yes	native
santolinUnpub.3	6.8	CF	yes	yes	foreign
Ecklund−Flores1996.2	0	HPP	yes	yes	native
Ecklund−Flores1996.4	0	HPP	no	yes	native
Ecklund−Flores1996.6	0	HPP	no	yes	native
vandenboschdern.2020.3	5.4	CF	yes	no	native
vandenboschdern.2020.2	5.2	CF	yes	no	native
ference2018	6	CF	no	no	native
Ecklund−Flores1996.8	0	HPP	no	yes	native
sorcinelli2019.1	9.1	CF	no	no	foreign
shultz2010.3	3.4	CF	yes	no	foreign
shultz2010.4	3.8	CF	yes	no	foreign
shultz2010.7	3.8	CF	yes	no	foreign
Vouloumanos2010.2	3.3	CF	yes	yes	native
segal2011.3	6.7	CF	no	no	native
shultz2010.6	3.8	CF	yes	no	foreign
shultz2010.2	3.4	CF	yes	yes	foreign
yamashiro2019	9.1	CF	no	no	foreign
curtin2013	12.5	CF	no	no	native
Vouloumanos2004.1	2.5	CF	no	no	native
Vouloumanos2004.2	4.6	CF	no	no	native
Vouloumanos2007.1	0.1	HAS	no	no	native
vouloumanos2014	12.5	CF	no	no	native
shultz2010.1	3.4	CF	yes	yes	foreign
spence1987	0.1	HAS	yes	yes	native
Cooper1994	1.1	CF	no	yes	native
vouloumanos2009.1	5	CF	yes	yes	foreign
Vouloumanos2004.3	6.5	CF	no	no	foreign
shultz2010.5	3.8	CF	yes	no	foreign
colombo1981	4.3	CF	no	no	native
Ecklund−Flores1996.7	0	HPP	no	yes	native
shultz2010.9	3.6	CF	yes	yes	foreign
shultz2010.8	3.6	CF	yes	yes	foreign
segal2011.5	11.5	CF	no	no	native
segal2011.1	6.4	CF	no	no	native
vandenboschdern.2020.4	5.4	CF	yes	yes	native
Ecklund−Flores1996.3	0	HPP	yes	yes	native
vouloumanos2009.3	5.2	CF	yes	yes	foreign
vouloumanos2009.4	5.1	CF	yes	yes	foreign
segal2011.4	9.1	CF	no	no	native
vouloumanos2009.2	5.2	CF	yes	yes	foreign
vouloumanos2009.5	5.1	CF	yes	yes	foreign
segal2011.2	9.1	CF	no	no	native
Ecklund−Flores1996.5	0	HPP	no	yes	native

Figure 6. Forest plot of effect sizes available in the literature, along with their respective moderator status. The average effect size is plotted on the bottom line.

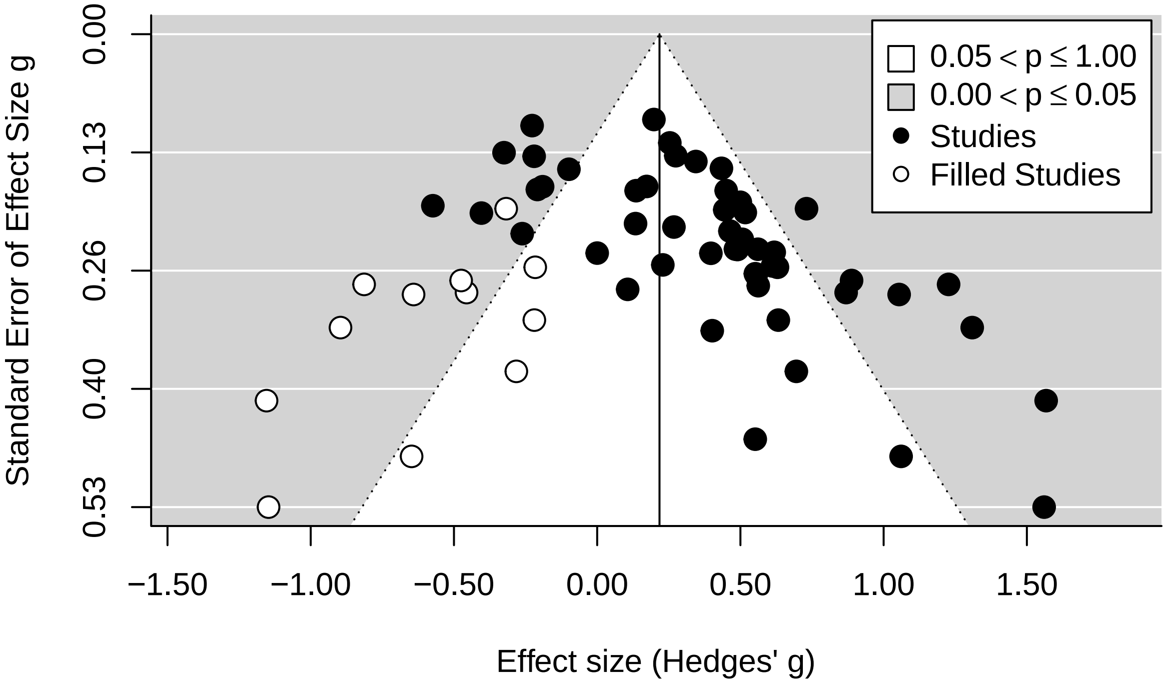


Figure 7. Funnel plot of effect sizes and their respective standard errors. Black dots: effect sizes observed in the literature. White dots: missing effect sizes, suggestive of a publication bias^2. Vertical line: average effect size after filling the missing effect sizes.

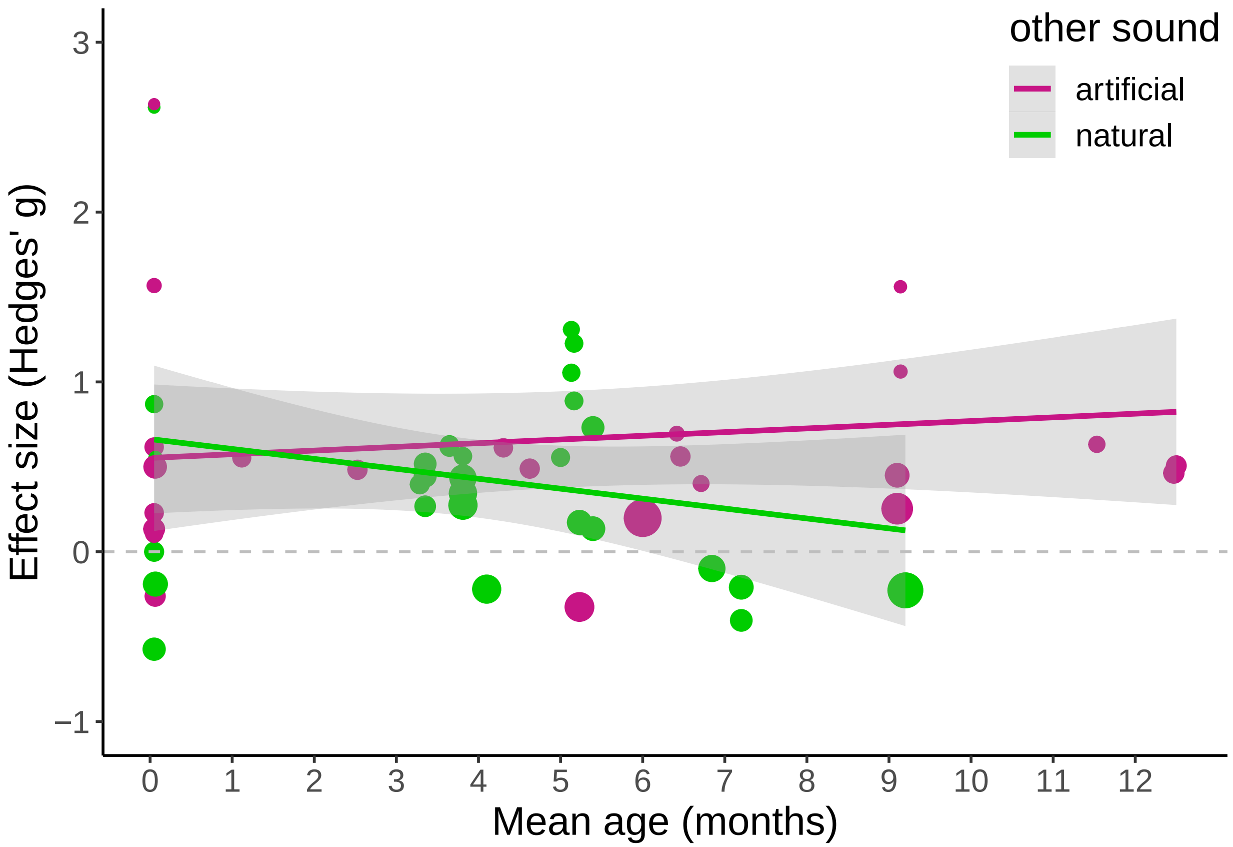


Figure 8. Effect sizes as a function of age and natural quality of the competitor. The size of each dot is inversely proportional to the variance. Positive effect sizes reflect a preference for the speech sound, negative effect sizes reflect a preference for the competitor sound.

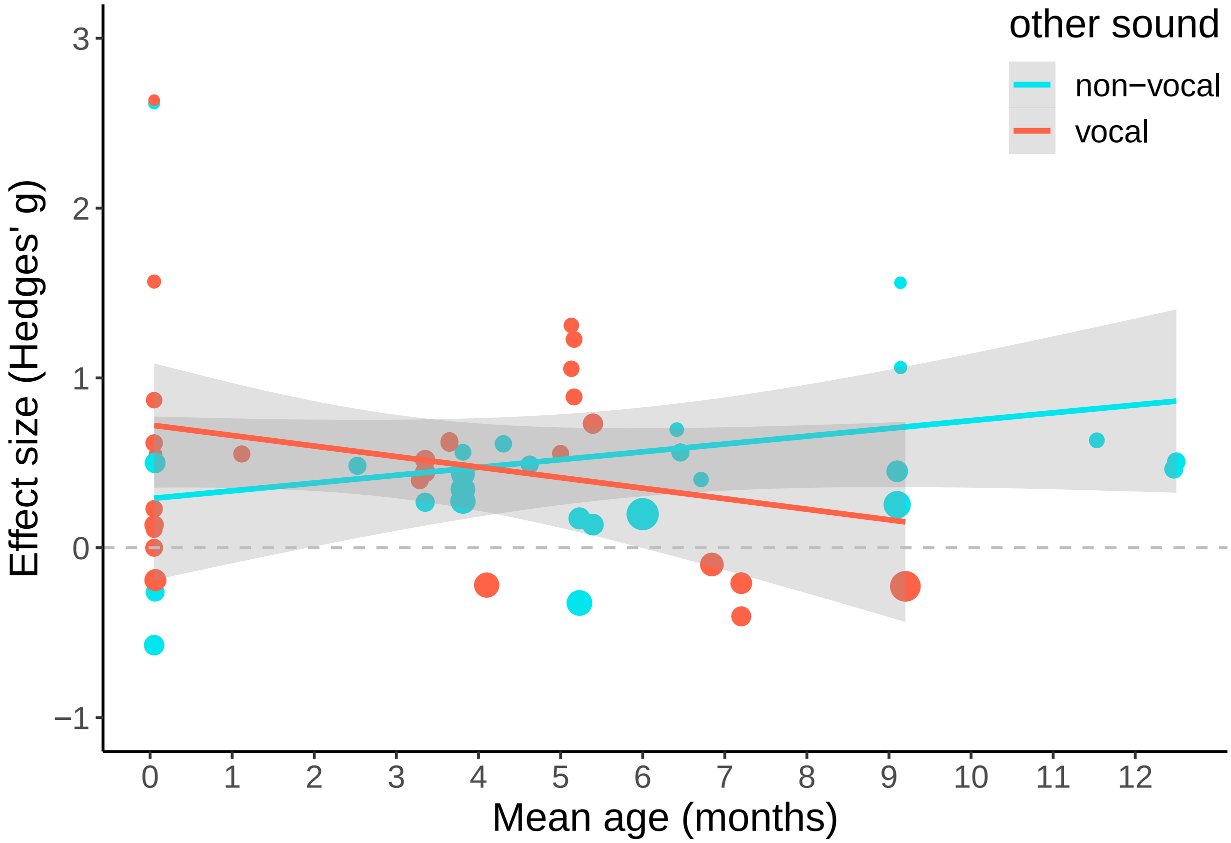


Figure 9. Effect sizes as a function of age and vocal quality of the competitor. The size of each dot is inversely proportional to the variance. Positive effect sizes reflect a preference for the speech sound, negative effect sizes reflect a preference for the competitor sound.

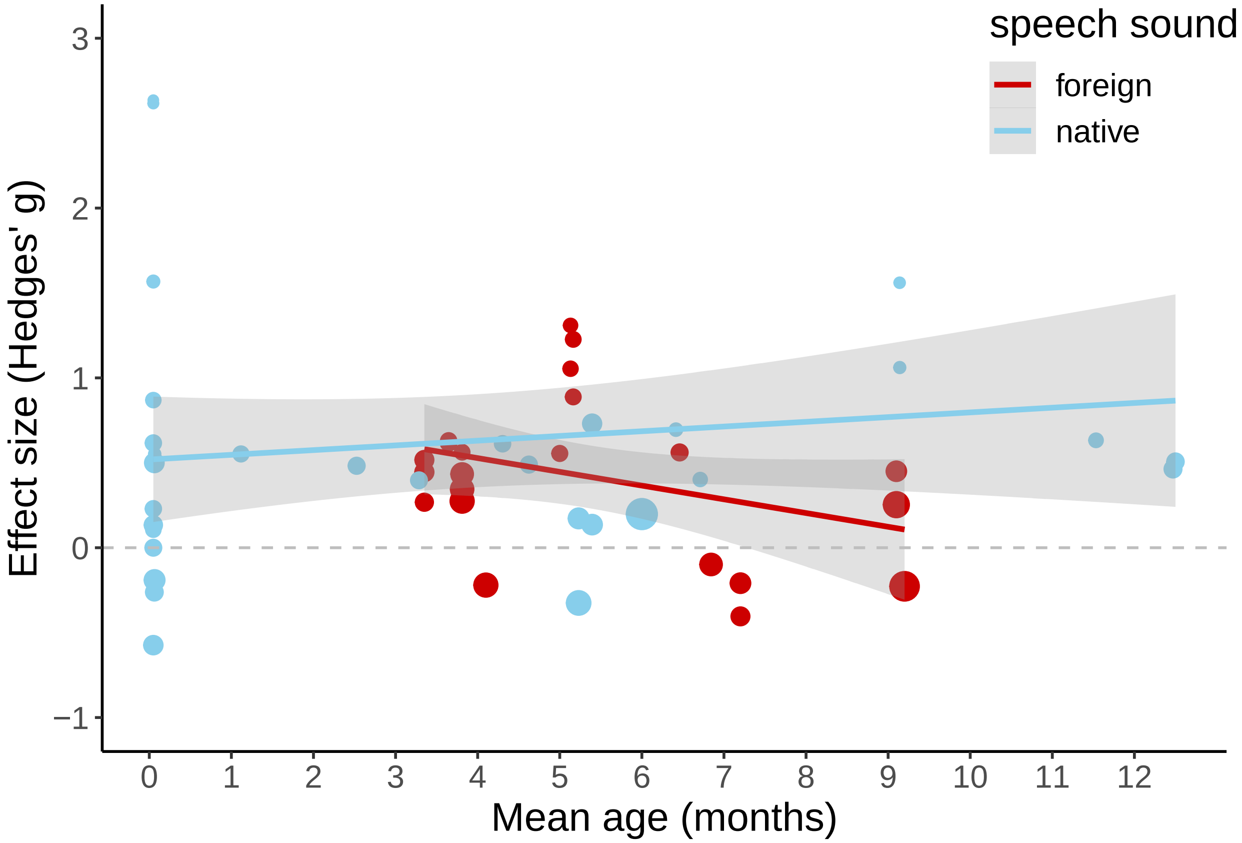


Figure 10. Effect sizes as a function of age and familiarity with the speech sounds. The size of each dot is inversely proportional to the variance. Positive effect sizes reflect a preference for the speech sound, negative effect sizes reflect a preference for the competitor sound.