Infants' preference for speech decomposed: Meta-analytic evidence

Cécile Issard[1], Sho Tsuji[2], & Alejandrina Cristia[1]

[1] Laboratoire de Sciences Cognitives et Psycholinguistique, Ecole Normale Supérieure, Département d'Études Cognitives

[2] International Research Center for Neurointelligence, The University of Tokyo

Author Note

Correspondence concerning this article should be addressed to Cécile Issard, Laboratoire de Sciences Cognitives et Psycholinguistique, Département d'Études Cognitives, Ecole Normale Supérieure, 29 rue d'Ulm, 75005 Paris, France. E-mail: cecile.issard@gmail.com

Abstract

The human auditory system is amazingly efficient at processing speech, with a preference for these sounds reported by full term birth. More generally, infants tested at a variety of ages have been presented with contrasts between native or foreign speech and another sound, which may be vocal or not, natural or not. These data constitute a rich pool of evidence that can be sourced from to assess to what extent familiarity, vocal quality, and naturalness affect speech preference across development. We synthesized the literature by conducting a meta-analysis of studies testing speech preference in infants from birth to one year of age. We found a medium effect size, with infants preferring speech over other sounds. This preference was not significantly moderated by familiarity, vocal quality, or naturalness. 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 contradict current views of the literature, and call for further investigation of the phenomenon, especially in older infants.

Keywords: Meta-analysis, infants, speech preference, auditory development, natural sounds

Infants' preference for speech decomposed: Meta-analytic evidence

Highlights

- Infants reliably prefer natural speech over other types of sounds, 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 difference between whether infants are familiar or not with the language used was not significant

Introduction

Given the importance of speech for human vocal communication, it is conceivable that infants are born equipped with a preference for speech, which becomes stronger with age and exposure. Here, we synthesize empirical data on infants' preferences for speech over non-speech sounds to assess the explanatory role of three factors: stimulus naturalness, vocal quality, and familiarity.

Potential dimensions underlying preference patterns

There are three key conceptual explanations for infants preference for speech over competitor sounds: Preference for (a) natural over artificial sounds; (b) familiar over unfamiliar sounds; and (c) vocal over non-vocal sounds (Figure 1). These explanations are mutually compatible, and one or more may be true.

Naturalness.   A first hypothesis postulates a preference for natural over artificial sounds. Natural sounds are those produced by biological systems, including vocal tracts but

also the sound of walking and heart rate. In many cases natural and artificial sounds differ in their acoustic characteristics. For example, backward speech has unnatural formant transitions and seemingly abrupt closures compared to naturally produced sounds. Natural sounds are processed more efficiently by the auditory system, from the cochlea (Smith & Lewicki, 2006) to the auditory cortex (e.g., Mizrahi, Shalev, & Nelken, 2014). This predicts a preference for speech over artificial competitors that is present from birth, consistent with existing literature (e.g., Vouloumanos & Werker, 2007).

Familiarity. Perhaps infants prefer speech to other sounds since it is a frequent sound. Newborns prefer their native speech to prosodically distinct foreign speech (e.g., Mehler et al., 1988), which supports a preference for sound patterns heard frequently in the womb. There are no behavioral results directly testing the prediction that infants show stronger preferences for speech over a foil when tested with more familiar speech stimuli (for instance, spoken in their native, as compared to a foreign language), but results from neuroimaging studies provide indirect evidence for this view. For instance, newborns' brain activation was different for forward than backward speech when the native language was used as the speech stimuli, but not when a foreign language was used (May, Gervain, Carreiras, & Werker, 2018).

Vocal quality. Many results summarized above may be accommodated by a third hypothesis, postulating a preference for vocal over non-vocal sounds. Vocal sounds are those made with a mouth, and thus typically a subset of natural sounds[1]. Newborns made more head-turns to speech than to heartbeat (Ecklund-Flores & Turkewitz, 1996), arguably both equally natural and familiar to them, but they listened equivalently to speech and monkey calls, despite the greater familiarity of the former (Vouloumanos, Hauser, Werker, & Martin, 2010).

---

[1]In the case of filtered speech, the modulations introduced by the vocal tract are still present at the retained frequencies. For this reason, filtered speech can be considered as vocal but not natural.

Changes as a function of development

Development may affect the preference for speech in various ways. Whereas newborns do not prefer speech over monkey calls, three-month-olds do (Vouloumanos et al., 2010). This suggests that as they age, infants might develop an increasingly narrow definition of the stimulus they prefer. In this case naturalness, familiarity, and vocal quality effects should change as a function of age: Very close stimuli (e.g., speech versus another natural sound) initially leads to a weak preference, but, as infants age, this preference may be as strong as that found for very different stimuli (e.g., speech versus an artificial sound). Many articles discuss potential changes in the pattern of preference as a function of age (e.g. Ferry, Hespos, & Waxman, 2013; Shultz & Vouloumanos, 2010; Shultz, Vouloumanos, Bennett, & Pelphrey, 2014). To our knowledge, only two papers from the same laboratory include multiple age groups tested with the exact same stimulus categories and procedure (Vouloumanos & Werker, 2004; Vouloumanos et al., 2010). In fact, statements about age-related changes are often done using the demonstrably problematic method of concluding that there is an interaction without actually testing for it statistically (Gelman & Stern, 2006). It is therefore important to directly test these statements.

A meta-analytic approach

In sum, previous work on infants' preferences is broadly compatible with preference for natural over artificial, vocal over non-vocal, and familiar over unfamiliar sounds, potentially interacting with infants' age. In this paper, we seek to directly test these interpretations of the literature by employing a meta-analytic approach. Meta-analyses involve combining studies that may vary in their methodology. One limitation is therefore that one cannot isolate specific variables as well as in direct experimentation. Therefore, meta-analyses may miss subtle effects. Nonetheless, they have several useful features. They can reveal small effects not obvious in individual studies by combining them to obtain larger samples.

Additionally, by integrating data across different laboratories, they provide evidence for the generalizability of effects across labs. Finally, meta-analyses offer tools to detect publication bias in the literature.

Specifically for the present case, a meta-analysis allows to statistically test different explanations. We can test the effect of factors that are not part of the original design, by redescribing the stimuli used as a function of those factors. For instance, a study measuring preference for native speech over native backward speech provides data on a natural versus artificial, as well as a vocal versus non-vocal contrast. We can also draw a developmental timeline across the age range covered by the literature.

Meta-analyses can even provide theoretical and empirical insights that contradict qualitative reviews. For example, it has 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, Bergmann and Cristia (2016) found stable familiarity preferences for word segmentation in natural speech across the first two years; and Black and Bergmann (2017) found a stable novelty effect for artificial grammars implemented in synthesized speech, whereas those implemented in natural speech led to stable familiarity preferences. Meta-analyses are therefore important to statistically and systematically test the theoretical predictions proposed in qualitative reviews.

The present study

Given the scarcity of direct evidence on the potential explanations laid out above (naturalness, vocal quality, and familiarity, as a function of age), we conducted a meta-analysis to test whether infants' preference for speech sounds over other types of sounds is stable in newborns, and how it develops over the first year of life. Assuming all

three factors are true, 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 natural sounds as a function of age, but a stable 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

Literature search

We composed the initial list of studies with suggestions by experts (authors of this work); one google scholar searches (("speech preference" OR "own-species vocalization") AND infant - "infant-directed"), the same search in PubMed and PsycInfo (last searches on 24/09/2019); and a google alert. We also inspected the reference lists of all included papers.

Inclusion criteria

After a first screening based on titles and abstracts using more liberal inclusion criteria, we decided on inclusion based on full paper reading. We included studies that tested human infants from birth to 1 year of age, and contrasted speech sounds with any other type of sound, measuring behavioral responses to the sounds (e.g., looking times). We excluded studies that only contrasted foreign against native language, did not present natural speech sounds at all, presented speech in the mother's voice, or intentionally mixed speech with other vocal sounds within the same sound condition. We also excluded neuroimaging studies

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). We documented all the studies that we inspected in a decision spreadsheet (available in the online supplementary materials; Anonymized link, 2019).

Coding

The critical variables for our purpose are infant age, methodological variables (testing method: central fixation, high amplitude sucking, head-turn preference procedure, high amplitude sucking/passive listening), and key stimuli characteristics. Specifically, we coded the language in which the speech sounds were recorded (native or foreign), and whether the sound opposed to speech was natural or not, vocal or not. This competitor was coded as natural if it was produced by a biological organism without any further acoustic manipulation. If the authors applied acoustic manipulations it was coded as artificial. This sound was considered as vocal if it was produced by an animal vocal tract, either original or modified.

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

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

173 the t-statistic between the two sound conditions, or an F-statistic provided this was a

174 two-way comparison. If effect sizes were directly reported as a Cohen's d or a Hedges' g, we

175 also coded this.

176 The PRISMA checklist, data, and code can be found on the online supplementary

177 materials (Anonymized, 2019).

178 **Effect sizes**

179 Once the data were coded, we extracted effect sizes, along with their respective

180 variance. Effect sizes were standardized differences (Cohen's d) between response to speech

181 and to the other sound. If they were not directly reported in the papers, we computed them

182 using the respective means and SDs (Lipsey & Wilson, 2001), or a t- or F-statistic (Dunlap,

183 Cortina, Vaslow, & Burke, 1996). As our effect sizes came from within-subject comparisons

184 (e.g. looking time of the same infant during speech and during monkey calls), we needed to

185 take into account the correlation between the two measurements in effect sizes and effect size

186 variances computations. We computed this correlation based on the t-statistic, the respective

187 means and SDs (Lipsey & Wilson, 2001) if they were all reported; or imputed this

188 correlation randomly if not. We finally calculated the variance of each effect size (Lipsey &

189 Wilson, 2001). Cohen's d were transformed to Hedges' g by multiplying d by a correction for

190 small sample sizes based on the degree of freedom (Borenstein, Hedges, Higgins, & Rothstein,

191 2011). This procedure led to 47 (some of them coming from the same infant group, hence

192 not mutually independent) effect sizes, 46 from published, peer-reviewed paper, and 1 from a

193 thesis.

194 All analyses use the R (R Core Team, 2018) package Robumeta (Hedges, Tipton, &

195 Johnson, 2010), which allows to fit meta-analytic regressions that take into account the

196 correlated structure of the data, when repeated measures are obtained from the same infant

197 groups within papers.

Results

Database description

200 We found a total of 15 papers reporting 47 (not mutually independent) effect sizes, see
201 Figure 4. 14 papers have been submitted to or published in peer-reviewed journals (Colombo
202 & Bundy, 1981; Cooper & Aslin, 1994; Curtin & Vouloumanos, 2013; Ecklund-Flores &
203 Turkewitz, 1996; Segal & Kishon-Rabin, 2011; Shultz & Vouloumanos, 2010; Sorcinelli,
204 Ference, Curtin, & Vouloumanos, 2019; Spence & DeCasper, 1987; Vouloumanos & Curtin,
205 2014; Vouloumanos & Werker, 2004, 2007; Vouloumanos, Druhen, Hauser, & Huizink, 2009;
206 Vouloumanos et al., 2010, 2010; Yamashiro, Curtin, & Vouloumanos, 2019). The remaining 1
207 paper was a thesis (J. D. Ference, 2018).

208 Studies tended to have small sample sizes, with a median N of 16 children (Range =
209 52, M = 20.66, Total: 659). Infants ranged from 0 to 12 months (1.50 to 380.50 days),
210 although the majority were under 9 months of age (66.67% of the studies). Individual
211 samples comprised 48 % of female participants on average. Infants were native of 6 different
212 languages across the whole database (English, French, Russian, Yiddish, Hebrew, Italian).
213 Studies were performed in 10 different laboratories from 4 different countries (United States,
214 Canada, Israel, Italy). 3 experimental methods were used: 12 studies used Central Fixation
215 (CF) (Colombo & Bundy, 1981; Cooper & Aslin, 1994; Curtin & Vouloumanos, 2013; J. D.
216 Ference, 2018; Segal & Kishon-Rabin, 2011; Shultz & Vouloumanos, 2010; Sorcinelli et al.,
217 2019; Vouloumanos & Curtin, 2014; Vouloumanos & Werker, 2004; Vouloumanos et al., 2009,
218 2010; Yamashiro et al., 2019); 3 used High-Amplitude Sucking (HAS) (Spence & DeCasper,
219 1987; Vouloumanos & Werker, 2007; Vouloumanos et al., 2010) ; and 1 used Head-turn
220 Preference Procedure (HPP) (Ecklund-Flores & Turkewitz, 1996).

Summary effect size

Integrating across all studies in a meta-analytic regression without any moderator, we found a summary effect size g of 0.53 (SE = 0.09, CI = [0.34 , 0.73]) (Table 1, and Figure 4, diamond), corresponding to a medium effect size.

Publication bias

We assessed 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 5)[2]. A regression test on these data was significant (z = 6.70, p = 0.00), as was the Kendall's tau rank correlation test for funnel plot asymmetry (Kendall's tau = 0.53, p = 0.00), indicating a publication bias in the literature. To further investigate this bias, we symmetrized the funnel plot with the "trim and fill" method (Duval & Tweedie, 2000). 12 (SE = 4.08) missing studies were needed on the left side of the plot to symmetrize the funnel plot.

Moderator analyses

We then tested if the preference found above could be explained by the dimensions discussed in the literature. Following our hypothesis, we fit a meta-analytic model with the following moderators:

- mean age of children;
- familiarity with the language used (native or foreign);

---

[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.

Table 1

Statistical results of meta-regression with all main effects. The 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	
summary effect size	0.53	0.09	5.65	0.34	0.73
familiarity	0.14	0.24	0.61	-0.39	0.68
naturalness	-0.03	0.27	-0.10	-0.63	0.58
vocal quality	-0.12	0.27	-0.46	-0.75	0.50
age	0.00	0.00	0.34	0.00	0.00

240 • naturalness of the contrastive sound (coded as yes if it was natural and no otherwise);

241 • vocal quality of the contrastive sound (coded as yes if it was vocal and no otherwise).

242   None of the moderators was significant (see Figure 6 and Table 1).

243   Due to the relatively low number of effect sizes available in the literature, we did not

244 add interactions with age to the model to avoid overfitting. Inspection of results in Figure 5

245 show that the confidence intervals of all conditions overlap almost exactly across the tested

246 ages, excluding the possibility of such interactions.

247   Readers may wonder to what extent our results are obscured by the influence of

248 experimental method, which is known to be sizable in the cognitive developmental literature

249 (Bergmann et al., 2018). Inspection of plots where effect sizes has been residualized from

250 experimental method (Supplementary figure S1) looks virtually identical.

Discussion

₂₅₁

₂₅₂   Our meta-analysis synthesizes the available literature on infants' preference for speech

₂₅₃ sounds. Our results confirm that infants reliably prefer speech over other types of sounds

₂₅₄ from birth. When all studies were considered together with no moderators, we found a

₂₅₅ sizable intercept (g=0.53). For comparison, the main effect for native vowel discrimination

₂₅₆ using looking time methods is estimated at 0.25 (Tsuji & Cristia, 2014, data inspected in

₂₅₇ http://metalab.stanford.edu on 2019-10-18). We had predicted infants' speech preference to

₂₅₈ be larger when the competitor was an artificial sound than when it was a natural one; when

₂₅₉ the competitor was non-vocal; and when the speech was in the infants' native language. In

₂₆₀ fact, we were unable to disprove the null hypothesis of no difference for all three factors, with

₂₆₁ widely overlapping distributions of effect sizes for studies varying along the three dimensions.

₂₆₂   We had also hypothesized age to play a major role, because it may correlate with a

₂₆₃ reshaping of the category definition for speech itself. Indeed, studies comparing processing of

₂₆₄ human speech against human non-speech as well as animal vocalizations more generally

₂₆₅ (McDonald et al., 2019; Vouloumanos et al., 2010) often discuss these age-related differences

₂₆₆ in categorization of these sounds. Surprisingly, age did not significantly moderate the overall

₂₆₇ preference for speech.

₂₆₈   From birth and regardless of changes co-occurring with age, infants show a preference

₂₆₉ for speech, which cannot be reduced to three simpler explanations: naturalness, vocalness, or

₂₇₀ familiarity (represented here by the native/foreign contrast). This capacity to preferentially

₂₇₁ listen to speech sounds from birth suggests that infants are born with the capacity to

₂₇₂ recognize their conspecifics' communication signals. This parallels what has been proposed

₂₇₃ by the Conspec model for faces: infants would be born with knowledge about faces, enabling

₂₇₄ them to orient their attention toward them, even without any prior exposure to faces

₂₇₅ (Morton & Johnson, 1991). The fact that familiarity with the language used in the

experiment did not modulate infants' preference suggests that exposure did not play a

crucial role for speech either. However, contrary to faces, fetuses are exposed to speech that

is 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, independently of the language spoken.

The Conspec model proposes that faces would be detected because of their spatial

structure (Morton & Johnson, 1991). Similarly, it is possible that infants prefer speech

because of its complex acoustic structure and fast transitions (Rosen & Iverson, 2007).

Speech is characterized by joint spectral and temporal modulations at specific rates (Singh &

Theunissen, 2003). It is possible that infants attune to this specific spectro-temporal

structure (though see Minagawa-Kawai, Cristià, Vendelin, Cabrol, & Dupoux, 2011, for

evidence that these factors taken separately may not be sufficient for neural responses).

Testing this explanation would require to carry out acoustic analyses of the actual stimuli

used in the studies. Thus, we recommend interested researchers to gather more data in

which the competitor is acoustically simple versus complex; and to deposit the actual stimuli

in a public archive such as the Open Science Framework (Foster & Deardorff, 2017).

One may wonder whether we fail to find many differences because of a lack of

statistical power, particularly in view of between-study variability. We think it is unlikely

that all null results reported in this paper are due to this. Inspection of results in Figure 6

show that the confidence intervals of all conditions overlap almost exactly. Moreover, Table 1

shows that the estimate for all these factors is close to zero (the maximum being 0.14). That

said, more data would be welcome to confirm our results with more statistical power. It

would also be important to carry out more tests on infants older than 9 months. Language

production gains in complexity at about this age (Oller, Eilers, Neal, & Schwartz, 1999),

which could affect infants' speech preference. We particularly recommend using as

competitor natural vocal stimuli, and as target foreign speech, which would help fill in an important gap in our dataset.

Another finding of our meta-analysis is that the distribution of effect sizes in the literature is consistent with publication bias, in view of a strong asymmetry of the funnel plot. In fact, the trim-and-fill method suggested 12 points may be missing, which is a considerable number given that we have 47 effect sizes in total (i.e., a quarter more would be missing). Unsurprisingly, the missing studies are in the negative section, i.e., a preference *against* speech, a result that could lead authors to doubt their own data and not submit it to journals, or that would be considered odd by reviewers and editors, who may ask that the data be removed (or who may recommend the paper to be rejected altogether). These missing studies constitute an important limitation of our results. The literature being biased toward positive effect sizes, the true effect size might be smaller than the one we found (vertical line on Figure 5).

Ultimately, preferential processing of speech may support higher level cognitive tasks. The human species is a highly social one. Detecting speech signals would allow to integrate it with other sensory percepts, such as faces, to form multisensory representations of conspecifics (Vouloumanos et al., 2009). This would lay the track for social cognition. Identifying speech signals and paying attention to them would allow infants to form complex representations of the sensory world, that they can manipulate cognitively. 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; Ferry et al., 2013; Fulkerson & Waxman, 2007). Interestingly, infants categorized visual stimuli when presented with speech, melodies, or monkey vocalizations (Ferry et al., 2013; Fulkerson & Haaf, 2003). These results support the idea that infants may preferentially process complex sounds. 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). It is therefore

important to take stock of what we know today.

Given the crucial importance of understanding infants' speech preference, we make the following recommendations for further data collection, analysis, and reporting. First, authors should strive to increase their sample sizes. The median sample size at present is 20, which is close to the field standard (Bergmann et al., 2018) but much lower than current recommendations (Oakes, 2017). Second, authors should consider proposing their studies as registered reports (Kiyonaga & Scimeca, 2019). In this new publication scheme (available for Developmental Science, Infancy, Infant Behavior and Development, and Journal of Child Language at the time of writing, see a full up-to-date list on https://cos.io/rr/), manuscripts are submitted before data are collected. Reviewers and editors make publication decisions based solely on the introduction and methods. Once the paper is accepted, the author collects the data, analyses it according to a pipeline described in the accepted methods, and writes up the rest of the manuscript. The paper is then reviewed once more for readability, but it cannot be rejected if the results are surprising or uncomfortable for the field. Third, for authors who would rather not follow this publication route, we still strongly recommend the use of pre-specified analysis plans. These have the virtue of, when used correctly, allowing both authors and readers to separate confirmation from exploration, reducing the likelihood of inadvertently engaging in questionable research practices (Simmons, Nelson, & Simonsohn, 2011), known to increase false positives. Finally, we strongly recommend reviewers and editors to evaluate submitted manuscripts on the basis of the quality of the methods, and not of the results. If a study fails to report a speech preference, or actually reports a preference for the competitor, this may actually reflect the reality of this phenomenon. For interested readers who intend to collect such data, we recommend caution when designing the study, and transparency when reporting it. Our dataset can be community-augmented, and we invite researchers investigating this phenomenon to complement it with any data they would have (Anonymized link), whatever the results and publication status.

Bergmann, C., & Cristia, A. (2016). Development of infants' segmentation of words from native speech: A meta-analytic approach. *Developmental Science*, *19*(6), 901–917. doi:10.1111/desc.12341

Bergmann, C., Tsuji, S., Piccinini, P. E., Lewis, M. L., Braginsky, M., Frank, M. C., & Cristia, A. (2018). Promoting Replicability in Developmental Research Through Meta-analyses: Insights From Language Acquisition Research. *Child Development*, *89*(6), 1996–2009. doi:10.1111/cdev.13079

Black, A., & Bergmann, C. (2017). Quantifying infants' statistical word segmentation: A meta-analysis. In (pp. 124–129). Cognitive Science Society. Retrieved from https: //pure.mpg.de/pubman/faces/ViewItemOverviewPage.jsp?itemId=item_2475527

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2011). *Introduction to Meta-Analysis*. John Wiley & Sons.

Colombo, J., & Bundy, R. S. (1981). A method for the measurement of infant auditory selectivity. *Infant Behavior and Development*, *4*, 219–223. doi:10.1016/S0163-6383(81)80025-2

Cooper, R. P., & Aslin, R. N. (1994). Developmental Differences in Infant Attention to the Spectral Properties of Infant-Directed Speech. *Child Development*, *65*(6), 1663–1677. doi:10.2307/1131286

Curtin, S., & Vouloumanos, A. (2013). Speech Preference is Associated with Autistic-Like Behavior in 18-Months-Olds at Risk for Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *43*(9), 2114–2120. doi:10.1007/s10803-013-1759-1

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological*

378   *Methods*, *1*(2), 170–177. doi:10.1037/1082-989X.1.2.170

379   Duval, S., & Tweedie, R. (2000). Trim and Fill: A Simple Funnel-Plot–Based Method of

380   Testing and Adjusting for Publication Bias in Meta-Analysis. *Biometrics*, *56*(2),

381   455–463. doi:10.1111/j.0006-341X.2000.00455.x

382   Ecklund-Flores, L., & Turkewitz, G. (1996). Asymmetric headturning to speech and

383   nonspeech in human newborns. *Developmental Psychobiology*, *29*(3), 205–217.

384   doi:10.1002/(SICI)1098-2302(199604)29:3<205::AID-DEV2>3.0.CO;2-V

385   Ference, J. D. (2018). The Role of Attentional Biases for Conspecific Vocalizations.

386   doi:http://dx.doi.org/10.11575/PRISM/31878

387   Ferry, A. L., Hespos, S. J., & Waxman, S. R. (2010). Categorization in 3- and 4-Month-Old

388   Infants: An Advantage of Words Over Tones. *Child Development*, *81*(2), 472–479.

389   doi:10.1111/j.1467-8624.2009.01408.x

390   Ferry, A. L., Hespos, S. J., & Waxman, S. R. (2013). Nonhuman primate vocalizations

391   support categorization in very young human infants. *Proceedings of the National*

392   *Academy of Sciences of the United States of America*, *110*(38), 15231–15235.

393   doi:10.1073/pnas.1221166110

394   Foster, E. D., & Deardorff, A. (2017). Open Science Framework (OSF). *Journal of the*

395   *Medical Library Association : JMLA*, *105*(2), 203–206. doi:10.5195/jmla.2017.88

396   Fulkerson, A. L., & Haaf, R. A. (2003). The Influence of Labels, Non-Labeling Sounds, and

397   Source of Auditory Input on 9- and 15-Month-Olds' Object Categorization. *Infancy*,

398   *4*(3), 349–369. doi:10.1207/S15327078IN0403_03

399   Fulkerson, A. L., & Waxman, S. R. (2007). Words (but not Tones) facilitate object

400   categorization: Evidence from 6- and 12-month-olds. *Cognition*, *105*(1), 218–228.

doi:10.1016/j.cognition.2006.09.005

Gelman, A., & Stern, H. (2006). The Difference Between "Significant" and "Not Significant" is not Itself Statistically Significant. *The American Statistician*, *60*(4), 328–331. doi:10.1198/000313006X152649

Hedges, L. V., Tipton, E., & Johnson, M. C. (2010). Robust variance estimation in meta-regression with dependent effect size estimates. *Research Synthesis Methods*, *1*(1), 39–65. doi:10.1002/jrsm.5

Hunter, M. A., & Ames, E. W. (1988). A multifactor model of infant preferences for novel and familiar stimuli. *Advances in Infancy Research*, *5*, 69–95.

Kiyonaga, A., & Scimeca, J. M. (2019). Practical Considerations for Navigating Registered Reports. *Trends in Neurosciences*, *42*(9), 568–572. doi:10.1016/j.tins.2019.07.003

Lecanuet, J.-P., & Granier-Deferre, C. (1993). Speech Stimuli in the Fetal Environment. In B. de Boysson-Bardies, S. de Schonen, P. Jusczyk, P. McNeilage, & J. Morton (Eds.), *Developmental Neurocognition: Speech and Face Processing in the First Year of Life* (pp. 237–248). Dordrecht: Springer Netherlands. doi:10.1007/978-94-015-8234-6_20

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis.* Thousand Oaks, CA, US: Sage Publications, Inc.

May, L., Gervain, J., Carreiras, M., & Werker, J. F. (2018). The specificity of the neural response to speech at birth. *Developmental Science*, *21*(3), n/a–n/a. doi:10.1111/desc.12564

McDonald, N. M., Perdue, K. L., Eilbott, J., Loyal, J., Shic, F., & Pelphrey, K. A. (2019). Infant brain responses to social sounds: A longitudinal functional near-infrared spectroscopy study. *Developmental Cognitive Neuroscience*, *36*, 100638.

doi:10.1016/j.dcn.2019.100638

Mehler, J., Jusczyk, P., Lambertz, G., Halsted, N., Bertoncini, J., & Amiel-Tison, C. (1988).
A precursor of language acquisition in young infants. *Cognition*, *29*(2), 143–178.
doi:10.1016/0010-0277(88)90035-2

Minagawa-Kawai, Y., Cristià, A., Vendelin, I., Cabrol, D., & Dupoux, E. (2011). Assessing
Signal-Driven Mechanisms in Neonates: Brain Responses to Temporally and
Spectrally Different Sounds. *Frontiers in Psychology*, *2*. doi:10.3389/fpsyg.2011.00135

Mizrahi, A., Shalev, A., & Nelken, I. (2014). Single neuron and population coding of natural
sounds in auditory cortex. *Current Opinion in Neurobiology*, *24*, 103–110.
doi:10.1016/j.conb.2013.09.007

Morton, J., & Johnson, M. H. (1991). CONSPEC and CONLERN: A Two-Process Theory of
Infant Face Recognition. *Psychological Review*, *98*(2), 164–181.

Oakes, L. M. (2017). Sample Size, Statistical Power, and False Conclusions in Infant
Looking-Time Research. *Infancy*, *22*(4), 436–469. doi:10.1111/infa.12186

Oller, D. K., Eilers, R. E., Neal, A. R., & Schwartz, H. K. (1999). Precursors to speech in
infancy: The prediction of speech and language disorders. *Journal of Communication
Disorders*, *32*(4), 223–245. doi:10.1016/S0021-9924(99)00013-1

Querleu, D., Renard, X., Versyp, F., Paris-Delrue, L., & Crèpin, G. (1988). Fetal hearing.
European Journal of Obstetrics & Gynecology and Reproductive Biology, *28*(3),
191–212. doi:10.1016/0028-2243(88)90030-5

R Core Team. (2018). R: A Language and Environment for Statistical Computing. Vienna,
Austria: R Foundation for Statistical Computing. Retrieved from

446 https://www.R-project.org

447 Rosen, S., & Iverson, P. (2007). Constructing adequate non-speech analogues: What is

448   special about speech anyway? *Developmental Science*, *10*(2), 165–168.

449   doi:10.1111/j.1467-7687.2007.00550.x

450 Segal, O., & Kishon-Rabin, L. (2011). Listening Preference for Child-Directed Speech Versus

451   Nonspeech Stimuli in Normal-Hearing and Hearing-Impaired Infants After Cochlear

452   Implantation Ovid. *Ear and Hearing*, *32*(3), 358–372.

453   doi:10.1097/AUD.0b013e3182008afc

454 Shultz, S., & Vouloumanos, A. (2010). Three-Month-Olds Prefer Speech to Other Naturally

455   Occurring Signals. *Language Learning and Development*, *6*(4), 241–257.

456   doi:10.1080/15475440903507830

457 Shultz, S., Vouloumanos, A., Bennett, R. H., & Pelphrey, K. (2014). Neural specialization

458   for speech in the first months of life. *Developmental Science*, n/a–n/a.

459   doi:10.1111/desc.12151

460 Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2011). False-Positive Psychology:

461   Undisclosed Flexibility in Data Collection and Analysis Allows Presenting Anything

462   as Significant. *Psychological Science*, *22*(11), 1359–1366.

463   doi:10.1177/0956797611417632

464 Singh, N. C., & Theunissen, F. E. (2003). Modulation spectra of natural sounds and

465   ethological theories of auditory processing. *The Journal of the Acoustical Society of*

466   *America*, *114*(6), 3394. doi:10.1121/1.1624067

467 Smith, E. C., & Lewicki, M. S. (2006). Efficient auditory coding. *Nature*, *439*(7079),

978–982. doi:10.1038/nature04485

Sorcinelli, A., Ference, J., Curtin, S., & Vouloumanos, A. (2019). Preference for speech in infancy differentially predicts language skills and autism-like behaviors. *Journal of Experimental Child Psychology*, *178*, 295–316. doi:10.1016/j.jecp.2018.09.011

Spence, M. J., & DeCasper, A. J. (1987). Prenatal experience with low-frequency maternal-voice sounds influence neonatal perception of maternal voice samples. *Infant Behavior and Development*, *10*(2), 133–142. doi:10.1016/0163-6383(87)90028-2

Tsuji, S., & Cristia, A. (2014). Perceptual attunement in vowels: A meta-analysis. *Developmental Psychobiology*, *56*(2), 179–191. doi:10.1002/dev.21179

Vouloumanos, A., & Curtin, S. (2014). Foundational Tuning: How Infants' Attention to Speech Predicts Language Development. *Cognitive Science*, *38*(8), 1675–1686. doi:10.1111/cogs.12128

Vouloumanos, A., & Werker, J. F. (2004). Tuned to the signal: The privileged status of speech for young infants. *Developmental Science*, *7*(3), 270–276. doi:10.1111/j.1467-7687.2004.00345.x

Vouloumanos, A., & Werker, J. F. (2007). Listening to language at birth: Evidence for a bias for speech in neonates. *Developmental Science*, *10*(2), 159–164. doi:10.1111/j.1467-7687.2007.00549.x

Vouloumanos, A., Druhen, M. J., Hauser, M. D., & Huizink, A. T. (2009). Five-month-old infants' identification of the sources of vocalizations. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(44), 18867–18872. doi:10.1073/pnas.0906049106

Vouloumanos, A., Hauser, M. D., Werker, J. F., & Martin, A. (2010). The tuning of human

491   neonates' preference for speech. *Child Development*, *81*(2), 517–527.

492   doi:10.1111/j.1467-8624.2009.01412.x

493   Yamashiro, A., Curtin, S., & Vouloumanos, A. (2019). Does an Early Speech Preference

494   Predict Linguistic and Social-Pragmatic Attention in Infants Displaying and Not

495   Displaying Later ASD Symptoms? *Journal of Autism and Developmental Disorders*.

496   doi:10.1007/s10803-019-03924-2