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Judgment of infant cry: The roles of acoustic characteristics and sociodemographic characteristics

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Abstract: Adult judgments of infant cry are determined by both acoustic properties of the cry and listener sociodemographic characteristics. The main purpose of this research was to investigate how these two sources shape adult judgments of infant cry. We systematically manipulated both the acoustic properties of infant cries and contrasted listener sociodemographic characteristics. Then, we asked participants to listen to several acoustic manipulations of infant cries and to judge the level of distress the infant was expressing and the level of distress participants felt when listening. Finally, as a contrasting condition, participants estimated the age of the crying infant. Using tree-based models, we found that judgments of the level of distress the infant was expressing as well as the level of distress listeners felt are mainly accounted for by select acoustic properties of infant cry (proportion of sound/ pause, fundamental frequency, and number of utterances), whereas age estimates of a crying infant are determined mainly by listener sociodemographic characteristics (gender and parental status). Implications for understanding infant cry and its effects as well as early caregiver-infant interactions are discussed.

Key words: infant cry, perception of cry, tree-based models.

Infants from many animal species emit distress vocalizations when hungry, pained, alone, attacked by predators (see Lingle, Pellis, & Wilson, 2005), and to communicate their needs to the social environment (Barr, Konner, Bakeman, & Adamson, 1991; Newman, 2007; Zeifman, 2003). Although of variable sound quality, these vocalizations appear remarkably similar across a wide taxonomic range and across different behavioral contexts (Lingle, Wyman, Kotrba, Teichroeb, & Romanow, 2012); they also have a powerful effect on mothers and fathers who quickly approach to accompany, retrieve, hold, or feed the infant, (Newman, 2004; Zeifman, 2003) or to defend it against predators (Benedict, 2007; Lingle et al., 2005).

People do not hesitate to label certain vocalizations of human infants as “cries” despite the considerable variation across the contexts in which these sounds are produced and substantial differences in their acoustic parameters (Esposito, Nakazawa, Venuti, & Bornstein, 2012, 2013; Esposito, Venuti, & Bornstein, 2011).Although acoustic indications of urgency can be identified and related to the modulation of specific acoustic parameters of the cry (Esposito & Venuti, 2008; 2010; Gustafson, Wood, & Green, 2000; Lin & McFatter, 2012; Venuti, Esposito, & Giusti, 2004; Zeskind, Klein, & Marshall, 1992), other characteristics of cries are not easily identifiable. For example, even mothers are sometimes unable to reliably distinguish the specific reasons for a cry (Gustafson & Harris, 1990; Zeifman, 2004). Person variables and contextual variables interact to inform adult perceptions (Donate-Bartfield & Passman, 1985). As suggested in the literature, responses to infant cry depend both on the acoustic characteristics of the cry (e.g., the relative proportion of sound vs. pause, fundamental frequency, number of utterances, attitudes; Del Vecchio, Walter, & O’Leary, 2009; Lin & Green, 2007), and listener characteristics (e.g., gender, sensitivity; Joosen et al., 2012) and past experience (e.g., parental status; Gustafson & Harris, 1990; Irwin, 2003). An infant cry is distressing for a parent as well as for a nonparent, and for females as well as for males, but the infant cry may also have different effects on women and men, mothers and fathers, parents and nonparents (De Pisapia et al., 2012).

The main purpose of the present study was to investigate how certain prominent acoustic characteristics of the infant cry and listener sociodemographic characteristics coact to modulate adult judgments of infant cry. Adult judgments of the distress level they feel and the distress expressed by the infant cries, as well as adult perception of the age of the infant crier shape caregiver-infant interactions. For example, Esposito and Venuti (2008) showed that adults felt more distress, believed the crier expressed more distress, and incorrectly estimated child age (attributing a younger age to the crier) when listening to cries of atypically developing (i.e., autism spectrum disorders) infants, thus jeopardizing the effectiveness of the mother-infant interaction.

In this study, we asked females and males, parents and non-parents, to listen to episodes of infant crying and quantify two types of judgments. We manipulated both acoustic properties of the cry (pause length,fundamental frequency, and number of utterances) and the listener sociodemographic characteristics (gender and parental status). Specifically, we asked participants to listen to acoustic manipulations of cries and judge the level of distress the infant was expressing in each episode of cry and the level of distress they felt when listening to each episode of cry. As a contrast condition specific to our analytic plan, we also asked adults to estimate the age of the crying infant. On the basis of the extant literature, we hypothesized that judgments of the levels of distress the infant was expressing as well as the distress listeners felt when hearing cries would be influenced by acoustic properties of the cry, whereas estimates of the age of a crying infant would be determined by both the acoustic properties of the cry and the sociodemographic characteristics of the listener (gender and parental status). Judgments of cry stimuli were then submitted to recursive partitioning (also known as tree-based models; Costello et al., 2003) to analyze the respective roles that acoustic properties of the cry and listener sociodemographic characteristics play in adult judgments. This application of treebased models is novel. Given a set of independent variables (here acoustic features and listener sociodemographic characteristics) and a dependent variable (here levels of distress associated with cry and estimated age), tree-based models provide unique information about the hierarchy of contribution of independent variables in explaining the distribution of the dependent variable and which values of the independent variables subdivide the dependent variable into groups that differ statistically. Moreover, this methodology allowed us to use different levels of factors (at one level the acoustic features of the cry and at another level sociodemographic features of a signal receiver) simultaneously and to examine how they interact, overcoming a central limitation of more traditional (general linear model; GLM) approaches.

Method

Participants.

A total of 80 Japanese adults recruited in the urban area of Chiba, 40 parents (20 females, age 31.5 ± 3.5 years; 20 males age 32.1 ± 3.3 years) and 40 nonparents (20 females, age 27.5 ± 3.2 years; 20 males, age 29.9 ± 3.1 years) participated. The invitation to participate in the study was made through telephone calls to people belonging to a database of volunteers available at Chiba University.

Stimulus selection.

Cry stimuli were generated from a digital audio file of a cry of a 6-monthold boy before the infant’s scheduled feeding. The infant was born term and showed no signs of any clinical conditions at birth or after.A set of five cries was selected for their typical rhythmic quality. Next, 10 adults (5 parents/5 nonparents) were asked to judge the cries and to judge how it was representative of a “typical” cry (using a 7-point Likert-type scale).Then,the ratings of the 10 adults were analyzed, and the 25-s portion of the cry that was most representative of a typical cry for a 6-month-old was selected (called here: BASE).Although defining a “typical” cry is challenging, in this study we refer to acoustical parameters that have been reported in different studies on cry acoustics (Esposito&Venuti, 2010; Rothgänger, 2003;Sheinkopf, Iverson, Rinaldi,& Lester, 2012), and we defined as typical a cry that has a fundamental frequency between 400– 500 Hz, frequency ranges that vary between 250 Hz and 750 Hz,and a maximum of one utterance per second.

Stimulus manipulation.

The BASE file was then experimentally manipulated employing open source Praat software (ver. 5.3.1) for audio editing. Seven different audio files were produced, with the goal of making stimuli that were valid examples of typical cries as an appropriate range of fundamental frequencies, pauses, and utterances. First, the duration of the pauses (both before and after the expiratory segment of the cry) was manipulated to produce three cry episodes with: (a) pauses lengthened by 50% (PAUSE+50, the cry had the same number of pauses as the BASE, but the pauses were 50% longer); (b) pauses shortened by 50% (PAUSE-50, the cry had the same number of pauses as the BASE, but the pauses were 50% shorter); (c) pauses shortened by 100% (PAUSE-100, the cry had no pause at all). The fundamental frequency (f0) was also manipulated, and two cry episodes of 15 s each were produced with a (d) first spectral peak (FSP; the frequency value in Hz of the first amplitude peak across the long-term average spectrum, considered to be an estimate of the average f0 of the episode of crying) augmented by 250 Hz (FSP+250) and with (e) FSP decreased by 250 Hz (FSP-250). Finally, we manipulated the speed altering the final number of utterances to produce two cry episodes with (f) the number
of utterances increased by 50% (UTTERANCES+ 50, the cry had more pauses than the BASE to produce 50% more utterances) and (g) the number of utterances decreased by 50% (UTTERANCES-50, the cry had fewer pauses than the BASE to produce 50% fewer utterances). Because the BASE and the seven manipulated audio files had different durations, only the first 15-s portions of each file were selected and used in the study to normalize the duration of each stimulus.

Stimulus presentation.

The eight audio files (one BASE and seven acoustic manipulations) were presented randomly to participants (recorded at 44,100 Hz with 32-bit stereo resolution) using a personal computer and a headset. During stimulus presentation, the computer screen was blank. Participants were asked to rate the level of distress the infant was expressing by crying (called Expressed Distress) using a 7-point Likert-type scale, where 1 = the lowest level of distress and 7 = the highest level of distress, to rate the level of distress they felt when listening to the episodes of crying (called Felt Distress) using a 7-point Likert-type scale where 1 = the lowest level of distress and 7 = the highest level of distress, and to estimate the age (in months) of the infant who was crying.

Analytic plan.

To compare responses to the eight stimuli, a GLM with repeated measures and eight levels was employed. To determine which sociodemographic characteristic(s) of the participants (Gender and Parental Status) and which acoustic feature(s) of the cry (pause length, fundamental frequency, and number of utterances) were operative,we employed recursive partitioning, specifically regression tree models (Costello et al., 2003). Recursive partitioning explores the structure of a dataset while developing easy-to-visualize decision rules for predicting a continuous (regression tree) outcome. The regression tree or treebased model consists of two main steps: growing (exploring relations among variables) and pruning (avoiding overfitting the data). Tree-based models provide information about the hierarchy of the importance of independent variables in explaining the distribution of the data points of the dependent variable and which value (defined as the "node") of the independent variable subdivides (defined as the "split") the dependent variable in two groups that differ statistically. Using the r-part package for the statistical software R (ver. 3.1–52), the set of parameters used for the splits was: (a) a node must have at least 30 data-point pairs to be considered for a split, (b) at least 20 datapoint pairs were required for each terminal node, and (c) surrogate splits were permitted to allow for missingness. The complexity parameter was set to zero to allow each tree to grow to its full size, and the tree was then pruned (resulting in the optimal tree) to remove branches containing nodes with a t-value greater than −1.645 ($\alpha = 0.05$). Tree models show the top-down hierarchy of the importance of independent variables in explaining dependent variables. Below we report the optimal trees that predict the worst to best dependent variable distribution. In each plot (see Figures 1 and 2), the bottom rectangles show the distribution the dependent variable from worst (left) to best (right). The values in the oval leaves of the tree refer to the condition of the independent variable that statistically divides the distribution of the dependent variable. Below each oval leaf, the indications "yes" or "no" refer to whether or not the condition is met. Each leaf is divided in two subleaves. The terminal leaves (quadrangles) represent subgroups that cannot be further subdivided.The n value in the terminal leaves represents the size of the group, and $M$is the mean value of the group for the dependent variable.

Results

Preliminary analyses.

Prior to data analysis, univariate and multivariate distributions of Expressed Distress, Felt Distress, and Estimated Age scores of the eight stimuli were examined for normality, homogeneity of variance, outliers, and influential cases (Fox, 1997). The variables were normally distributed. The distance of each case to the centroid was evaluated to screen for multidimensional

outliers (Fox, 1997).As expected, statistically significant correlations between Expressed Distress and Felt Distress scores were found, $r(78) = 0.59$, $p < .01$; however, they shared only 35% of common variance, so we treated the variables Expressed Distress and Felt Distress separately. No significant correlations between Expressed Distress or Felt Distress emerged with Estimated Age. No significant difference emerged between females and males, or between parents
and nonparents, for either Expressed Distress or Felt Distress; thus, for these variables females and males, as well as parents and nonparents, were collapsed into a single group for analyses.

Expressed distress level.

A GLM with repeated measures and eight levels (the 8 stimuli) was employed. The participants rated Expressed Distress as follows: BASE: 2.89 ± 1.32; PAUSE+50: 2.99 ±1.37; PAUSE-50: 3.22 ±1.27; PAUSE-100: 3.93 ±1.55; FSP+250: 3.59 ±1.28; FSP-250: 2.99 ± 1.16; UTTERANCES+ 50: 2.91 ± 1.12; UTTERANCES-50: 3.39 ± 1.28. Significant differences emerged, $F(1, 79) = 11.42$, $p \leq .001$, $\eta p\ 2 = 0.07$.Tukey HSD post hoc tests indicated that some stimuli generated relatively higher levels of expressed distress than the BASE: PAUSE-50 (mean difference = 0.44, *SE* = 0.05, $p \leq .05$), PAUSE-100 (mean difference = 1.05, *SE* = 0.23, $p \leq .05$), FSP+250 (mean difference = 0.7, *SE* = 0.04, $p \leq .05$), and UTTERANCES-50 (mean difference = 0.50, *SE* = 0.01, $p \leq .05$); no significant differences were found among the other stimuli (see Figure 1A). Next, we employed recursive partitioning to explore the structure of the data set. Specifically, we used a regression tree model to determine which of the five sociodemographic and acoustic variables might influence the level of Expressed Distress. Figure 1B shows the resulting optimal tree (shaded). Only the acoustic manipulations of fundamental frequency (FSP+250) and waveform modulation (UTTERANCES+50) played a significant role in the model.

Felt distress level.

A GLM with repeated measures and eight levels was again employed. The participants rated their Felt Distress as follows: BASE: 1.75 ± 0.93; PAUSE+50: 1.97 ± 1.13; PAUSE-50: 1.97 ± 1.09; PAUSE- 100: 2.38 ± 1.39; FSP+250: 2.15 ± 1.13; FSP-250: 1.80 ± 0.94; UTTERANCES+50: 1.83 ± 0.88; UTTERANCES-50: 2.12 ± 1.22. Significant differences emerged, $F(1, 79) = 6.59$, $p \leq .01$, $\eta p\ 2 = 0.05$. Tukey HSD post hoc tests indicated that some stimuli generated relatively higher levels of felt distress than the BASE: PAUSE- 100 (mean difference = 0.64, *SE* = 0.45, $p \leq .05$), FSP+250 (mean difference = 0.41, *SE* = 0.19, $p \leq .05$), and UTTERANCES-50 (mean difference = 0.29, *SE* = 0.01, $p \leq .05$); no significant differences were found among the other stimuli (see Figure 1C). Next, we again employed recursive partitioning to explore the structure of the data set. Specifically,we used a regression tree model to see how the five sociodemographic and acoustic variables might influence the level of Felt Distress. Figure 1D shows overgrown and pruned optimal tree (shaded). Only the acoustic manipulations of pause (PAUSE- 50, PAUSE-100) played a significant role in the model.

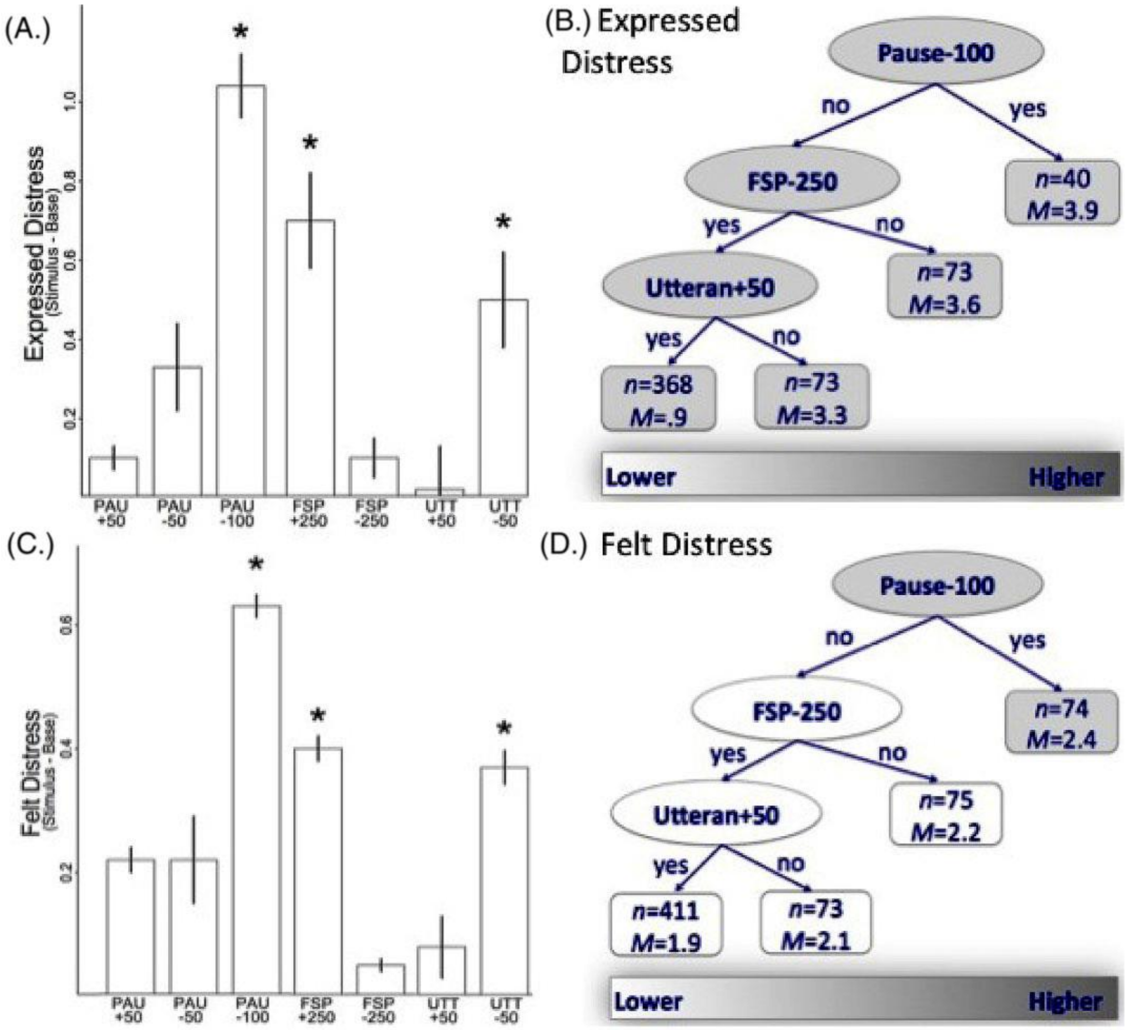

Figure 1 Expressed and Felt Distress. (A) Mean and SEM for the difference between the levels of Expressed Distress for each stimulus and the BASE for each acoustic manipulation of the cry stimulus. (B) The optimal tree (shaded) using a tree-based model to predict the Expressed Distress. (C) Mean and SEM for the difference between the levels of Felt Distress for each stimulus and the BASE stimulus. (D) Initial tree (whole) and the optimal tree (shaded) to predict the Felt Distress. For each group, the mean of the level of Felt Distress is reported. **p* ≤ .05.

Estimated age.

Table 1 shows the absolute distance between the real age and the estimated age for the BASE cry and for the seven acoustic manipulations.A GLM with repeated measures and eight levels and two between factors (Gender and Parental Status) was employed.A significant interaction emerged for Gender × Parental Status, $F(1, 76) = 4.49$, $p \leq .05$, ηp 2 = 0.08. Significant main effects emerged for the different stimuli, $F(1, 76) = 10.79$, $p \leq .001$, ηp 2 = 0.06; and for Gender (*F* ratio more accurate than mean; $F(1, 76) = 10.61$, $p \leq .01$, ηp 2 =

0.07). Specifically, Tukey HSD post hoc tests showed that for the different stimuli, the EstimatedAge forBASE was significantly more accurate than for PAUSE+50 (mean difference = 0.61, *SE* = 0.5, p < .05), PAUSE-100 (mean difference = 1.29, *SE* = 0.9, p < .001), FSP-250 (mean difference = 1.92, *SE* = 1.1, p < .001), UTTERANCES+50 (mean difference = 0.96, *SE* = 0.6, p < .05), UTTERANCES-50 (mean difference = 0.94, *SE* = 0.9, p < .05). Next, recursive partitioning was employed to explore the structure of the data set. Specifically, we used a regression tree model to ascertain how the five sociodemographic and acoustic variables might influence the level of the variable Estimated Age. Figure 2 shows the resulting optimal tree (shaded).The variables Gender, Parental Status, and the acoustic manipulations of fundamental frequency (FSP+250) and pause (PAUSE-50) played significant roles in the model. However, the two most important variables to predict correct estimates of infant
age were Gender (females better than males) and Parental Status (parents better than nonparents).

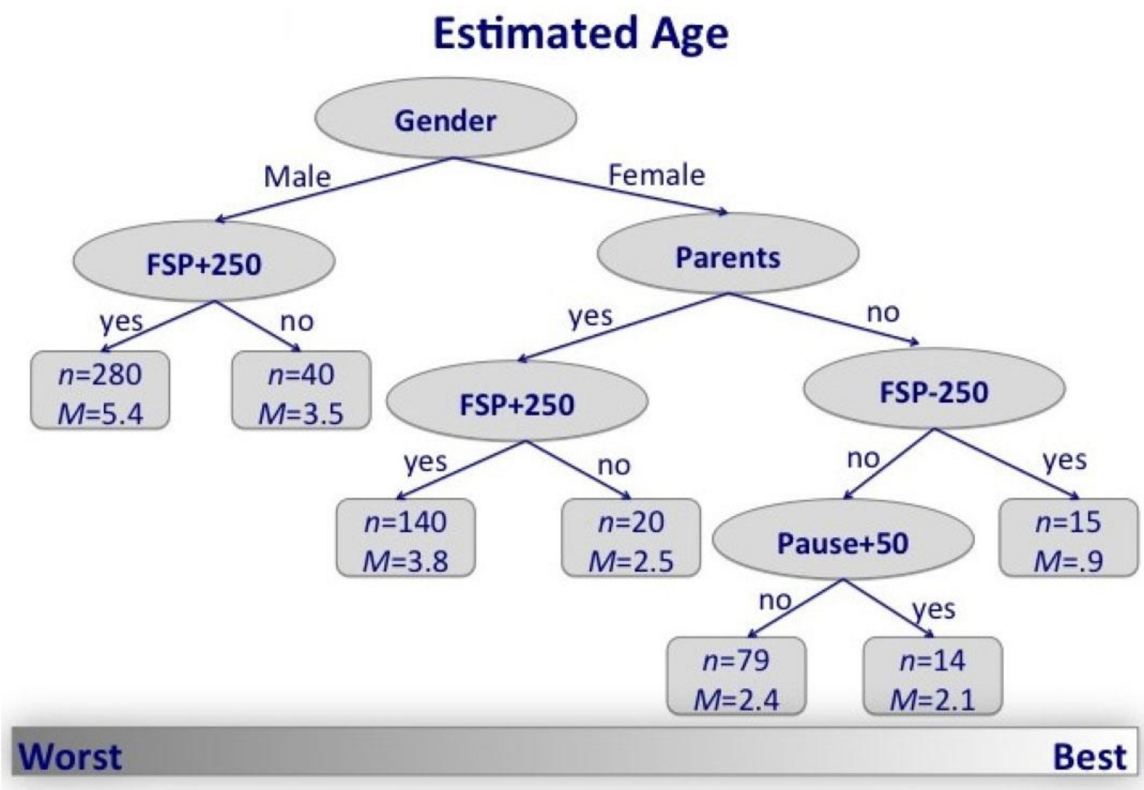

Figure 2 Optimal tree that predicts the worst to best infant age estimated is shown. The mean is the mean value of the group for the absolute distance between the real age of the infant and the age estimated from the participant.

Table 1 The absolute distance between the real age and the estimated age in months for the BASE cry and for the seven acoustic manipulations

	Nonparents		Parents	
	F	*M*	*F*	*M*
Base	1.20	1.10	1.00	1.55
Pause+50	2.15	1.90	1.80	2.45
Pause-50	2.80	1.50	1.20	2.60
Pause-100	2.20	2.30	2.15	3.35
FSP+250	1.60	1.55	1.40	1.75
FSP-250	3.45	2.75	2.40	3.95
Utterances+50	2.80	1.60	1.65	2.65
Utterances-50	2.15	2.25	1.65	2.55

Discussion

In this study, we assessed adult judgments of infant cries that were modulated by acoustic parameters and some central sociodemographic characteristics of listeners. We employed treebased modeling using three main acoustic parameters of the cry (pause length, fundamental frequency, and number of utterances) and two prominent listener socioemographic characteristics (Gender and Parental Status) of listeners as the independent variables. Treebased models explained the distributions of three dependent variables, Expressed Distress, Felt Distress, and Estimated Age, revealing the top-down hierarchy of the importance of independent variables. For Expressed Distress, for example, the most important (topmost) variable (in Figure 1B) was modification of the cry by pause length, PAUSE-100. This class of models is also useful because it defines which value ("node") of the independent variable subdivides ("split") the dependent variable in two groups that differ statistically (in the example, the topmost variable, the first node, divides the dependent variable Expressed Distress in two groups that differ statistically). Using the tree models we found that judgments of distress are mainly driven from the acoustical properties of the cry sounds, but the estimated age of the infant is driven by sociodemographic variables. These results imply that judgments of infant cry are multilevel phenomena, where both infant behavior and physiology (i.e., the way the cry sound is produced) and adult previous experiences strongly contribute.

With respect to our first hypothesis, the present study deconstructs ratings of distress of infant cries to ascertain the relative importance of some chief acoustic characteristics of the cry for expressed and felt distress. Many studies have pointed to fundamental frequency (*f*0) as the principal negative influence in responses to infant cry. Confirming our previous study (Esposito, del Carmen Rostagno, Venuti, Haltigan, & Messinger, 2014), here we found that pause length had the strongest impact on judgments of distress compared to *f*0 and the number of utterances in the cry. It may be that previous research has overlooked pauses as important because infant vocalizations have mainly been manipulated in terms of *f*0 rather than the absence of vocalizations (i.e., pauses).

We found no differences among females and males or parents and nonparents in judging expressed and felt distress to infant cries; however, in agreement with our second hypothesis we found that mothers were better than fathers, and parents were better than nonparents, at estimating infant age. It would appear from these data that infant cries are potent and robust emotional stimuli for all adult listeners, but that mothers acquire a certain expertise (from experience in rearing their own infants?), and this expertise generalizes to judgments of infant characteristics, such as age.

Together, the results of this study extend previous reports that suggest how the interpretation and response to infant cry are mediated by different factors, including the acoustic characteristics (Zeifman, 2003) of the cry as well as listener attitudes (Del Vecchio et al., 2009; Donate-Bartfield & Passman, 1985; Lin & McFatter, 2012), experience, (Gustafson & Harris, 1990), and sociodemographic characteristics (current study).

Some limitations of these experiments point to future directions of study. In this experiment, we only analyzed audible features of crying. It may be that nonmanifest features of the cry (i.e., emissions in the ultrasound range) increase the level of distress perceived or felt by directly influencing the perceiver autonomic nervous system. For this reason, it would be informative to replicate the present study usin cries recorded with a large range of sounds (from the lower limit of the human hearing to the low level of ultrasounds, 30 kHz). Further follow-up studies should investigate the role of other acoustic features, such as harmonic-tonoise ratio, homogeneity, frequency range, and energy, that previous studies have shown to reflect developmental changes in cries (Scheiner, Hammerschmidt, Jürgens, & Zwirner, 2002). Such work could improve our understanding of the relation between acoustic features and age estimation.Another limitation of the study is the fact that we assessed adults only in a specific cultural context (Japan; see Bornstein, 1989). Additional studies might assess the different cultural contexts of parents and nonparents of infants. Our results also point to the desirability of future research on brain responses of adults to infant cry. Future studies might therefore employ neuroimaging techniques to identify brain neural networks that contribute to the adult judgments of infant cry and how these neural networks differ in females and males as well as in mothers and fathers. These studies may also aim to provide fresh insights into early caregiver-infant interaction and the neural changes that take place with the transition to parenthood.

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