Parenting unraveled : predictors of infant attachment and responses to crying

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3 Sensitive and harsh caregiving responses to infant crying: The role of cry pitch and perceived urgency in an adult twin sample

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ABSTRACT

Objective: To examine the underlying mechanisms of adults' intended caregiving responses to cry sounds in a behavioral genetic design and to investigate the role of cry pitch and perceived urgency in sensitive and harsh caregiving responses.
Methods: The sample consisted of 184 adult twin pairs (18-69 years), including males and females, parents and nonparents. In an experimental design we presented cry sounds varying in pitch and measured adults' perception and their intended caregiving responses. Cry stimuli were based on a 10-second cry sample of a 2-day old infant with a fundamental frequency averaging 500 Hz. Two additional cry sounds were created by digitally increasing the fundamental frequency to 700 and 900 Hz.
Results: Individual differences in the perceived urgency of infant crying and sensitive caregiving responses were explained by genetic factors (38% and 39% respectively), while the variance in harsh caregiving responses was due to shared (31%) and unique (69%) environmental influences. Adults who perceived the cry sounds as more urgent were more likely to indicate sensitive caregiving responses, while high-pitched cry sounds were directly associated with more harsh caregiving responses.
Conclusions: The influence of genetic factors on intended caregiving responses to infant crying is substantial for normal variations in sensitive caregiving, but absent for harsh caregiving responses. The findings further suggest that the perception of infant crying as urgent paves the way for more immediate and affectionate caregiving responses, while an extreme increase in cry pitch may present a direct risk factor for more irritated, negative and even harsh parenting.
Practice implications: Infants who display abnormal cry acoustics such as extreme increases in pitch may be at risk for harsh parenting. Interventions should promote parental sensitive response to distress vocalizations to prevent harsh parenting in case of at-risk infants.

INTRODUCTION

Crying is one of the most salient behaviors during infancy: crying elicits care and nurturance, promotes parental proximity and conveys information to the parent about the health of the infant (Bell & Ainsworth, 1972; Murray, 1979; Zeifman, 2001; Zeskind & Lester, 1978). However, excessive as well as high-pitched crying may also be a proximal cause of abuse, neglect and even infanticide (Barr, Trent, & Cross, 2006; Frodi, 1985). Little is known about the underlying mechanisms of sensitive versus harsh responses to infant crying. Although the acoustic structure of the cry sound has a profound influence (LaGasse, Neal, & Lester, 2005), some adults are more negatively affected by infant crying than others, as manifested in more hostile attributions and heightened physiological reactivity (Bauer & Twentyman, 1985; McCanne & Hagstrom, 1996).

In the current twin study, we investigate the underlying mechanisms of adults' intended caregiving responses to cry sounds varying in pitch. First, we explore to what extent genetic and environmental factors contribute to the variance in sensitive and harsh caregiving responses. Second, we examine the influence of cry pitch and perception as more specific predictors of intended caregiving response.

Infant crying can be considered as a 'biological siren' (Ostwald, 1972), evolved to elicit parental proximity and caregiving (Bowlby, 1969; Murray, 1979; Zeifman, 2001). Given the limited evidence for qualitatively distinct cry types, crying can be viewed as a graded signal (Gustafson, Wood, & Green, 2000; Murray, 1979; Porter, Miller, & Marshall, 1986; Zeskind, Klein, & Marshall, 1992; Zeskind, Wilhite, & Marshall, 1993). Cry vocalizations vary along several acoustical dimensions, reflecting the intensity of the infant's distress. For example, cry pitch or fundamental frequency is directly related to parasympathetic activity in the child (Green, Irwin, & Gustafson, 2000; Porter, Porges, & Marshall, 1988). Adults are sensitive to these acoustic variations and use these cues as well as contextual information to interpret the cry and infer its causes. Many studies have demonstrated that adults' perception of cry sounds and their caregiving responses depend on a wide range of acoustic characteristics (LaGasse et al., 2005). In particular high-pitched cries are perceived as more urgent, elicit more physiological reactivity and more tender and caring responses on the part of the adult (Crowe & Zeskind, 1992; Zeskind, 1980; Zeskind & Marshall, 1988). This suggests a synchrony of arousal in parent and child, so that crying functions to elicit parental arousal and subsequent caregiving that alleviates the infant's distress (Zeskind, Sale, Maio, Huntington, & Weiseman, 1985).

Given the adaptive value of infant crying, reciprocal mechanisms may have evolved in the adult to perceive infant cries adequately and to respond appropriately (Newman, 2007; Zeifman, 2001). Indeed, several studies have shown that specific brain structures, neurotransmitters and peptide hormones are involved in the perception of infant crying and parental sensitivity to infant signals (Bakermans-Kranenburg & Van IJzendoorn, 2008; Feldman, Weller, Zagoory-Sharon, & Levine, 2007; Fleming, Corter, Stallings, & Steiner, 2002; Lorberbaum et al., 2002; Swain, Lorberbaum, Kose, & Strathearn, 2007;

Van IJzendoorn, Bakermans-Kranenburg, & Mesman, 2008). Both parents and nonparents respond with increased autonomic arousal to infant crying (Crowe & Zeskind, 1992; Frodi, Lamb, Neff et al., 1978). While listening to their own infants' cries, mothers were shown to display specific cardiac responses that are associated with preparation for action or intervention (Wiesenfeld, Malatesta, & Deloach, 1981).

On the other hand, infant crying has also been described as a proximal cause of abuse and neglect, and even infanticide (Soltis, 2004). Indeed, several studies of shaken baby syndrome have suggested that excessive, prolonged and inconsolable crying may trigger an abusive episode (Barr et al., 2006; Lee, Barr, Catherine, & Wicks, 2007; Talvik, Alexander, & Talvik, 2008). Apart from excessive crying, specific acoustic characteristics of cry sounds may also contribute to the development of abusive parent-child interactions, especially extreme increases in fundamental frequency (Frodi, 1985; Soltis, 2004). Infants with medical or neurological conditions or prenatal and perinatal complications often display these abnormal cry acoustics (Soltis, 2004; Wasz-Höckert, Michelsson, & Lind, 1985), while the same infants are also known to be at increased risk for abuse and neglect. Indeed, it has been shown that the cry sounds of these infants are perceived as especially aversive and elicit greater autonomic arousal in mothers than the cries of healthy infants (Frodi, Lamb, Neff et al., 1978; LaGasse et al., 2005; Zeskind & Lester, 1978). Mothers also reported that they were less willing to interact with premature infants after listening to their cry sounds (Frodi, Lamb, Neff et al., 1978). Therefore, parents' continued exposure to excessive and high-pitched crying accompanied by high levels of physiological arousal may suppress empathic responses in favor of more abusive responses (Frodi, 1985).

In addition to the influence of cry pitch, some parents may be more susceptible to stressful child stimuli than others. Experimental studies have shown that abusive parents feel more annoyed and hostile, and less sympathetic towards a crying infant compared to nonabusive parents (Bauer & Twentyman, 1985; Frodi & Lamb, 1980). Although abusive parents are able to differentiate between cry sounds varying in fundamental frequency, they perceive cry sounds with hyperphonation as less urgent than comparison parents and more similar to the cries of their own infants (Zeskind & Shingler, 1991). In addition, they tend to display excessive physiological arousal in response to crying, reflecting a hyperreactive trait (Frodi & Lamb, 1980; McCanne & Hagstrom, 1996). Interestingly, Crowe and Zeskind (1992) found that individuals at risk for child abuse displayed this heightened physiological response *before* they had children of their own. The authors conclude that "there may be some constitutional quality of some adult listeners that may predispose them to finding the psychophysical qualities of crying to be particularly grating and aversive" (p.27).

Therefore, both the acoustic structure of cry sounds as well as parents' perceptual and physiological responses to crying may influence their caregiving responses. Nevertheless, few studies have directly examined the relation between perception and caregiving. Two studies reported that adults waited longer to respond to infant cries which they had previously rated as sounding less distressed (Wood & Gustafson, 2001) and less aversive (Del Vecchio, Walter,

& O'Leary, 2009). However, these studies used cry sounds with a limited range in fundamental frequency, and focused on timing of intervention instead of type of caregiving responses. A prompt and sensitive response may be elicited only when cry sounds are perceived as aversive, arousing and urgent, especially when these perceptions are accompanied by feelings of empathy for the child (Zeifman, 2003). The perception of high-pitched cry sounds as aversive may be precisely what makes this cry so effective in eliciting care and nurturance. On the other hand, a strong aversion of infant crying, particularly when the cry is extremely high-pitched, may also lead to insensitive (Frodi, Lamb, Neff et al., 1978) and even harsh caregiving responses. To the best of our knowledge, no study has directly examined how cry pitch and adults' perceptions of cry sounds are related to active, harsh caregiving responses.

In the current twin study, we examined the underlying mechanisms of sensitive and harsh responses to infant crying in more detail. In an experimental paradigm we presented cry sounds varying in pitch and measured adults' perception and their intended caregiving responses. One of the cry sounds was extremely high-pitched, comparable to premature infants' cries (Wasz-Höckert et al., 1985) and associated with an increased risk for abusive parenting (Frodi, 1985).

First, we explored the extent to which individual differences in intended caregiving response are due to genetic and environmental influences. Although contextual factors affect how and when parents respond to their crying infant (Wood & Gustafson, 2001), genetic influences may also be important in making parents more or less sensitive to aversive and stressful child stimuli. Few behavior genetic studies have investigated parenting practices of adult twins who are also parents (Ganiban et al., 2007; Losoya, Callor, Rowe, & Goldsmith, 1997; Neiderhiser, Reiss, Lichtenstein, Spotts, & Ganiban, 2007; Neiderhiser et al., 2004; Pérusse, Neale, Heath, & Eaves, 1994; Spinath & O'Connor, 2003). Some studies have shown that positive parental behavior (such as parental warmth) is more heritable compared to parental control, negativity and discipline (Kendler & Baker, 2007; Losoya et al., 1997; Spinath & O'Connor, 2003).

Second, we examined the influences of cry pitch and perception of cry sounds as more specific predictors of intended caregiving responses. We hypothesized that cry sounds with a higher pitch as well as cry sounds that were perceived as more urgent and aversive would be related to both more sensitive and more harsh caregiving responses. Gender, age and parental status were also taken into account. Since cry sounds may be perceived as more negative by males and younger adults (Zeifman, 2003), we hypothesized that they would indicate less sensitive and more harsh caregiving responses. Lastly, experience with infant caregiving may be predictive of more differentiated caregiving responses, dependent on cry pitch. Therefore, we hypothesized that adults with children of their own would be more sensitive to the high-pitched cry sounds and would indicate less harsh caregiving behavior than adults without children.

Method

Participants

Participants were recruited using the municipal registers of five cities in the western region of the Netherlands, through advertisements and a website asking for participants, and by word of mouth. Of the total sample of 201 twin pairs, 17 pairs were not able to visit our lab due to a variety of reasons (e.g. health problems, too busy, personal reasons). The final sample consisted of 50 male and 134 female twin pairs, mean age 33.0 years (*SD* = 10.8, range 18 – 69). The majority of the twins were born in the Netherlands (93%) and they were from a predominantly middle-class population; their mean educational level was 3.46 (*SD* = 0.93) on a scale ranging from 1 (elementary school) to 7 (Bachelor's or Master's degree). Eighty-five percent of the participants worked outside the home, for an average of 31 hours per week (*SD* = 10.9). Twenty-nine percent of the participants were parents, the age range of their children varied from 1 month to 35 years. Ninety-three twin pairs (51%) were monozygotic and 91 were dizygotic (49%). Zygosity was determined on the basis of a questionnaire (Magnus, Berg, & Nance, 1983) and was verified using genetic analyses of some selected polymorphisms. Permission for the study was obtained from the local ethics committee and informed consent was obtained for all participants.

Procedure

Twin pairs were invited to the lab for a session lasting about three hours. They were tested individually in two quiet rooms. The lab visit started with several cognitive assessments; after a short break and an hour long interview, the cry perception task was administered. The task lasted about 30 minutes. Heart rate and skin conductance were measured during the interview and the cry perception task. Here we report on adults' perceptions of cry sounds and their intended caregiving responses.

Measures

Cry Paradigm. The cry perception task was administered using a laptop with E-prime software. Cry stimuli were derived from the spontaneous crying of a healthy two-day old, full birth-weight and full term female infant while she was in a supine position in its bassinette, midway between scheduled feedings. The cry was recorded at a sampling rate of 44.1 kHz using a directional microphone held approximately 20 cm from the infant's mouth. A 10-sec portion of the sustained period of crying, containing seven expiratory sounds, was selected for presentation. The durations and peak fundamental frequencies (Peak F_0) of each expiratory component were determined from a digital sound spectrographic display. The frequency of the Peak F_0 was obtained from the power spectrum resulting from a Fast Fourier Transform (FFT) of the 25 msec point at which the fundamental frequency reached its highest point in the expiratory sound. The seven cry expirations had a mean duration of 1055 msec (range: .6195 to 1899 msec) and a mean Peak F0 of 452.6 Hz (range: 425.2 to 515.6 Hz). The Peak F_0 of the entire cry was 515$\pm$15 Hz. Two new 10-sec cry stimuli were created by digitally increasing the original cry by approximately 200 and 400 Hz, respectively, resulting in two new 10-sec cry sounds with an overall Peak F_0 of 714.5 Hz (700 Hz Cry) and 895.8 Hz (900 Hz Cry). Changes in the Peak F_0 of these two cries were made with comparable changes in the harmonic structures of the seven cry expirations across the entire 10-sec cry sound segments while holding the temporal components constant.

The cry stimuli were presented at a constant volume through Sennheiser HD202 headphones. During the first part of the task, participants rated their perception of the cry sounds on four 5-point rating scales. During the second part of the task, participants rated the same cry sounds on seven 5-point rating scales to indicate their intended caregiving response. Subjects started the first and second part of the task with a practice trial where the 500 Hz cry was presented. After the practice trial the cry stimuli were presented in three cycles, the order of presentation was random within each cycle.

Perception. Participants rated each cry on four 5-point rating scales in order to assess the perceptions of the informative content of the cry sounds: aroused – not aroused, aversive – not aversive, sick – healthy, urgent – not urgent (Zeskind & Lester, 1978; Zeskind & Marshall, 1988). Each cry sound was presented and rated three times. For each fundamental frequency, a principal component analysis (PCA) with varimax rotation was conducted, which included the twelve ratings for perception (three ratings for arousal, three for aversion, three for urgent and three for sick). Each PCA pointed to one underlying component explaining between 42% and 46% of the variances, with factor loadings varying from .53 to .77. Therefore, the twelve ratings for perception were aggregated to obtain scores for the overall perceived urgency of the sound. Cronbach's alpha ranged from .88 to .89.

Intended caregiving responses. During the second part of the task, participants indicated their intended caregiving responses to each cry sound on seven 5-point rating scales. They were asked to indicate how likely they would respond with the following behaviors: pick up, cuddle, wait and see, give pacifier, feed (Zeskind, 1980, 1983), and focus on something else than on the crying baby. We additionally included 'firm handling' as a harsh response, to cover more extreme forms of insensitive behavior. The Dutch meaning of 'firm handling' explicitly refers to a harsh response, being strict and physically unpleasant for the baby. A PCA with varimax rotation was conducted for each fundamental frequency, including 21 variables (seven caregiving responses each rated three times per fundamental frequency). In all PCAs, three components were extracted (explained variance ranging from 50% to 54%). For the 500 Hz cry stimulus, the first component referred to sensitive care and included the items 'pick up', 'focus on something else' (reversed), 'feed', 'wait and see' (reversed) and 'cuddle' (factor loadings .39 - .76). The second component consisted of the items 'give pacifier' (factor loadings .76 - .78), and the third component referred to the harsh response 'firm handling' (factor loadings .74 - .83). For the 700 and 900 Hz cries, the caregiving items loaded similarly on the components, except that 'feeding' was sometimes included in the second (instead of the first) component. In these cases the factor loadings were only slightly higher for the second component compared to the first component. Therefore, we included 'feeding' in the first component, resulting in similar components across all cry sounds. This did not negatively impact internal consistency. The factor loadings for the 700 and 900 Hz cry sounds varied from .31 to .77 for the first component, from .72 to .83 for the second component, and from .66 to .89 for the last component. For the main analyses, we focused only on sensitive and harsh caregiving responses (first and third component), as these items clearly represent positive and negative styles of parenting. The ratings for pick up, cuddle, feed, wait and see (reversed) and focus on something else (reversed) were aggregated to obtain scores for (intended) sensitive response, whereas the ratings for firm handling were used as indicators for (intended) harsh response. Cronbach's alpha ranged from .79 to .91.

Analyses

First, we performed behavior genetic analyses in order to examine the sources of variance in the perception of infant crying and caregiving responses. Structural equation modeling was employed to quantify the relative contribution of additive genetic influences (A), shared (C) and unshared (E) environmental influences, by modeling these influences as latent (unmeasured) factors affecting individual differences in perception or caregiving. The relative importance of A, C and E was estimated by maximum likelihood methods in Mx (Neale, Boker, Xie, & Maes, 2003). The significance of A and C was tested by comparing the fit of a CE, AE, and E model to that of the full, saturated ACE model using likelihood ratio tests. When selecting the preferred model, Akaike's Information Criterion (AIC) was also considered as an index for the goodness-of-fit. Parsimonious models with a good fit to the data are indicated by large, negative values of AIC.

Behavior genetic analyses are reported for the 500 Hz cry sound, which is the original cry sound of a healthy infant. We subsequently examined whether the results for the 700 and 900 cry sounds were similar to those of the 500 Hz cry sound. We investigated the influence of gender and parenthood by conducting the behavior genetic analyses separately for the female twin pairs and for the twin pairs where both twins did not have children of their own. These were by far the largest groups.

Secondly, we employed multilevel regression models to estimate the effects of pitch and perception on sensitive and harsh caregiving responses. The choice for multilevel analyses resulted from the hierarchical structure of the data: the separate measurements of perception and caregiving were nested within individuals, while the individuals were nested within twin pairs. Therefore, three levels were specified: the twin level, the person level and the stimulus level. Gender, parenthood and age were entered to the model as predictors at the person level, while pitch and perception were entered as stimulus level predictors. All independent variables were centered around their mean. Multilevel regression models were fitted using MLwiN, version 2.02 (Rasbash, Charlton, Browne, Healy, & Cameron, 2005). Fixed regression coefficients were estimated by maximum likelihood and tested using two-tailed z-tests. Likelihood ratio tests were used to evaluate the variance of the random intercepts as well as overall model improvement.

A sequence of models was tested for sensitive and harsh caregiving responses separately. We started with an intercept-only model, which decomposed the variance in caregiving into three independent components (pertaining to the twin, person and stimulus level). This model was used as a baseline model. Gender, parenthood and age were added to the intercept-only model to examine the effect of these background variables on caregiving. In the next two steps, first pitch and then perception were entered into the model as predictors of caregiving, while the last model also included the interaction between perception and pitch.

RESULTS

Preliminary analyses

Descriptive statistics for perception and intended caregiving responses are reported in Table 1. The MZ and DZ twin correlations are displayed in Table 2; the model fitting results for the 500 Hz cry sounds can be found in Table 3. For most of the variables, a definite choice between AE and CE models was made on the basis of the pattern of twin correlations, the AIC values (for a direct comparison between non-nested models) as well as the χ^2 values.

Table 1.
Means and standard deviations of perception and intended caregiving response

	Males				Females				Total	
	Children		No children		Children		No children			
	M	SD	M	SD	M	SD	M	SD	M	SD
Perception[a]										
Cry 500 Hz	1.71	0.55	2.06	0.69	1.72	0.63	1.98	0.62	1.92	0.64
Cry 700 Hz	2.62	0.67	2.98	0.67	2.43	0.72	2.90	0.72	2.79	0.74
Cry 900 Hz	2.79	0.71	3.24	0.71	2.60	0.85	3.05	0.76	2.97	0.79
Sensitive response[b]										
Cry 500 Hz	2.79	1.05	2.92	0.73	3.17	0.92	3.14	0.87	3.08	0.88
Cry 700 Hz	3.91	0.77	3.78	0.57	3.80	0.77	3.95	0.64	3.89	0.67
Cry 900 Hz	3.71	0.88	3.75	0.56	3.75	0.78	3.75	0.74	3.75	0.73
Harsh response[b]										
Cry 500 Hz	1.23	0.50	1.42	0.67	1.20	0.49	1.38	0.67	1.34	0.63
Cry 700 Hz	1.31	0.85	1.54	0.73	1.31	0.59	1.43	0.72	1.42	0.71
Cry 900 Hz	1.29	0.70	1.47	0.70	1.39	0.81	1.44	0.82	1.42	0.79

[a] *N* = 368 (268 females and 100 males; 108 with children and 260 without children). [b] *N* = 363 (266 females and 97 males; 107 with children and 256 without children).

Table 2.
MZ and DZ twin correlations for perception and intended caregiving response

Cry sound	500 Hz		700 Hz		900 Hz	
	MZ	DZ	MZ	DZ	MZ	DZ
Perception[a]	.40**	.18	.31**	.23*	.33**	.18
Sensitive response[b]	.38**	.20	.27**	.20	.27*	.05
Harsh response[b]	.25*	.33**	.19	.30**	.14	.35**

Note. [a]$n = 93$ MZ twin pairs, $n = 91$ DZ twin pairs. [b]$n = 93$ MZ twin pairs, $n = 86$ DZ twin pairs. *$p < .05$ **$p < .01$

Table 3.
Model-fitting results for perception and intended caregiving responses (500 Hz cry sound)

Model	χ^2	df	p	AIC	A (%)	C (%)	E (%)
Perception[a]							
ACE					38 (0 – 53)	0 (0 – 37)	62 (47 – 79)
CE	2.41	1	.12	0.41		29 (16 – 42)	71 (58 – 85)
AE	0	1	-	-2.00	38 (22 – 53)		62 (47 – 78)
E	18.85	2	< .01	14.85			100
Sensitive response[b]							
ACE					38 (0 – 53)	0 (0 – 38)	61 (47 – 80)
CE	2.10	1	.15	0.10		29 (15 – 42)	71 (58 – 85)
AE	0	1	.99	-2.00	39 (21 – 53)		61 (47 – 79)
E	17.41	2	< .01	13.41			100
Harsh response[b]							
ACE					10 (0 – 53)	24 (0 – 44)	66 (47 – 84)
CE	0.13	1	.72	-1.87		31 (16 – 44)	69 (56 – 84)
AE	1.29	1	.26	-0.71	40 (20 – 55)		60 (45 – 80)
E	15.52	2	< .01	11.52			100

Note. 95% confidence intervals for A, C and E are reported in parentheses. A = genetic factors, C = shared environmental factors, E = unique environmental factors and measurement error, AIC = Akaike's Information Criterion.
[a]$n = 93$ MZ twin pairs, $n = 91$ DZ twin pairs. [b]$n = 93$ MZ twin pairs, $n = 87$ DZ twin pairs.

Perception. The twin correlation was substantially higher for MZ than for DZ twins, $r_{MZ}(92) = .40$, $p < .01$; $r_{DZ}(90) = .18$, $p = .09$. Model fitting results showed that the fit of the AE model was not significantly worse compared to the full ACE model (χ^2 [1, N=184] = 0, $p > .99$, AIC = -2.00). The CE model also fitted the data adequately (χ^2 [1, N=184] = 2.41, $p = .12$, AIC = 0.41), but the E model resulted in a significantly worse fit compared to the ACE model (χ^2 [2, N =184] = 18.85, $p < .01$, AIC = 14.85). The AE model was selected as the final model because the fit of this model was as good as the fit of the saturated model, the MZ twin correlation was substantially higher than the DZ twin correlation, and AIC was more negative for this model than for the CE model. Genetic factors explained 38% of the variance in the perceived urgency of infant crying, and unique environment (including measurement error) 62% of the variance.

Sensitive response. Both the AE model (χ^2 [1, N=180] = 0, $p > .99$, AIC = -2.00) and CE model (χ^2 [1, N=180] = 2.10, p = .15, AIC = 0.10) fitted the data adequately, while the E model resulted in a significantly worse fit compared to the ACE model (χ^2 [2, N=180] = 17.41, $p < .01$, AIC = 13.41). Based on the AIC values and pattern of twin correlations (r_{MZ}[92] = .38, $p < .01$; r_{DZ}[85] = .20, p = .07), the AE model was selected as the preferred model, with genetic factors explaining 39% of the variance in intended sensitive response, and unique environmental factors and measurement error 61% of the variance.

Harsh response. The twin correlations for an intended harsh response were similar for MZ and DZ twin pairs (r_{MZ}[92] = .25, p = .02; r_{DZ}[85] = .33, $p < .01$). The CE model (χ^2 [1, N=180] = 0.13, p = .72, AIC = -1.87) and the AE model (χ^2 [1, N =180] = 1.29, p = .26, AIC = -0.71) did not provide a significantly worse fit to the data compared to the ACE model, in contrast to the E model (χ^2 [2, N=180] = 15.52, $p < .01$, AIC = 11.52). Given the twin correlations and AIC values, the CE model is suggested as the preferred model, with differences in intended harsh responding explained by shared (31%) and unique (69%) environment (including measurement error).

Additional analyses. In order to examine possible gender differences, the same behavior genetic analyses were conducted for the female twin pairs (n = 67 MZ twin pairs, n = 69 DZ twin pairs). As for the total group, the AE model was the preferred model for perceived urgency ($p > .99$) and sensitive response (p = .83); the CE model was selected as the final model for harsh response (p = .50). In addition, we examined the influence of parenthood on the results of the behavior genetic analyses. Model fitting results based on the twin pairs in which both twins had no children of their own (n = 63 MZ, n = 52 DZ) showed that the AE model was again the preferred model for perceived urgency ($p > .99$) and sensitive response ($p > .99$), while the CE model was selected as the final model for harsh response (p = .51).

Finally, we investigated whether the same models applied for the 700 and 900 Hz cry sounds. Individual differences in perceived urgency of the 700 Hz cry were best described by a CE model (p = .73), while the preferred model for the 900 Hz cry was an AE model (p = .85) which is consistent with the results for the 500 Hz cry. For sensitive responses, a definite choice between an AE model (p = .63) and a CE model (p = .58) could not be made, while the E model was the preferred model for the 900 Hz cry (p = .06). With respect to harsh response, the CE model adequately described the data for both the 700 Hz ($p > .99$) and 900 Hz cry sounds ($p > .99$).

Effects of pitch and perception on intended sensitive response

Following the behavior genetic analyses, the effects of pitch and perception on intended caregiving responses were examined using multilevel analyses. For sensitive response, the twin level could be excluded from the intercept-only model ($\chi^2[1] = 0.18$, $p = .67$). Results of this model including the person and stimulus levels are presented in Table 4 (Model 1). The estimated value of the intraclass correlation was 0.08/(0.08+0.15) = 0.35 for the person level, providing clear evidence for a two-level hierarchical data structure. The mean rating for sensitive response across all cry sounds was 2.88. Gender, parenthood and age were added to the intercept-only model, but the inclusion of these variables did not explain additional variance compared to the intercept-only model ($\chi^2[3] = 3.81$, $p = .28$). Therefore, these variables were excluded from the next models.

The addition of pitch to the intercept-only model (Model 2) resulted in an improved fit ($\chi^2[1] = 29.97$, $p < .01$); an increase in pitch was associated with more sensitive responses ($z = 5.63$, $p < .01$). When perceived urgency was added in the next model (Model 3), pitch was no longer significant ($z = 1.50$, $p = .13$) but an increase in perceived urgency was associated with more sensitive responses ($z = 5.80$, $p < .01$). Overall, the fit of this model was good in comparison with Model 2 ($\chi^2[1] = 30.46$, $p < .01$). In the final model, the interaction between perceived urgency and pitch was added (Model 4). This model fitted well ($\chi^2[1] = 11.59$, $p < .01$); the interaction effect was significant ($z = 3.30$, $p < .01$). Separate multilevel regression models were estimated for each cry pitch. An increase in perceived urgency was associated with more sensitive responses for the 500 Hz ($z = 3.38$, $p < .01$) and 900 Hz cries ($z = 2.71$, $p = .01$), but not for the 700 Hz cry sound ($z = 1.53$, $p = .13$).

Effects of pitch and perception on intended harsh response

Results of the intercept-only model are presented in Table 4 (Model 1). The estimated value of the intraclass correlation was 0.12/(0.12+0.25+0.30) = .18 for the twin level and 0.25/(0.12+0.25+0.30) = .37 for the person level, providing evidence for a three-level hierarchical data structure. Across all cry sounds, the mean rating for harsh response for this sample was 1.39. Gender, age and parenthood were then added as predictors to the intercept-only model, but the model did not result in an improved fit ($\chi^2[3] = 4.60$, $p = .20$). Therefore, none of these three background variables were included in the next models. Cry pitch was subsequently added (Model 2) and the fit of this model was good in comparison with the intercept-only model ($\chi^2[1] = 13.87$, $p < .01$). An increase in pitch was associated with more harsh responses ($z = 3.67$, $p < .01$). Inclusion of perceived urgency did not explain additional variance in harsh response ($\chi^2[1] = 1.75$, $p = .19$); adding the interaction between urgency and pitch did also not result in an improved model fit compared to a model with only the main effects of perception and pitch ($\chi^2[1] = 0.01$, $p = .92$).

Table 4.
Effects of pitch and perception on sensitive and harsh response

	Sensitive response				Harsh response	
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2
Fixed effects						
Intercept	2.88 ± 0.02 (<.01)	2.88 ± 0.02 (<.01)	2.88 ± 0.02 (<.01)	2.89 ± 0.02 (<.01)	1.39 ± 0.04 (<.01)	1.39 ± 0.04 (<.01)
Pitch		0.05 ± 0.01 (<.01)	0.02 ± 0.01 (.13)	0.01 ± 0.01 (.27)		0.04 ± 0.01 (< .01)
Perception			0.06 ± 0.01 (<.01)	0.06 ± 0.01 (<.01)		
Perception*Pitch				-0.03 ± 0.01 (<.01)		
Variance components						
Twin level intercept (σ^2_{u0})					0.12 ± 0.03	0.12 ± 0.03
Person level intercept (σ^2_{u0})	0.08 ± 0.01	0.08 ± 0.01	0.08 ± 0.01	0.08 ± 0.01	0.25 ± 0.03	0.25 ± 0.03
Stimulus level intercept (σ^2_{u0})	0.15 ± 0.00	0.15 ± 0.00	0.15 ± 0.00	0.15 ± 0.00	0.30 ± 0.01	0.30 ± 0.01
Deviance	3694.87	3664.90	3634.45	3622.85	6217.06	6203.19

Note. Values refer to the estimates ± SD (two-sided p value Z-test).

Discussion

In the current study we examined the underlying mechanisms of adults' intended caregiving responses to infant cry sounds varying in pitch. Although genetic factors explained a substantial part of the variance in sensitive caregiving responses, individual differences in harsh caregiving responses were solely due to shared and unique environmental factors. Adults who perceived the cries as more urgent were also more likely to indicate sensitive caregiving responses, while high-pitched cry sounds were directly associated with more harsh responses. Gender, age and parental status were not related to intended caregiving responses; the behavior genetic results were comparable for males and females, and for parents and nonparents.

With regard to intended sensitive responses, an increase in cry pitch was associated with more immediate and affectionate caregiving responses, but the effect of pitch became nonsignificant when perceived urgency was taken into account. The interaction effect between cry pitch and perceived urgency was also significant: adults who perceived the 500 and 900 Hz cry sounds as more urgent, indicated that they were more likely to display sensitive responses. Taken together, these results are consistent with the view of crying as a graded signal (Gustafson et al., 2000; Murray, 1979; Zeskind et al., 1992; Zeskind et al., 1993) and the concept of differential responsiveness (Hubbard & Van IJzendoorn, 1991). Sensitive parents adapt their caregiving response to the specific acoustic characteristics of the cry reflecting the intensity of the infant's distress. Prompt responses to mild distress vocalizations (e.g. fussing) may only reinforce crying behavior and interfere with the development of emotion regulation skills (Van IJzendoorn & Hubbard, 2000), while severe distress vocalizations require prompt and sensitive caregiving for the development of a secure attachment relationship (Ainsworth, Blehar, Waters, & Wall, 1978). Two previous studies have also shown that adults were more likely to respond quickly to infant cries they perceived as more distressing and aversive (Del Vecchio et al., 2009; Wood & Gustafson, 2001). However, these studies concerned only *timing* of intervention to cry sounds with a limited range in cry pitch. The current study adds to these results by showing that high-pitched cry sounds are perceived as more urgent, paving the way for more affectionate and immediate responses.

The importance of an accurate perception of the level of infant distress has been demonstrated by Lester and colleagues (1995). They showed that a match between the acoustic structure of an infant's cry and maternal perceptions of the cry predicts improved language and cognitive skills at 18 months. It was argued that mothers who read their infant's signals accurately will modify their behavior accordingly and thereby support their infant's development. Studies on parent-infant synchrony have also demonstrated that parents' careful adaptations to their infants' social cues regulate their infants' heart rhythms (Moore & Calkins, 2004) and predict later psychosocial adjustment (Feldman, 2007).

Consistent with the hypothesis that high-pitched crying is a proximal cause of abuse (Frodi, 1985; Soltis, 2004; Zeskind & Lester, 1978), the results of the current study show that cry sounds with a higher pitch elicit more intended harsh caregiving responses. Although some studies have investigated the relation between the acoustic structure of the cry and withdrawn caregiving responses (Frodi, Lamb, Neff et al., 1978; Schuetze & Zeskind, 2001; Schuetze, Zeskind, & Eiden, 2003), this is the first study showing a direct association between high-pitched crying and active, harsh caregiving. An extremely high pitch can be observed in transient pain cries of normal, healthy infants (Porter et al., 1986), but chronic and severe acoustic abnormalities are especially characteristic of infants with a range of medical and neurological conditions, such as brain damage, chromosomal disturbances, asphyxia and severe prematurity (LaGasse et al., 2005). Soltis (2004) has argued that in premodern environments, severely ill infants would have had very low chances of survival, and in these circumstances selective withdrawal of parental investment could be adaptive. Thus, chronic and severely abnormal crying as indicative of severe illness may increase the risk for abuse and neglect, especially in combination with other risk factors at the parent, family and community level (Belsky, 1993).

Controlling for the effects of cry pitch, the overall perception of infant crying was not related to intended harsh caregiving responses. Two previous studies have also shown that abusive parents are able to differentiate between cry sounds varying in the amount of hyperphonation (Crowe & Zeskind, 1992; Zeskind & Shingler, 1991). Abusive parents' distorted perceptions of infant crying that have been found in previous studies may involve more specific attributions referring to hostility and frustration rather than the perceived urgency (Bauer & Twentyman, 1985; Frodi & Lamb, 1980). These biased perceptions of crying may only become apparent in stressful situations (Schellenbach, Monroe, & Merluzzi, 1991). Finally, parental negative emotions elicited by infant crying may present a risk for abuse only when accompanied by lack of empathy (Milner, Halsey, & Fultz, 1995; Zeifman, 2003).

Most strikingly, genetic factors explained a significant amount of variance in intended sensitive caregiving responses, while harsh caregiving responses were explained by shared and unique environmental factors instead of genetics. Spinath and O'Connor (2003) also found that rejection was not due to genetic factors but to the shared environment. In that study, rejecting parents were described as "parents who indicated that having children was regarded as a burden they found hard to handle" (p. 791). For rejecting parents high-pitched or excessive and inconsolable crying may indeed elicit harsh parenting behavior. In line with these results, genetic influences were found to be larger for positive support than for negative control (Losoya et al., 1997). Other twin studies have not demonstrated that negativity, control and discipline were less heritable than the positive aspects of the parent-child relationship (Ganiban et al., 2007; Neiderhiser et al., 2007; Neiderhiser et al., 2004), but these studies focused exclusively on parenting of adolescents. In fact, the difference in heritability of sensitive versus harsh responses to infant crying replicates the findings of Jaffee and colleagues (2004). In their E-Risk Longitudinal Twin Study, they showed that children's genetically influenced behavior elicited physical discipline, but not maltreatment from their parents. Whereas their design included twins-as-children and their parents, the current study extends these results by experimentally showing that in a low-risk sample, harsh parenting is less influenced by the parent's genes than more normal variations in sensitive or insensitive parenting.

The role of genetic factors in the perceived urgency of crying and intended sensitive responses that we documented is consistent with previous findings suggesting that measures of the family environment are under significant genetic control (Ganiban et al., 2007; Losoya et al., 1997; Neiderhiser et al., 2007; Neiderhiser et al., 2004; Pérusse et al., 1994; Spinath & O'Connor, 2003). With regard to sensitive parenting in response to infant signals, two recent molecular genetic studies have demonstrated that observed sensitive parenting was associated with the less efficient variants of the oxytocin receptor and serotonin transporter genes (Bakermans-Kranenburg & Van IJzendoorn, 2008) and with specific genetic polymorphisms affecting the dopaminergic system in the context of daily hassles (Van IJzendoorn et al., 2008). Future studies may examine whether these polymorphisms modulate parental perception of and caregiving responses to infant crying (Newman, 2007; Swain et al., 2007). Genetic factors also influence physiological reactivity to stress (e.g. De Geus, Kupper, Boomsma, & Snieder, 2007), which may mediate genetic effects on caregiving behavior.

The current study has some limitations. First, the factor structure of the perception of crying was similar for all cries regardless of pitch. Zeskind and Lester (1978) found that the perception of high-pitched cry sounds was best described by two dimensions: the first dimension reflected the extent to which the infant sounded sick and the second dimension represented the perceived aversiveness. However, they used cry sounds that not only differed in cry pitch but also in other acoustic characteristics which may have affected adult perception. Further, the random presentation of the cries in the current study may have diminished the differences in factor structure between the cry sounds. Second, only three cry sounds of relatively short duration were used and presented in a laboratory context, with subjects reporting their caregiving responses. Although the use of standardized infant stimuli presented in a standardized context is necessary to disentangle the influences of cry sounds and perception from contextual factors, future research may combine these measures with more dynamic measures of perception and observed caregiving (Del Vecchio et al., 2009; Frodi & Senchak, 1990; Hubbard & Van IJzendoorn, 1991). Further, crying has a complex acoustic structure that changes during a long cry bout (Green, Gustafson, & McGhie, 1998), and future research should take into account the natural richness of cry bouts.

In sum, the current study shows that sensitive caregiving responses are influenced by genetic factors and are associated with the perceived urgency of the cry. Harsh caregiving responses were influenced by both shared and unique environmental factors, and cry pitch may present a direct risk factor for harsh parenting. Intervention studies aiming at an accurate perception of infant cry sounds and sensitive responses to severe distress vocalizations should therefore be given priority in order to prevent the negative consequences of harsh parenting in response to infant crying.