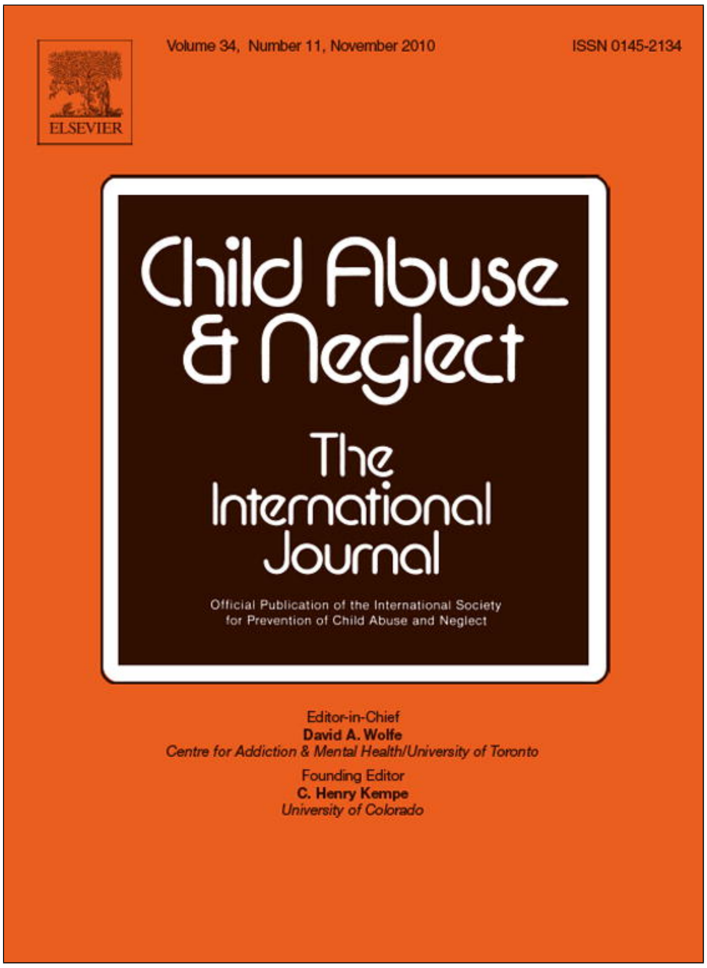
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Intended sensitive and harsh caregiving responses to infant crying: The role of cry pitch and perceived urgency in an adult twin sample☆

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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 intended 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 were more likely to indicate sensitive caregiving responses to higher-pitched cry sounds and when they perceived the cries as more urgent, while high-pitched cry sounds were also directly associated with 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 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.

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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 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 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 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, some parents may be more reactive to stressful child stimuli than others. Experimental studies have shown that abusive parents feel more annoyed, 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 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 adults' anticipated 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 very high-pitched, associated with an increased risk for abusive parenting (Frodi, 1985), and comparable to severe distress vocalizations in healthy infants (Porter et al., 1986) and to the cries of infants with medical and neurological conditions (Wasz-Höckert et al., 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 factors may play a role in making parents more or less sensitive to aversive and stressful child stimuli. There are several indications that basal neurobiological factors are involved in the perception of and response to infant crying (e.g., Newman, 2007; Swain et al., 2007). Furthermore, some adults are more reactive to the aversive features of cry sounds, even before they have children of their own (McCanne & Hagstrom, 1996). However, few behavior genetic studies have investigated parenting practices of adult twins with children (but see Ganiban et al., 2007; Losoya, Callor, Rowe, & Goldsmith, 1997; Neiderhiser, Reiss, Lichtenstein, Spotts, & Ganiban, 2007; Neiderhiser et al., 2004; Perusse, 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 (e.g., Zeifman, 2003), we hypothesized that they would indicate less sensitive and more harsh caregiving responses. Finally, experience with infant caregiving may affect caregiving responses. 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 5 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 5 (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 mean age of their children was 12.02 years (SD = 7.27). 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 3 hours. They were tested individually in 2 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 2-day old, full birth-weight, and full term female infant while she was in a supine position in her 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-second portion of the sustained period of crying, containing 7 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 millisecond point at which the fundamental frequency reached its highest point in the expiratory sound. The 7 cry expiratory sounds had durations with a mean of 1.055 seconds (ranging from .545 to 1.899 seconds), and a mean Peak F_0 of 452.6 Hz (range: 425.2–515.6 Hz). The Peak F_0 of the entire cry was 515 ± 15 Hz. Two new 10-second cry stimuli were created by digitally increasing the original cry by approximately 200 and 400 Hz, respectively, resulting in 2 new 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 2 cries were made with comparable changes in the harmonic structures of the 7 cry expirations across the entire 10-second cry sound segments while holding the temporal components constant.

The cry stimuli were presented at a similar 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 3 cycles. Each cycle consisted of 3 cry sounds (500, 700, and 900 Hz); 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 3 times. For each fundamental frequency, a principal component analysis (PCA) with varimax rotation was conducted, which included the 12 ratings for perception (3 ratings for arousal, 3 for aversion, 3 for urgent, and 3 for sick). Each PCA pointed to 1 underlying component explaining between 42% and 46% of the variances, with factor loadings varying from .53 to .77. Therefore, the 12 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 (see also Zeskind, 1980, 1983): pick up, cuddle, wait and see, give pacifier, feed, 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 (7 caregiving responses each rated 3 times per fundamental frequency). In all PCAs, 3 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. Monozygotic (MZ) and dizygotic (DZ) twins differ in their genetic relatedness: MZ twins share 100% of their genes whereas DZ twins share on average 50% of their genes. By comparing the resemblance of MZ twins for a trait with the resemblance of DZ twins, it is possible to estimate to what extent genetic factors explain phenotypic variation for that trait. Environmental influences are *shared* by both members of a twin pair when they make them more similar in their behavior, whereas *unique* environmental factors make twins more different. In order to quantify and test the significance of genetic factors (A) and shared environmental (C) and unique environmental (E, including measurement error) factors, structural equation modeling was employed, in which each of these (genetic and environmental) influences is modeled as a latent (unmeasured) factor affecting individual differences in perception or caregiving. These latent factors represent the effects of many unidentified genes or environmental factors. The relative importance of A, C, and E was estimated by maximum likelihood methods in Mx, version 1.7.03 (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. For example, when the fit of a CE model is significantly worse compared to the ACE model, genetic factors explain

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

Note: Differences in intended caregiving responses between males and females, parents and nonparents, and the association with fundamental frequency are examined in the multilevel analyses.

[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).

a significant part of the variance in perception or caregiving. 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 Hz 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.

Second, we employed multilevel regression models to estimate the effects of pitch and perception on intended 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 was entered into the model as a predictor at the twin level, parenthood and age were entered 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 fit 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. Twin correlations were similar when we controlled for diagnosed hearing difficulties (ranging from tinnitus to a poor sense of hearing on one side), reported by 6.5% of the sample; the mean change in correlations was $r = .02$. 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.

Perception. The twin correlation was substantially higher for MZ than for DZ twins, rMZ (91) = .40, $p < .01$ and rDZ (89) = .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 fit 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].

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**

[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	–	−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, $N = 86$ DZ twin pairs.

Due to the relatively small sample size, a choice between an AE and CE model could not be made solely on the basis of the χ^2 values. However, 3 indicators pointed to the AE model as the best-fitting model: the fit of the AE model was as good as the fit of the saturated model, the MZ twin correlation was substantially higher than the DZ twin correlation, and the AIC value was more negative for this model than for the CE model (see Table 3). Genetic factors explained 38% of the variance in the perceived urgency of infant crying, and unique environment (including measurement error) 62% of the variance.

Intended sensitive response. Both the AE model [χ^2 (1, $N = 179$) = 0, $p > .99$, AIC = -2.00] and CE model [χ^2 (1, $N = 179$) = 2.10, $p = .15$, AIC = 0.10] fit the data adequately, while the E model resulted in a significantly worse fit compared to the ACE model [χ^2 (2, $N = 179$) = 17.41, $p < .01$, AIC = 13.41]. Based on the AIC values and pattern of twin correlations [rMZ(91) = .38, $p < .01$; rDZ(84) = .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.

Intended harsh response. The twin correlations for an intended harsh response were similar for MZ and DZ twin pairs [rMZ (91) = .25, $p = .02$; rDZ(84) = .33, $p < .01$]. The CE model [χ^2 (1, $N = 179$) = 0.13, $p = .72$, AIC = −1.87] and the AE model [χ^2 (1, $N = 179$) = 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, $N = 179$) = 15.52, $p < .01$, AIC = 11.52]. The twin correlations and AIC values pointed to the CE model as the preferred model, with differences in intended harsh response explained by shared environment (31%) and unique environment (69%, including measurement error).

Additional analyses. In order to examine possible gender differences, the same behavior genetic analyses were conducted for the female twin pairs ($N = 65$ 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 intended sensitive response ($p > .99$), while the CE model was selected as the final model for harsh response ($p = .51$). In sum, for female twin pairs and nonparents, as for the total sample, the variance in perceived urgency and sensitive response was explained by genetic

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	3.57 ± 0.03 (<.01)	3.57 ± 0.03 (<.01)	3.57 ± 0.03 (<.01)	3.63 ± 0.03 (<.01)	1.39 ± 0.04 (<.01)	1.39 ± 0.04 (<.01)
Pitch		0.34 ± 0.02 (<.01)	0.21 ± 0.02 (<.01)	0.19 ± 0.02 (<.01)		0.04 ± 0.01 (<.01)
Perception			0.24 ± 0.02 (<.01)	0.23 ± 0.02 (<.01)		
Perception × pitch				−0.16 ± 0.02		
Variance components						
Twin level intercept (σ^2_{u0})	0.09 ± 0.03	0.09 ± 0.03	0.07 ± 0.02	0.08 ± 0.02	0.12 ± 0.03	0.12 ± 0.03
Person level intercept (σ^2_{u0})	0.16 ± 0.03	0.17 ± 0.03	0.18 ± 0.03	0.18 ± 0.03	0.25 ± 0.03	0.25 ± 0.03
Stimulus level intercept (σ^2_{u0})	0.72 ± 0.02	0.64 ± 0.02	0.62 ± 0.02	0.60 ± 0.02	0.30 ± 0.01	0.30 ± 0.01
Deviance	8,689.40	8,330.47	8,206.39	8,145.13	6,217.06	6,203.19

Note: Values refer to the estimates ± SE (two-sided *p*-value *z*-test).

factors and unique environmental factors; individual differences in intended harsh response were mainly due to shared and unique environmental factors.

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 was consistent with the results for the 500 Hz cry. For intended sensitive responses to the 700 Hz cry sound, 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 anticipated 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. The estimated value of the intraclass correlation was 0.09/(0.09 + 0.16 + 0.72) = .09 for the twin level and 0.16/(0.09 + 0.16 + 0.72) = .16 for the person level, providing evidence for a 3-level hierarchical data structure. Results of this model with the twin, person and stimulus levels are presented in Table 4 (Model 1). The mean rating for intended sensitive response across all cry sounds was 3.57. 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 [χ^2 (3) = 2.82, $p = .42$]. 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 [χ^2 (1) = 358.93, $p < .01$]; an increase in pitch was associated with more reported sensitive responses ($z = 19.71$, $p < .01$). When perceived urgency was added in the next model (Model 3), pitch remained significant ($z = 10.60$, $p < .01$), and an increase in perceived urgency was associated with more intended sensitive responses ($z = 11.24$, $p < .01$). Overall, the fit of this model was good in comparison with Model 2 [χ^2 (1) = 124.07, $p < .01$]. In the final model, the interaction between perceived urgency and pitch was added (Model 4). This model fit well [χ^2 (1) = 61.26, $p < .01$]; the interaction effect was significant ($z = 7.75$, $p < .01$). Separate multilevel regression models were estimated for each cry pitch. An increase in perceived urgency was associated with more intended sensitive responses for the 500 Hz ($z = 4.50$, $p < .01$) and 900 Hz cries ($z = 3.58$, $p < .01$), but not for the 700 Hz cry sound ($z = 0.16$, $p = .87$).

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 3-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 [χ^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 [χ^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 [χ^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 [χ^2 (1) = 0.01, $p = .92$]. The results of the multilevel analyses did not change when hearing difficulties were taken into account.

Discussion

In this first twin study on adult responses to infant crying we examined the underlying mechanisms of intended caregiving responses to infant cry sounds varying in pitch. Although genetic factors explained a substantial part of the variance in intended sensitive caregiving responses, individual differences in anticipated harsh caregiving responses were solely due to shared and unique environmental factors. Adults were more likely to indicate sensitive caregiving responses to high-pitched cry sounds and when they perceived the cries as more urgent, while high-pitched cry sounds were also directly associated with indicated 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, participants were more likely to indicate immediate and affectionate caregiving responses to high-pitched cries and to cries that were perceived as more urgent. 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, 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. Indeed, Zeskind and Collins (1987) found that in a naturalistic setting prompt and comforting caregiving behaviors occurred more often in response to higher-pitched compared to lower-pitched cries.

The importance of an accurate perception of the level of infant distress has been demonstrated by Lester et al. (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 also 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 et al., 1978; Schuetze & Zeskind, 2001; Schuetze, Zeskind, & Eiden, 2003), this is the first study showing a direct association between high-pitched crying and intended harsh caregiving responses. 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 (for a review see 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, whereas an increase in pitch generally elicits more immediate and affectionate responses, chronic and severely abnormal crying as indicative of severe illness may increase the risk for abuse and neglect in the presence of 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).

It should be noted that intended harsh caregiving responses were assessed using a single item ("firm handling"), referring to negative, harsh, and insensitive behaviors towards the infants (e.g., slapping, shaking, yelling). We did not include items describing specific aggressive behaviors (in order to avoid socially desirable responses), but the negative and authoritarian meaning of the item "firm handling" is unequivocal. This is supported by the finding that high-pitched cry sounds elicited more intended harsh responses, and that higher ratings on this item were associated with higher ratings on aversiveness (one of the items included in the perceived urgency construct on the basis of the PCA) and with lower ratings for intended sensitive responses. The associations with cry pitch and perceived aversiveness are consistent with central assumptions about the role of infant crying in harsh and abusive caregiving (e.g., Frodi, 1985; Zeskind & Lester, 1978). Thus, although replication of our findings with additional measures of observed harsh caregiving is necessary, our results confirm previous findings that extremely high-pitched cry sounds may form a risk factor for more irritated, negative, and harsh parenting.

Most strikingly, the behavior genetic analyses suggested that 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 our 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, 2004), but these studies focused exclusively on parenting of adolescents. In fact, the difference in heritability of intended sensitive versus harsh responses to infant crying is consistent with the findings of Jaffee et al. (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, intended harsh parenting is less influenced by the parent's genes than more normal variations in intended sensitive or insensitive parenting.

The role of genetic factors in the perceived urgency of crying and intended sensitive responses is in line 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, 2004; Perusse et al., 1994; Spinath & O'Connor, 2003). The results of the current study suggest that there are genetic factors that influence individual differences in reactivity to cry sounds. Some parents are, for genetic reasons, more affected by their infants' crying than others. Previous studies have shown that genetic factors influence physiological reactivity to stress (e.g., De Geus, Kupper, Boomsma, & Snieder, 2007), which may mediate genetic effects on caregiving behavior. The presence of other risk factors such as parenting stress due to excessive and/or aversive crying may turn a genetic risk into insensitive or harsh parenting (see for a comparable discussion on vulnerable parents MacKenzie & McDonough, 2009; St. James-Roberts, Conroy, & Wilsher, 1998). More knowledge about these causal mechanisms is essential for designing effective intervention programs. Two recent molecular genetic studies have already 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).

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. Secondly, the relatively small sample size made it more difficult to select the best-fitting model in the behavior genetic analyses. The results are nevertheless consistent with previous twin studies of parenting (e.g., Losoya et al., 1997). Furthermore, only three cry sounds of relatively short duration were used and presented in a laboratory context, with subjects reporting their intended caregiving responses. The experimental design—standardized infant stimuli, a laboratory context, and self-report of anticipated caregiving behavior—was necessary to disentangle the influences of cry sounds, perception, and heritable adult characteristics 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; Green, Gustafson, & McGhie, 1998; Hubbard & van IJzendoorn, 1991; Zeskind & Collins, 1987). In these studies, it would also be essential to investigate how anticipated caregiving responses are related to actual parenting behavior.

In sum, the current study shows that adults' intended sensitive caregiving responses are influenced by genetic factors and are associated with cry pitch and the perceived urgency of the cry. Intended 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.

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