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Human Emotional Vocalizations Can Develop in the Absence of Auditory Learning

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Are emotional expressions shaped by specialized innate mechanisms that guide learning, or do they develop exclusively from learning without innate preparedness? Here we test whether nonverbal affective vocalisations produced by bilaterally congenitally deaf adults contain emotional information that is recognisable to naive listeners. Because these deaf individuals have had no opportunity for auditory learning, the presence of such an association would imply that mappings between emotions and vocalizations are buffered against the absence of input that is typically important for their development and thus at least partly innate. We recorded nonverbal vocalizations expressing 9 emotions from 8 deaf individuals (435 tokens) and 8 matched hearing individuals (536 tokens). These vocalizations were submitted to an acoustic analysis and used in a recognition study in which naive listeners ($n = 812$) made forced-choice judgments. Our results show that naive listeners can reliably infer many emotional states from nonverbal vocalizations produced by deaf individuals. In particular, deaf vocalizations of fear, disgust, sadness, amusement, sensual pleasure, surprise, and relief were recognized at better-than-chance levels, whereas anger and achievement/triumph vocalizations were not. Differences were found on most acoustic features of the vocalizations produced by deaf as compared with hearing individuals. Our results suggest that there is an innate component to the associations between human emotions and vocalizations.

Keywords: emotion, learning, innateness, vocalizations, preparedness

Supplemental materials: <http://dx.doi.org/10.1037/emo0000654.supp>

Whether learning can fully account for human emotional signals is a hotly contested issue (e.g., Barrett, 2011; Shariff & Tracy, 2011). This question is crucial to understanding what emotions really are: If emotions exclusively depend on acquired associations, they can be fully understood by mapping out the specific

environmental mechanisms that shape emotional development. If, however, some predispositions for emotional development are provided by inherited factors, insights into the evolutionary forces and mechanisms that have shaped this system will provide an important route to understanding emotions (Ariew, 2006; Griffiths, 1997).

Innateness and learning are not mutually exclusive because learning does not only occur in the development of systems that lack preparedness. For example, healthy kittens are genetically predisposed to develop vision, but if deprived of light from birth, their visual system develops atypically (Wiesel & Hubel, 1963). In the study of human emotion, a common approach to the nature-nurture question has been to use cross-cultural comparisons, based on the logic that innate components are largely shared across groups, whereas learned aspects vary. Cross-cultural studies of emotional communication have found considerable consistency in emotions like fear, anger, and sadness for both facial and vocal expressions (e.g., Ekman, Sorenson, & Friesen, 1969; Sauter, Eisner, Ekman, & Scott, 2010b). However, many types of social and environmental input are shared across cultural groups, allowing for the possibility that emotion-expressions pairings may be learned from input that is consistent across human societies.

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A different method is to look for homologues of human emotional expressions in nonhuman animals, which indicate deep evolutionary roots. Some of the strongest evidence for phylogenetic continuity of emotional expressions comes from studies of vocalizations: All great apes species laugh when tickled (Davila Ross, Owren, & Zimmermann, 2009), and laughter is also found in other social mammals during play (Knutson, Burgdorf, & Panksepp, 1998). Retching in response to offensive food is found across mammals (see Toronchuk & Ellis, 2007), and many species emit screams when threatened, including primates (e.g., Linnankoski, Laakso, Aulanko, & Leinonen, 1994) and birds (Hogstedt, 1983). The production of sighs in response to the removal of threat occurs in nonhuman social mammals (Soltysik & Jelen, 2005). And in addition to the complex grief behavior seen in chimpanzees (Cronin, van Leeuwen, Mulenga, & Bodamer, 2011), many species of apes and monkeys emit distress calls in response to separation (see Maestripieri & Call, 1996). However, there is a lack of research on some emotional signals often studied in humans, including behaviors produced in response to unexpected (surprising) events.

A further approach is to examine to what extent functions are affected by the absence of sensory input: In contrast to traits that rely exclusively on learning, traits that have an innate foundation tend to be buffered (e.g., protected thanks to redundancy) against variation in the environmental parameters that are important for their development (Ariew, 2006; see also Mameli & Bateson, 2006). Studies have capitalized on this fact by examining individuals who have had reduced opportunity for specific kinds of learning because of the absence of a type of sensory input, such as populations with congenital blindness or deafness. In one remarkable example, a sign language was found to have developed in a community of deaf Nicaraguans who lacked exposure to a developed language. The emergence of a language in a community with reduced opportunity for language learning points to innate mechanisms to develop human language (Senghas, Kita, & Ozyürek, 2004). Regardless of whether the innate mechanisms underlying an ability are specific or general, their existence means that development is not merely the result of individual learning opportunities (see Ariew, 2006).

In this study we examined nonverbal emotional vocalizations produced by bilaterally congenitally deaf adults to test for learning preparedness in the mapping between nonverbal vocal expressions and affective states. In humans, as well as some other species, hearing is essential for normal vocal development (see Brainard & Doupe, 2000). Developmental studies of deaf individuals' vocal production point to an important role of audition, even for simple vocalizations. For example, findings indicate that although hearing and hearing-impaired infants broadly have the same vocal repertoire (Scheiner, Hammerschmidt, Jürgens, & Zwirner, 2004), experienced listeners, but not nonexperts, are able to discriminate cries produced by deaf, as compared with hearing, infants (Möller & Schönweiler, 1999). Vocal babbling is also different in deaf as compared with hearing infants (Oller & Eilers, 1988), and an analysis of the vocalizations of a child born without any cochleas (i.e., total deafness) found that the 3-year-old largely produced sounds characteristic of early infant vocal production (Lynch, Oller, & Steffens, 1989). However, although several studies have examined emotional vocalizations of individuals born deaf, most

have studied infants in whom the emotional states are difficult to verify.

One study has examined nonverbal vocalizations in deaf adults, specifically focusing on laughter (Makagon, Funayama, & Owren, 2008). Makagon et al. found that auditory learning was not necessary for the development of laughter because the laughter of deaf and hearing individuals was acoustically similar. However, little is known about the role of auditory learning in the development of other nonverbal vocalizations, such as sad sobs, triumphant cheers, disgusted retching, or relieved sighs.

We aimed to test whether the links between a range of positive and negative emotional states and vocalizations develop exclusively as a result of individual auditory learning or whether they show evidence of learning preparedness. Behavioral recognition data were collected to test whether the information in the deaf vocalizations would be sufficient for naive listeners to be able to infer which emotional state the producer was expressing. Acoustic information was measured, primarily intended to add descriptive information to the experimental data, but also to show which, if any, specific types of cues differ across deaf and hearing vocalizations. If the vocalizations of congenitally deaf individuals are similar to the vocalizations of hearing people, and recognizable to listeners in terms of emotional content, this would provide evidence in support of learning preparedness because these mappings would then be buffered against the absence of auditory learning. Such a finding cannot be accounted for by a learning-only account. If, in contrast, vocal expressions produced by people born deaf are not recognizable, this would point to the associations between vocal signals and emotions likely being based on individual auditory learning.

Method

Stimuli

The stimuli were produced by eight congenitally bilaterally deaf Dutch individuals (four males; mean age 43 years, age range 29–72 years) and eight matched controls (four males; mean age 42 years, age range 29–70 years). All gave informed consent and were recorded individually in a sound-proof room. All deaf individuals reported severe to profound hearing impairment (i.e., deafness according to the criteria of the Dutch Audiological Society). In seven of eight cases, this was confirmed by audiological records. Five of the deaf producers were deaf because of genetic causes (and had deaf parents). In one case, deafness was due to maternal illness during pregnancy. In two cases, the cause of deafness is unknown. All were diagnosed in early infancy. Participants self-defined as having a primary and positive identity of being deaf, and all used sign as their primary language. Most had tried hearing aids, but none used a hearing aid regularly (hearing impairment in decibel and hearing aid use per deaf individual are provided in [online supplemental materials](#)).

Using brief written scenarios (see [online supplemental materials](#)) offered to subjects in a sign translation by a deaf assistant, participants produced acted nonverbal vocalizations of nine emotions (anger, fear, sadness, disgust, surprise, amusement, relief, achievement/triumph, and sensual pleasure; examples of vocalizations available in [online supplemental materials](#)), based on demonstrations that these emotions can be reliably inferred from nonverbal vocalizations produced by

hearing individuals (Sauter, Eisner, Calder, & Scott, 2010a). Recordings were made onto digital video tape with two JVC BR-DV 6000 recorders and two microphones, using 48-kHz sampling rate and 16-bit quantization. This yielded 515 vocalizations produced by deaf individuals and 543 vocalizations produced by hearing individuals. The peak amplitude of the stimuli was scaled to 0.95 Pa. A research assistant, who was blind to the category of each stimulus (deaf or hearing, and emotion), listened through all stimuli and excluded stimulus clips in which stimuli were not audible (e.g., because of background noise), or where the sound was not caused by a vocalization (e.g., sounds produced by other body parts). The final stimulus set consisted of 971 stimuli, 435 produced by deaf individuals and 536 produced by hearing individuals (see [online supplemental materials](#) for a breakdown of the number of deaf and hearing vocalizations per emotion).

Participants

An a priori power calculation showed that 83 judgments were needed per stimulus to obtain power of .95, α error probability = .0055 (Bonferroni corrected) at effect size .5. To prevent participant fatigue and boredom (estimated task duration with 971 stimuli is nearly 3 hours), each participant heard approximately one eighth of the total number of stimuli, yielding a minimum sample size of 664 participants. Each participant heard 121 randomly selected stimuli of the total set of 971 stimuli. We adopted a grouped randomization method in which, for every batch of eight participants, 968 stimuli from the pool of 971 stimuli were randomly assigned into eight groups of 121 stimuli. The eight participants were each randomly assigned to one of the eight groups of stimuli. This procedure was repeated for each batch of eight participants. In total, each stimulus was judged on average 101.19 times ($SD = 4.54$; range = 88–121 times). Because the 968 stimuli selected from the pool of 971 stimuli were totally random, some stimuli would be selected more often than others, following a normal distribution. To ensure that the least sampled stimulus would be judged minimally 83 times, we sought to recruit a total of 800 participants to allow for dropouts and participants who did not have functioning audio. Participants were recruited via MTurk for an online study advertised as research on emotion recognition from sounds. When 800 participants had completed the task, 33 participants were in the process of completing it, so we allowed those participants to complete the task. This yielded a total number of 833 participants. Of these, 21 failed the sound check (see *Design and Procedure*), leaving a sample of 812 participants who took part in the main experiment (424 males, 387 females, one preferred not to say; mean age = 37.25 years, age $SD = 10.79$ years). Informed consent was given by all participants.

Design and Procedure

Participants were directed to a survey on the online platform Qualtrics (Provo, UT). Before starting the experiment proper, participants were asked to put on headphones and to set their audio level to a comfortable listening level. To check that they could hear well and that they were completing the task in earnest, they first completed three practice trials in which they were played an audio clip of a word and were asked to select from a list of options the word that they had heard. Only participants who completed all

three practice trials correctly were invited to continue with the main survey. During the task, participants also completed two check questions. One was an open-response question, intended to screen out bots; it was passed by all participants. The other was an attention check question, which was passed by all but 18 of 812 participants (~98% pass rate). The data from all participants were therefore included in the statistical analyses.

Within the 121 stimuli that a given participant heard, the order of the stimuli was randomized. The stimulus was played automatically at the onset of each trial. Participants could hear the stimulus again on any trial by clicking the play button on the screen. All response options were listed concurrently on the screen (anger, fear, sadness, disgust, surprise, amusement, relief, achievement/triumph, and sensual pleasure). Participants could proceed to the next trial once an answer had been given using a mouse click.

Acoustical Measurements

Acoustical measurements were made of all 971 stimuli for duration, amplitude onsets, pitch minimum, pitch maximum, pitch mean, pitch standard deviation, spectral center of gravity, and spectral standard deviation, using the Praat program (Boersma & Weenink, 2011). This set of acoustic measures were taken from a previous study of nonverbal emotional vocalizations because together they have been found to account for a considerable proportion of listeners' perceptual judgments of this class of sounds; further details are available in Sauter et al., 2010a.

Results

Behavioral Measures

In forced-choice tasks, performance can be artificially inflated for a particular category by the disproportionate use of that response option. To control for this possibility, Hu scores (unbiased hit rates ranging between zero [no correct responses] and one [perfect performance]) were calculated (Wagner, 1993). Condition-specific chance levels were also calculated following Wagner's formula to control for the unequal number of stimuli per condition. Because Hu scores are proportional, they were arcsine transformed before use in statistical tests.

Responses were largely accurate and consistent across deaf and hearing vocalizations (see [Figure 1](#) for confusion matrices). To test statistically whether listeners performed better than chance when identifying emotions of each stimulus type, a series of t tests were conducted, comparing Hu scores to chance (each emotion of the deaf and hearing vocalizations separately, using Bonferroni corrections for multiple tests). For the vocalizations produced by deaf individuals, seven emotions were recognized at better-than-chance levels, demonstrating that emotional information was preserved in nonverbal vocalizations of these emotions in the absence of auditory learning (see [Figure 2](#) for accuracy levels per condition). In contrast, deaf vocalizations of anger and achievement/triumph were not recognized at better-than-chance levels. Consistent with previous work, the emotional vocalizations produced by hearing individuals were well recognized for all emotions (see [Figure 2](#)). The results of the statistical tests of recognition performance compared with chance are shown in [Table 1](#), part A.

Figure 1. Confusion matrices of listeners' classifications of vocalizations produced by deaf (a) and hearing (b) individuals. Darker colors reflect more classifications (shown in percentages based on the classifications for all tokens of each emotion, averaged across participants), and accurate classifications run diagonally in bold. Numbers are rounded to the nearest integer. Stimulus categories are columns, and response categories are rows.

This result demonstrates that sufficient emotional information was present in vocalizations of both hearing and deaf individuals to ensure that listeners do better than guessing. However, was there an advantage for sounds produced by individuals who had opportunities for auditory learning? To test for a modulatory effect of auditory learning across emotions, we examined whether listeners performed better with vocalizations produced by hearing, as compared with deaf, individuals. An analysis of variance with the within-subjects factors group (two levels: deaf and hearing) and emotion (nine levels) revealed a significant main effect of hearing status ($F_{[1,265]} = 773.49, p < .001$; partial $\eta^2 = .75$), with listeners performing better with vocalizations produced by hearing individuals. There was also an interaction between emotion and hearing status ($F_{[8,2120]} = 78.30, p < .001$; partial $\eta^2 = .23$), confirming that the modulatory effect of auditory learning differed across emotions. To test for an effect of auditory learning for each emotion, a series of paired-sample t tests was used (one per emotion, using Bonferroni corrections for multiple tests; see Table 1, part B, for statistical results comparing performance on deaf and hearing stimuli). For all emotions except relief, an advantage was found for the vocalization produced by hearing individuals. This result shows that auditory learning has a modulatory effect on affective vocalizations and that the extent of this effect varies

across emotions. In particular, anger, disgust, and pleasure sounds were particularly influenced by auditory learning, whereas relief, fear, and amusement vocalizations were least affected (see Figure 2).

Acoustical Measures

The results of the acoustical measures are detailed in Table 2 and illustrated in Figure 3. To test for acoustic differences between the vocalizations produced by deaf and hearing individuals, a multivariate analysis of variance with the factors group (two levels: deaf and hearing) and emotion (nine levels) was conducted for the acoustical measures.

A main effect of group as well as an interaction between group and emotion was found on nearly all acoustic features (see Table 3). The one exception was an absence of a main effect for pitch variability. In general, vocalizations produced by deaf individuals were longer, with higher pitch (minimum, mean, and maximum) and with lower spectral center of gravity, than those of hearing individuals. All of these acoustic features also varied considerably across emotions, and the group differences were consistently modulated by emotion (see Figure 3). These results suggest that many acoustic features in emotional vocalizations are

Figure 2. Recognition performance (controlled for response biases using Hu scores) for each emotion category, for sounds produced by deaf (red bars) and hearing (green bars) individuals. Higher scores indicate better performance, with zero being no correct responses, and one being perfect performance. Error bars indicate standard errors. Performance was significantly better than chance for all conditions for stimuli produced by hearing individuals and for amusement, disgust, fear, sadness, surprise, sensual pleasure and relief for stimuli produced by deaf individuals. Recognition was significantly better for stimuli produced by hearing, as compared with deaf, individuals.

shaped by aspects of vocal production that are broadly modulated by auditory learning.

Discussion

The results of this study show that a considerable amount of emotional information in nonverbal vocalizations is present in the absence of auditory learning, suggesting that there is likely some preparedness for developing links between particular vocal signals and emotional states.

Emotional expressions from deaf individuals varied in terms of how well they were recognized, with particularly strong retention of amused laughter, disgusted retching, fearful screams, and sighs of relief. In addition, deaf individuals' sobs of sadness, exclamations of surprise, and moans of pleasure were also recognized at better-than-chance levels. Many of these emotion-vocalization mappings are present across cultures in humans (Sauter et al., 2010b) and develop early in life: Laughter emerges in infants at around 2 months (Nwokah, Hsu, Dobrowolska, & Fogel, 1994). For fear vocalizations, data from neonates are lacking, but 8- to

10-month-old infants produce fearful vocalizations in response to a range of fear-inducing scenarios, such as being approached by a large, odd-looking mechanical dog (Kochanska, Coy, Tjebkes, & Husarek, 1998). Displays of disgust have been documented at birth, both in the form of retching vocalizations (Forur, Zimmerman, & Chong, 2011) and distinct, recognizable facial configuration in response to bitter tastes (Rosenstein & Oster, 2005). Similarly, sweet flavors elicit displays of sensory pleasure in human infants as well as homologous displays in other primates (Steiner, Glaser, Hawilo, & Berridge, 2001). Distressed crying develops even before birth: It may occur as early as after 20 weeks of gestation and has been established in preterm infants from 23 weeks (see Hopkins, 2001). Although data on vocal reactions to novelty in infants is lacking, infants discriminate and imitate surprise expressions as early as 36 hr after birth (Field, Woodson, Greenberg, & Cohen, 1982) and produce surprise expressions specifically in response to surprising events from 10 months (Hiatt, Campos, & Emde, 1979; but see Camras, Lambrecht, & Michel, 1996). Finally, no studies to date have explicitly examined the

Table 1

Results of Statistical Tests of Recognition Performance (T Tests Testing Hu Scores Against Condition-Specific Chance, Using Bonferroni Corrections) for Deaf (Above) and Hearing (Below) stimuli (A), and Tests of a Modulatory Effect of Auditory Learning for Each Emotion (T Tests per Emotion Comparing Recognition Performance for Deaf and Hearing Stimuli, Using Bonferroni Corrections) (B)

Stimulus type	<i>t</i>	Cohen's <i>d</i>	CI lower	CI upper	<i>p</i>
A					
Deaf vocalizations					
Achievement	2.38		.00	.05	.02 (n.s.)
Amusement	28.44	1.62	.41	.47	<.001
Anger	1.65		.00	.03	.10 (n.s.)
Disgust	14.98	.89	.17	.22	<.001
Fear	15.21	.86	.13	.17	<.001
Relief	25.87	1.54	.37	.43	<.001
Sadness	7.97	.46	.05	.09	<.001
Pleasure	5.34	.32	.04	.08	<.001
Surprise	6.00	1.62	.03	.07	<.001
Hearing vocalizations					
Achievement	15.98	.97	.21	.27	<.001
Amusement	36.68	2.20	.62	.70	<.001
Anger	21.17	1.27	.30	.36	<.001
Disgust	31.93	1.88	.43	.49	<.001
Fear	21.85	1.28	.24	.29	<.001
Relief	26.12	1.51	.25	.29	<.001
Sadness	24.95	1.50	.35	.41	<.001
Pleasure	26.24	1.54	.30	.35	<.001
Surprise	23.62	1.38	.30	.36	<.001
B					
Test of modulation (recognition of deaf vs. hearing vocalizations)					
Achievement/Triumph	11.96	.73	.20	.27	<.001
Amusement	9.78	.60	.14	.21	<.001
Anger	17.42	1.07	.28	.36	<.001
Disgust	18.44	1.13	.28	.35	<.001
Fear	4.97	.31	.05	.12	<.001
Relief	-7.34	-.45	-.17	-.10	<.001
Sadness	14.35	.88	.22	.29	<.001
Pleasure	19.80	1.22	.30	.37	<.001
Surprise	15.35	.94	.23	.30	<.001

Note. CI denotes confidence interval of the difference. Degrees of freedom: 811; *p* refers to Bonferroni-corrected significance levels.

development of relief expressions, but crying infants as young as 1 month old start to soothe in anticipation of being picked up, as demonstrated by a reduction of negative vocalizations and increase in positive vocalizations (Lamb & Malkin, 1986). This suggests that the infants have developed associations between crying, being picked up, and soothing, which may indicate relief. In the present study, relief vocalizations were unique in that they were the only type of vocalizations that were not better recognized from hearing as compared with deaf vocalizations, suggesting particularly strong preparedness. In sum, there is evidence that vocalizations of amusement, fear, disgust, sadness, surprise, pleasure, and relief, found in the current study to show evidence for learning preparedness, are recognized across cultures and develop early in ontogeny. These results are consistent with the notion that these emotional expressions constitute fundamental human functions.

Other types of vocalizations were found to rely on auditory learning, with listeners unable to infer the emotional states from the deaf individuals' vocalizations. In particular, deaf vocalizations of achievement/triumph were not recognized at better-than-

chance levels. Triumphant sounds are also highly variable across cultures (Sauter et al., 2010b), further emphasizing the importance of individual learning for these vocalizations. The malleability of nonverbal vocal expressions of triumph is in stark contrast to the postural expression of a related emotion, pride. This signal is preserved in the absence of visual input, that is, in congenitally blind individuals (Tracy & Matsumoto, 2008). However, whereas pride expressions emphasize the high social status of the individual, triumph is an emotion that is often associated with strengthening within-group bonds (Sauter et al., 2010b). Recognition levels were also low for deaf vocalizations of anger. For this emotion, hearing individuals struggle to produce nonverbal vocalizations free of speech-like content in enactment situations. This may suggest that these emotions are more easily expressed using speech than nonverbal sounds (see also Sauter, 2006), but whether the acquisition of angry speech prosody relies on auditory learning is beyond the scope of the current study. Both triumph and anger have recently been found to be strongly affected by East Asian-specific cultural norms of interpersonal relationships. Japanese

Table 2

Acoustic Analysis of Nonverbal Emotional Vocalizations Produced by Deaf (Top) and Hearing (Bottom) individuals, as Means per Stimulus Category (Separate Rows), With Standard Deviations in Brackets

Stimulus type	Onset	Dur	Mean F0	Min F0	Max F0	F0 var	SCoG	SCoG var
Deaf								
Achievement	.24 (.13)	1.30 (.87)	254.81 (67.36)	173.07 (64.28)	356.18 (124.66)	50.62 (33.02)	1169.38 (507.51)	1290.64 (532.46)
Amusement	.24 (.08)	1.31 (.67)	265.22 (87.51)	171.66 (73.97)	376.81 (108.21)	47.83 (28.80)	728.03 (173.71)	866.90 (237.45)
Anger	.27 (.10)	.94 (.46)	289.41 (64.28)	186.72 (73.02)	407.31 (94.06)	60.65 (31.24)	1040.70 (934.91)	1201.49 (623.21)
Disgust	.24 (.13)	1.34 (.85)	228.61 (50.25)	141.57 (57.95)	329.31 (102.30)	50.70 (31.41)	1047.79 (346.79)	1166.54 (425.17)
Fear	.26 (.19)	1.55 (.84)	263.71 (55.74)	172.99 (75.47)	388.05 (103.55)	57.83 (43.00)	1097.63 (667.44)	1159.22 (610.50)
Relief	.12 (.04)	1.20 (.33)	212.51 (100.25)	174.48 (86.81)	256.00 (123.28)	25.73 (34.21)	1873.66 (1406.12)	2073.54 (954.86)
Sadness	.15 (.07)	1.90 (1.01)	266.65 (79.17)	184.09 (73.40)	354.57 (105.45)	42.82 (28.00)	818.18 (710.81)	1116.28 (713.30)
Pleasure	.17 (.08)	1.55 (.66)	236.63 (86.18)	154.90 (60.29)	322.02 (136.08)	42.87 (36.65)	817.58 (665.52)	1027.89 (751.81)
Surprise	.13 (.07)	1.64 (1.25)	251.34 (97.61)	178.55 (109.31)	360.17 (117.16)	54.58 (44.69)	852.40 (444.99)	1137.57 (576.36)
Hearing								
Achievement	.20 (.08)	1.24 (.66)	267.36 (79.74)	166.70 (79.22)	402.28 (102.32)	61.40 (27.10)	727.85 (331.25)	688.32 (399.61)
Amusement	.11 (.06)	1.48 (.64)	295.01 (86.50)	181.47 (70.51)	400.72 (107.22)	55.77 (28.92)	817.62 (654.90)	1103.93 (753.07)
Anger	.10 (.04)	1.13 (.50)	195.60 (91.09)	142.25 (74.26)	282.98 (134.69)	40.74 (32.15)	2697.88 (1960.33)	2389.45 (1006.25)
Disgust	.14 (.04)	.89 (.51)	207.36 (69.85)	114.49 (43.90)	326.10 (136.91)	64.73 (47.93)	1197.10 (989.11)	1350.89 (802.03)
Fear	.19 (.07)	.82 (.44)	230.84 (89.16)	162.57 (69.90)	295.64 (123.98)	40.14 (35.65)	870.86 (687.15)	1083.48 (680.58)
Relief	.14 (.08)	1.31 (.77)	226.41 (92.03)	164.26 (94.49)	315.55 (117.72)	38.82 (28.29)	1643.93 (1270.61)	1726.62 (1043.36)
Sadness	.15 (.09)	1.53 (.80)	256.93 (90.69)	167.23 (80.50)	361.96 (122.60)	53.04 (42.07)	1196.64 (1339.54)	1742.12 (1196.79)
Pleasure	.15 (.06)	1.53 (1.01)	203.82 (89.80)	129.45 (70.01)	306.28 (121.72)	44.09 (31.98)	998.19 (1052.37)	1637.63 (1189.41)
Surprise	.15 (.05)	.74 (.55)	248.70 (91.40)	167.48 (96.31)	340.46 (116.53)	51.63 (34.21)	1185.84 (966.69)	1394.66 (876.30)

Note. Dur = duration; Min = minimum; Max = maximum; var = variability; SCoG = spectral center of gravity. Onsets are number; duration is in seconds; pitch and spectral measurements are in Hertz.

vocalizations of these two emotions were found to be challenging to interpret for Dutch listeners, even though they communicated clear emotional meaning to Japanese listeners (Yoshi & Sauter, 2019). This suggests that vocal expressions of these emotions may be particularly dependent on individual learning. However, caution is particularly warranted in the interpretation of null findings. We cannot rule out that the deaf individuals failed to produce recognizable vocalizations for certain emotions because of more limited experiences with those emotions or that some aspect of the stimulus elicitation procedures limited the quality of those expressions.

The results from the current study are consistent with evolutionary accounts that emphasize the preparedness for developing some emotions and their associated nonverbal expressions (e.g., Ekman, 1992). It is worth noting that the absence of recognizable vocalizations in deaf individuals would be compatible with two types of explanations: explanations of emotional expressions as evolved mechanisms or alternatively accounts of learned emotional expressions occurring in the absence of any preparedness for such expression-emotion links. Findings of learning preparedness, however, are consistent only with the former but not the latter type of explanation.

Our results do not speak to the adaptive purpose of these vocalizations, in the sense that some emotional expressions are adaptations because they affected sensory acquisition in our ancestors, such as the size of the visual field and air velocity during inspiration (see Susskind et al., 2008). In present use, emotional expressions serve social, communicative functions; in some cases these may be the only functions served by a signal (see e.g., Fridlund, 1994).

Acoustical Measures

Acoustical analyses revealed differences between deaf and hearing vocalizations across many types of features in the vocaliza-

tions. Differences in acoustic cues between vocalizations of the different groups are an indication that the production of those vocal features is influenced by auditory learning. For example, the fact that several pitch features were different in the hearing vocalizations as compared with the deaf vocalizations suggests that the acquisition of vocal production that affects pitch features of emotional vocalizations are modulated via auditory perception.

Earlier findings on laughter has found pitch variability to be lower in laughter produced by deaf as compared with hearing individuals (Makagon et al., 2008). In the present study, we did not see an overall difference in pitch variability, but we did find an interaction between group (deaf vs. hearing) and emotion. This result implies that differences in pitch variability may occur only for a subset of vocalisation types. The differences in spectral cues found between deaf and hearing vocalizations in the present study are consistent with the fact that hearing impairment also delays language production (Miyamoto, Svirsky, & Robbins, 1997), partly through a reduction in laryngeal and articulatory control.

Auditory perception likely also affects the development of other, more complex features of vocalizations. Studies of preverbal vocalizations of deaf and hearing infants have found considerable similarity in terms of the acoustic structure of individual vocalizations, although differences were found in composition of sequences of vocalizations, including babbling (Scheiner, Hammer-schmidt, Jürgens, & Zwirner, 2006).

Acquiring Vocalizations via Visual Learning

The presence of recognisable emotional vocalizations in congenitally deaf people demonstrates that these expressions can develop in the absence of auditory learning. However, these individuals have had the opportunity to learn via visual information. Could it be that they have acquired these vocalizations from seeing others vocalize?

Figure 3. Acoustic features of nonverbal emotional vocalizations produced by deaf and hearing individuals, as means per stimulus category.

If vocalizations can be learned from visual information in the absence of audition, this would indicate that the mechanisms underlying the acquisition of emotional vocalizations are learning based but buffered against the absence of auditory input, an environmental parameter that is typically important for their development (Ariew, 2006). However, several factors argue against explaining the acquisition of these vocalizations wholly in terms of visual learning.

Many differences between vocally produced sounds depend on complex interactions between articulators that cannot be seen on the face (e.g., larynx and tongue) and interactions between visible (e.g., lips) and hidden articulators (Dodd, 1976; Fitch, 2000). Consequently, the acquisition of vocal signals from only visual information is difficult, even in cases when extensive feedback is given (Javkin et al., 1993). In nonverbal vocalizations, emotional content is conveyed using complex interactions between many acoustic cues (Sauter et al., 2010a), suggesting the involvement of the articulators that are not visible, in interaction with the visible articulators. Furthermore, a study analyzing facial muscle movements of hearing people who produced nonverbal vocalizations of emotions found little evidence for the existence of fixed patterns of facial muscle movements for different emotions during these vocalizations (Krumhuber & Scherer, 2011). Rather, each emotion was found to be signaled by several different facial configurations that shared multiple muscle actions. Such facial variability would

provide a considerable obstacle to learning to produce vocalizations from visual cues. In addition, the deaf vocalizers would have been unable to perceive any vocal feedback from others responding to their vocalizations, which is an important source of information for shaping prelinguistic vocal production (Gros-Louis, West, Goldstein, & King, 2006).

The study of individuals born both deaf and blind could help address the question of to what extent visual information contributes to learning vocalizations, but deaf-blind populations are difficult to study systematically as they tend to not develop typically in terms of cognitive abilities (Szeto & Christensen, 1988). However, an observational study of a deaf-blind child reported that she produced both laughter and frowns appropriately (see also Eibl-Eibesfeldt, 1973; Goodenough, 1932; McCarthy, 1929), lending support to the notion of innate associations between emotional states and nonverbal expressions.

If neither auditory nor visual learning can account for associations between vocalizations and emotional states, this would point to an innate foundation for this link. This would imply preparedness for the mapping of specific vocal expressions with particular affective states, with a relatively small role played by individual learning (Ariew, 2006; Griffiths, 1997). Similar learning preparedness in emotion systems has been demonstrated in, for example, the acquisition of fear responses to particular types of stimuli, such as snakes (see Öhman & Mineka, 2003), and illness-induced

Table 3

Results of Statistical Tests per Acoustic Feature (Separate Rows) of Difference in Acoustic Features Between Deaf and Hearing Vocalizations for Each Emotion (Above) and Interactions Between Group (Deaf vs. Hearing) and Emotion (Below)

Acoustic measure	F	Partial eta squared	p
A			
Main effect (group)			
Onset	82.44	.08	<.001
Duration	22.13	.02	<.001
F0 Mean	20.04	.02	<.001
F0 Min	20.68	.02	<.001
F0 Max	13.51	.01	<.001
F0 variability	.23	.00	.64
Spectral CoG	12.61	.01	<.001
Spectral CoG variability	19.43	.02	<.001
B			
Test of modulation (interaction Group $\times$ Emotion)			
Onset	14.78	.11	<.001
Duration	7.86	.06	<.001
F0 Mean	8.71	.07	<.001
F0 Min	3.49	.03	.001
F0 Max	10.36	.08	<.001
F0 variability	5.34	.04	<.001
Spectral CoG	10.02	.08	<.001
Spectral CoG variability	10.34	.08	<.001

Note. CoG = centre of gravity. Degrees of freedom of main effect of group are 1; degrees of freedom of interaction between group and emotion are 8; total degrees of freedom are 970.

aversions to the taste of foods (e.g., Logue, Ophir, & Strauss, 1981).

Limitations

The current study used a forced-choice paradigm, in which participants were asked to choose from a list of target emotion states. This methodology has been criticized because using response options determined by the researcher may inflate agreement on which emotion is communicated by a given stimulus (Russell, 1993). However, studies of both facial and vocal expression of emotion have demonstrated that the addition of a response alternative such as none of the above does not significantly affect the level of agreement compared with using the standard forced-choice response format (Frank & Stennett, 2001; Sauter, 2006). Nevertheless, the extension of the current study to include more open-ended paradigms would strengthen these findings.

Another limitation of the current study is that some of the deaf individuals had tried hearing aids, raising the possibility that they learned emotional vocalizations during these trials. This is unlikely for two reasons. First, although two of the eight deaf individuals in our study reported occasionally having used a hearing aid, half of the deaf individuals reported never having used hearing aids, and two others reported having tried a hearing aid and decided against using one (see online supplemental materials). The inclusion of tokens produced by nearly all the speakers across all of the

emotions and most speakers contributing tokens to all of the emotions undermines an explanation based on some of the deaf speakers' possible exposure to sounds. Inspection of the recognition rates per deaf speaker (see online supplemental materials) also does not indicate better recognition for deaf individuals who occasionally used hearing aids. However, given the small sample of deaf speakers, variable number of tokens contributed, and limited information about hearing aid use, no firm conclusions can be drawn on this point. Second, learning preparedness is defined as a trait being buffered against variation in the environmental parameters that are important for its development. Being congenitally deaf constitutes a variation in the main environmental parameter that would be expected to matter for the development of vocalizations, even for the two of the eight deaf individuals who had had a small amount of exposure to sounds through very occasional use of hearing aids. This is particularly true because the use of hearing aids for individuals with severe to profound hearing impairments does not provide them with anything like the auditory environment of a person with normal hearing, both because of limitations to current hearing aid technology and because of constraints imposed by the biological factors that originally caused the hearing impairments (e.g., the shape of the inner ear).

Similar to many other studies using deaf samples, (e.g., Dodd, 1976 ($n = 10$); Letourneau & Mitchell, 2011 ($n = 12$); Oller et al., 1988 ($n = 12$)), the sample size in the current study was small ($n = 8$ deaf individuals). Recruitment of congenitally, bilaterally deaf individuals willing to be recorded while producing vocalizations was difficult. It will be important to replicate these findings with a larger sample to capture a greater extent of variability in deaf vocalizations. Specifically, the inclusion of a larger sample with a range of hearing impairments would allow for the examination of a possible relationship between level of hearing impairment and ease of recognition of vocalization types that appear to depend on auditory learning.

Finally, although collecting spontaneous vocalizations of a range of emotions from a sample of deaf individuals would be immensely challenging, the current findings would certainly be further strengthened by replication with spontaneously occurring vocalizations. These limitations notwithstanding, the current study demonstrates that deaf individuals produce some emotional vocalizations that can be recognized by naive listeners.

Conclusion

In this study we show that naive listeners can infer emotional information from vocalizations produced by congenitally deaf individuals, suggesting that emotional information is retained for vocalizations that have developed in the absence of auditory learning. These results suggest that there is an innate component to the associations between human emotions and vocalizations. In addition, we demonstrate that the modulatory effect of auditory learning varies across emotions, with amused laughter, disgusted retching, fearful screams, and relieved sighs particularly well retained in the absence of auditory input. Our results, which are consistent with developmental and cross-cultural findings, highlight the interaction that can occur in development between preparedness and learning.

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