A Tale of Two Cases: Emotion and Prosody after Hemispherectomy

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Introduction

The role of emotion in the development of language has been largely overlooked (Bloom, 1997). In language, emotion is expressed through prosody, which is the intonational contour, or melody, and stress pattern of speech (Crystal, 1997). Through manipulating the contour of an utterance, speakers can convey various emotional states and pragmatic intents, from the rising pitch of a question, to the exaggerated emphasis of sarcasm:

Person A: “I’m going to Timbuktu next summer.”
Person B: “YOU’RE going?”
Person C: “You’re GOING?”

In this example, both B and C are incredulous about A’s travel plans, but B thinks that someone else should go, or that A in particular is not fit to go, while C had been under the impression that A had previously decided not to go. These nuances of meaning and affect are conveyed through linguistic intonation and accompanying paralinguistic cues, such as the facial expressions of B and C.

In normally developing children, emotion and prosody are likely integrated very early on, so that we do not think to examine the relationship between these two sets of skills. However, language learning is a social, interactive phenomenon (Berko Gleason, 1997; Ninio & Snow, 1996), and a main purpose of language is to establish personal relationships and communicate about subjectively meaningful states of the world (Tomasello, 2002). Therefore, a deep understanding of the nature of language development requires an understanding of the developmental relationship between emotion and the affective components of language (Bamberg & Reilly, 1996).

In turn, an understanding of emotion and language requires grounding these two cognitive skill sets in the neuropsychological mechanisms that support them (Lieberman, 1996). In most adults, for example, the syntactic and semantic aspects of language are mainly localized to the left hemisphere of the brain, while prosody and its associated skills are mainly handled by the right hemisphere (Kandel, Schwartz, & Jessell, 2000). Emotional processing is not as clearly divided between the two hemispheres, although the emotional profiles associated with left and right hemisphere damage are distinct (Lezak, 1995).

Therefore, in order to begin to address the relationship between language and emotion, it would be useful to examine development in cases where neurological damage has disassociated the skills associated with each hemisphere. To this end, I present a study of the emotional and prosodic development of two exceptional adolescent boys, Nico and Brooke, each of whom suffered severe localized brain seizures during childhood that resulted in the surgical removal of an entire hemisphere of his brain. Amazingly, despite the poor cognitive prognosis generally associated with this drastic procedure, both of these boys are compensating to previously unexpected degrees. Nico lost his right hemisphere at age three, yet he is now a charming and sociable 12-year-old with strong verbal skills, attending a mainstream school. Brooke lost his left hemisphere at age eleven, but, despite predictions that he would never talk again, at eighteen years old is planning to graduate from high school this year. Such boys as these are extremely rare, and we will never know if their successful outcomes may have been possible in part because of individual differences in their pre-surgery neurological profiles. Nonetheless, despite differences in their personal circumstances, they represent a unique opportunity to bring the standard neuropsychological case study approach (Caramazza, 1992; Gazzaniga, Ivry, & Mangun, 2002) to the study of emotion in language. How have these boys compensated, and

1 Both boys asked that they be identified by their real first names.
what can a close examination of their emotional and prosodic skills reveal about the
developmental relationship between these two constructs? These questions have implications for
our understanding of language development, socioemotional development, and plasticity in brain
development for both typically and atypically developing children.

**Theoretical context and motivation**

Although the parallels are not often highlighted in the developmental literature (Edgar,
1997), there exist various forms of converging evidence for the neuropsychological association
between emotion and prosody\(^2\). Moving from a review of this neuropsychological evidence to a
discussion of localization of these functions in the brain and recovery of these functions after
childhood brain damage, this section lays out the theoretical motivation for my study.

Most fundamentally, the neurological structures that support vocal prosody are also
involved in initiating physiologic manifestations of affect and emotion, such as change in heart
rate (Lieberman, 1996). On a less direct level, evidence comes both from development,
especially in atypical populations, and from neuropsychological conditions acquired in
adulthood. In adults, the general finding is that blunted emotional profiles tend to be associated
with flatter prosodic production, such as in depression (Betts, 1988), in dementia with apathy
(Marin, 1996), and in schizophrenia (Leentjens, Wielaaert, van Harskamp, & Wilmink, 1998;
Ross et al., 2001). Alexthymia, an acquired cognitive-affective disorder in which patients are
unable to recognize or describe feelings or emotional states, has also been associated with
aprosodia, or loss of prosody (Fricchione & Howanitz, 1985; Lane, Ahern, Schwartz, &
Kasznia, 1997). Conversely, it has been argued that adult aphasics make increased use of their
spared emotional and prosodic capacities to communicate, despite a loss of language (Lorch,
Borod, & Koff, 1998).

In development, emotion and prosody appear to be linked from the start. While infants
have long been known to prefer the exaggerated contours of motherese (Fernald, 1985; Fernald
& Simon, 1984), more recent work has shown that it may be the increased emotionality of
motherese that mediates this effect (Trainor, Austin, & Desjardins, 2000). As infants become
toddlers, they are most likely to express emotion while saying words or immediately after
(Bloom & Beckwith, 1989).

Evidence for a link between emotion and prosody during middle childhood and
adolescence comes mainly from atypically developing populations. For example, in autism and
its less severe form, Asperger’s Syndrome, flat affect and poor emotion recognition and
production are coupled with flat prosody (Nijokiktjien et al., 2001; Shriberg, Paul, McSweeny,
Klin, & Cohen, 2001). This is in contrast to a child with Landau-Kleffner syndrome, in whom
prosody and emotion were preserved despite a complete inability to comprehend or produce
phonemes (Doherty et al., 1999). In adolescents with schizotypal personality disorder, a risk
factor for schizophrenia, discrimination of emotion in prosody and facial expressions are
associated, and predict severity of later emotional problems and thought disturbances (Logan,
1999). In specific language impairment, primary prosodic symptoms (van der Meulen, Janssen,
& Os, 1997) have been associated secondarily with impaired emotion regulation (Fujiki, Brinton,
& Clarke, ). In the other direction, in depressed adolescent boys, primary emotional symptoms
have been linked to impaired prosodic recognition relative to their peers (Emerson, Harrison, &
Everhart, 1999).

\(^2\)In linguistics, prosody can be described at the level of individual words and syllables, and at the postlexical level of
whole phrases and sentences. Because the emotional aspects of prosody are conveyed at the level of sentence
contour, my dissertation focuses only on this level of description.
The association between prosody and emotion, and the relative dissociation of these constructs from the other aspects of language, may be explained by the distribution of processing in the normal brain. In most people, the left hemisphere handles the majority of lexical, syntactic, and semantic processing, while the right hemisphere mainly handles intonation and other aspects of prosody and pragmatics, including conversational turn-taking and situationally appropriate language use (Kandel et al., 2000). At the same time, the right hemisphere is also more strongly implicated in emotion (Compton, Heller, Banich, Palmieri, & Miller, 2000; Perry et al., 2001), especially facial expression of affect (Borod, Koff, Yecker, Santschi, & Schmidt, 1998; Corina, Bellugi, & Reilly, 1999), and the ability to feel and perceive negative emotions (Campbell, 1982; Jansari, Tranel, & Adolphs, 2000).

In children, the distribution of processing for language generally holds, although the distribution of emotional processing is less clear. Processing in children is also less focalized, and the localization of functions is more plastic (Kandel et al., 2000). Because of this, localized brain damage in children results in quite different patterns from damage in adults, both of deficit and of recovery (Bates et al., 2001). Compared to adults, in children the location of damage corresponds less predictably to the resulting neuropsychological profile. And, while severely brain damaged children usually do not catch up to their peers, they often recover remarkably well, unlike adults with comparable brain damage (Reilly, Bates, & Marchman, 1998). In short, children benefit from increased plasticity, in which intact brain regions presumably compensate for damaged areas (Battro, 2000).

In general, studies of plasticity after hemispherectomy have looked at commonalities between groups. While there is a history of work on recovery of language in hemispherectomized children (e.g. Boatman et al., 1999; Piacentini & Hynd, 1988; Smith & Sugar, 1975), there has been almost no work done on emotional or prosodic processing by these children, except to note that extensive brain injury usually results in behavioral and emotional problems (Hawley, 2003). Profiles of emotional (Trauner, Nass, & Ballantyne, 2001) and prosodic (Trauner, Ballantyne, Friedland, & Chase, 1996) deficit associated with less pervasive right versus left hemisphere lesions have yielded few differences between right and left hemisphere-damaged groups, although patients with right hemisphere lesions may fare worse than those with left hemisphere lesions on measures of recognition of facial affect (Voeller, Hanson, & Wendt, 1988).

At the same time, since there is significant variability in children’s paths to recovery from brain damage, case studies can contribute important insights into these trends and the plasticity that created them. For instance, a basic question has to do with the extent to which intact brain regions actually assume the processing characteristics of the damaged regions, and the extent to which they adapt the cognitive problem to fit their characteristic mode of processing. For example, Nico, with an intact left hemisphere, could be processing prosody in two ways, which would have distinctive signatures in his data. He could be processing prosody much like his peers or younger children, which would suggest that his left hemisphere has, by necessity, taken on the kind of processing normally handled by the right hemisphere. Or, he could be processing prosody as if it were the kind of syntactic problem that the left hemisphere normally handles, which would result in a qualitatively different data pattern than normal children show.

Therefore, given the outstanding issues of plasticity, emotion, and prosody reviewed here, my study has several purposes. While my study can not directly measure neurological reorganization in Nico and Brooke, I can contribute to knowledge about cognitive adaptation as it relates to developmental plasticity through elucidating parallels in neuropsychological
compensatory strategies in two closely related domains of processing. In addition, I contribute two new, much-needed case studies of emotional and prosodic functioning after childhood brain damage. Lastly, through juxtaposing these two cases’ emotional and prosodic profiles, I formulate a tentative theory of the developmental relationship between emotion and prosody, and new, testable hypotheses about the nature of this relationship in other normal and atypical populations.

**Methods**

**Prosody**

Comprehension of affective prosody is an area that has been largely overlooked in the developmental literature (Locke, 1993; Slobin, 1997). Consequently, there is not an established comprehensive protocol for assessing children’s abilities (Panagos & Prelock, 1997). In order to begin to investigate Nico’s and Brooke’s abilities in this area, I designed a battery to assess prosodic reception, starting from simple discrimination of the melodic patterns in speech, and systematically increasing in complexity to finally test inferences about speakers’ affective intent in a naturalistic story (see Figure 1). The basic discriminatory conditions are grounded mainly in the neuropsychological literature on acquired discriminatory deficits in adults with brain damage (e.g. Patel, 1997; Perkins, Baran, & Gandour, 1996). The more complex story-based conditions are grounded in part on developmental studies of children’s abilities to recognize and interpret sarcasm, deception, and sincerity through prosody (Capelli, Nakagawa, & Madden, 1990; Creusere, 1999; Milosky & Ford, 1997); (Demorest, Meyer, Phelps, Gardner, & Winner, 1984; Winner et al., 1987).

Developmentally, in naturalistic stories, young children have been shown to depend heavily on tone of voice information in interpreting sarcasm. Only in early adolescence do they effectively begin to use context, before finally combining context and tone to judge a speaker’s affect (Capelli et al., 1990). Therefore, in my battery, story conditions systematically manipulated the presence of context information, tone of voice information, and a required integration of the two sources, to predict the story outcome or infer a speaker’s affect. I judged developmental level based on children’s ability to make use of and integrate these sources of information, increasing from tone to context to integration.

Because it was important that the test items sound identical in each administration, and so that all boys could be tested in their native language and dialect, separate Argentine Spanish and American English versions of the tests were constructed and tape-recorded. While these versions were largely equivalent and usually direct translations of each another, they did contain minor differences that reflect differences in the prosodic structures of the two languages. Two native speakers of Nico’s home dialect were employed to translate and record the Spanish version under my close supervision; I personally recorded the English version, as I was raised in the same geographic area as Brooke, and our accents match fairly closely. Both recordings were digitally mastered and equalized for loudness and balance, and to add pauses and instructions between the test items. Test items were counterbalanced for primarily high/rising versus primarily low/falling pitch and for speaker intent (i.e. deception, sarcasm, or sincerity).

To establish a body of comparison data, cross-sectional longitudinal data from 8, 10, and 12-year-olds and adults were collected, in addition to data from ten age-matched comparison subjects each for Nico and Brooke. (Adult data were not included in the analyses of the discrimination tasks, but were examined only to check the validity of the measures.) While Nico

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3 Nico was tested in two rounds, at age ten and later at age twelve (appropriate comparison data were collected for each age). Brooke was tested at age 18.
and Brooke traveled to Cambridge for testing, comparison data were collected in school settings. An Argentine research assistant collected comparison data for Nico from the boys in Nico’s school; I and an American research assistant collected comparison data for Brooke in a suburban school system roughly comparable in size and socioeconomic status to Brooke’s. In both Argentina and the U.S., comparison boys were monolinguals for whom Spanish or English had been their first language. Subjects reporting learning, neurological, or hearing disabilities, or who had been identified to receive any special academic considerations or support at school (such as a Special Education Plan, in the American case) were excluded. To help ensure that the same-age comparison boys were roughly matched in academic ability to Nico and Brooke, same-age subjects were chosen from the lowest segregated ability levels of their classes. Younger comparison boys were chosen randomly from a group identified as average students by their teachers. Testing sessions with Nico and Brooke were videotaped while comparison data were audiotaped. Story condition data from all subjects were transcribed by native speakers; under my close supervision, native Argentine Spanish speakers also translated the story conditions in the Spanish data.

Once transcribed and translated, subjects’ answers and justifications in the story conditions were coded according to several dimensions (see Appendix 1 for a description of each code) including:

- Subjects’ judgements about the speaker's intent to joke, deceive, be sincere, or some combination of these,
- Subjects’ perspective taking, which involves making inferences about story characters’ feelings or mental states,
- Subjects' restating, inferring, or extrapolating from the story,
- Subjects' use of self as a reference point in making judgements about story characters,
- Subjects' explicit reliance on tone of voice information in making judgements,
- Subjects' use of generalizable rules to justify judgements about story characters,
- The internal consistency as well as plausibility of subjects' answers.

In all, there were a total of sixteen possible codes for each item. (Each story item could receive each code only once.) These codes were independent and combinable; no two codes duplicated one another and no two codes mutually excluded one another. For instance, an answer could simultaneously receive codes for first and second-order perspective taking, joking, sincerity, and extrapolating from the story, or any other combination.

All transcribed data were coded at least twice, once by me and once by an independent, native-speaking research assistant working blindly as to subjects’ identities and my hypotheses. In coding the Argentine data, I worked closely with an Argentine assistant to code the data in Spanish; a second Argentine assistant coded the data independently for comparison. The American reliability coder was trained on the translations of the Argentine data while the Argentine coders were trained on the American data. Training continued until a reliability of at least 0.95 was established; Cohen's Kappa calculations on a random subset of twenty percent of the final coded transcripts resulted in reliabilities of 0.94 for the Argentine data and 0.93 for the American data, both of which were significantly better than chance.

To analyze the prosodic reception data from Nico, Brooke, and the comparison subjects, I conducted two levels of analysis. First, after transcribing the data from all subjects, I scored the subjects’ answers on each item as either correct or incorrect, and calculated descriptive statistics for the comparison groups. Nico's and Brooke's scores were then calculated and compared to the mean scores of their same-language comparison groups, and to the mean of their same-language
age mates. I next undertook a qualitative and quantitative analysis of the coded justifications that each subject used to justify his answers in the tests involving story scenarios, and produced characterizations of the strategy profiles used by Nico and Brooke. Here, I analyzed how Nico, Brooke and comparison boys arrived at correct and incorrect answers, and investigated whether Nico and Brooke appeared to be developing normally, using strategies that are similar to those of their peers, whether they were delayed, using strategies similar to those of younger children, or whether they appeared to be following different developmental trajectories altogether.

**Emotion**

This study included two tests of emotion, one of production and one of reception. In order to assess the complexity, valence and intensity of Nico’s and Brooke’s emotional production, each boy participated in a standard cognitive and emotional "Self in Relationships" interview (SIR). This clinical-style interview provides a supportive context in which participants are asked to describe their feelings and understandings about themselves in their important personal relationships. It has been shown to be an effective way to support adolescents in constructing complex understandings of themselves and their feelings, and to assess the developmental level of these constructions (Fischer & Kennedy, 1997; Kennedy, 1994). In the interview, participants generate adjectives to describe their feelings in personal relationships, assign positive, negative, or neutral valence to these adjectives, and, with the help of a diagram, explain connections between different feelings. Normal adolescent boys can be expected to produce multifaceted positive and negative descriptions in this context, and, when supported, to explain how different feelings go together. Boys of Brooke’s age should also be able to integrate across emotions and relationships, in order to build abstract understandings of the ways that they feel, think, and act in their close relationships. Because typical performances for adolescents of different ages have been well described, no comparison data was collected for this phase.

In analyzing these data, I looked for evidence of range and intensity of emotions, from negative (e.g. sadness, anger) to positive (e.g. happiness, security) and from weak to strong intensity. To do this, I reviewed the list of adjectives that each boy produced and the valences that he assigned to these descriptors. For example, Nico had often been described as having very positive affect. Especially when specifically asked, did he talk about negative feelings, such as sadness or frustration, as well?

Next I assessed the complexity of the boys’ understandings, looking for evidence of single emotions such as happiness being incorporated into richer descriptions of connections between emotions or between similar emotions within different personal relationships. For instance, in talking about the grandmother who raised him, did Brooke integrate his feelings in a complex way, to describe how his feelings of security, for example, related to his feelings of resentment at being disciplined? Alternatively, did he simply list several emotions, such as security and resentment, without forging connections? Assuming that he produced both positive and negative emotion terms, did he make equally complex connections between negative as between positive emotions?

To complement this assessment of emotional production, Nico's and Brooke's abilities to discriminate basic emotions on faces was also tested using Ekman’s test of recognition of facial expression of emotion (Ekman & Friesen, 1975). This test consists of 110 close-up photos of actors’ faces depicting anger, disgust, fear, happiness, surprise, and sadness, as well as photos depicting neutral affect. These photos were developed for basic and cross-cultural research on emotion, and have been adapted for use in neuropsychological studies (Lezak, 1995). To administer the Ekman test, the experimenter showed the boy being tested one photo at a time,
printed on a 4X6-inch card, and ask him to describe the emotion on the face and to choose the emotion term (e.g. happy, sad, etc.) that best fit the facial expression. The photos were presented in the same randomly generated order for each boy. For Nico, an Argentine Spanish translation of Ekman's emotion terms was used. To establish this list, two native Argentine Spanish speakers independently translated Ekman's terms. The two lists were then compared, and because they were identical, were used in the experiment.

The boys’ responses were analyzed in two ways. First, I calculated the percentage of correct answers and tabulated the patterns of errors that the boys made. Then, I conducted a secondary analysis of the boys’ responses, looking for evidence of systematicity or bias in the boys’ correct and incorrect answers. For instance, was there evidence that Nico tended to confuse negative emotions, such as fear and disgust, but accurately differentiate positive emotions, such as happiness and surprise? Alternatively, might he or Brooke have shown a tendency to misclassify negative emotions as positive, e.g. confuse disgust with surprise? The results of this secondary analysis were then integrated with and understood in terms of the results of the SIR interview.

Results

Prosodic Reception

Somewhat contradictory to the neuropsychological prediction that Brooke would perform at or above average on tests of basic prosodic discrimination, he generally performed slightly below the mean in these conditions. Consistent with prediction, his scores fell off more rapidly than those of his peers in the most difficult conditions involving the integration of tonal information with context and background knowledge. In the test requiring the simple interpretation of story contexts, Brooke performed competently, accurately inferring story outcomes and speaker intents. However, the strategies that he used to approach these problems were substantially different from those of his peers or even younger children. Interestingly, these alternate strategies relied heavily on using tone of voice information to infer a speaker's emotion, especially through directly imitating and reenacting the speaker's final statement. Although atypical, these strategies worked well; in the condition involving ambiguous stories with speaker's tone of voice included, Brooke outperformed all but one of his 18-year-old peers, who performed equally to him.

Nico also defied neuropsychological prediction, but, in several ways, performed in a complementary way to Brooke. Surprisingly given his neurological profile, Nico performed at or above the mean on all of the basic discriminatory tests, and was a full standard deviation above the mean for his peers at age ten in the task involving matching a blank-syllable intonation pattern to a linguistic phrase. He was also competent in identifying deception, sarcasm and sincerity in the story conditions, although, like Brooke, the justifications he gave for his answers were very atypical. Interestingly and distinctly unlike Brooke, Nico never mentioned or imitated a speaker's tone of voice in justifying his decision, although all but two of his same-age peers did mention tone at least once. Nico's most consistent strategy involved making a snap judgement about the speaker's intent in a story, and then justifying his judgement by simply reiterating his own perspective. Despite his accuracy at identifying the speakers' tone of voice, he showed little willingness to reflect upon his strategies or to take the perspectives of story characters.

The most straightforward test neuropsychologically was differentiating statements from questions based on falling versus rising pitch contour. Brooke and Nico, like all of the other subjects, performed at ceiling on this task. All of the subjects except one 10-year-old American
scored ten out of ten; the one exception received a score of nine. (See Figure 2 for a comparative summary of Nico's and Brooke's prosodic discrimination abilities.)

In the pitch contour-matching task, in which subjects were asked to pick which of two differently intoned statements matched an intonation pattern on the meaningless syllables "na na," Brooke scored a 7 out of 10. This was somewhat below the mean of 8.2 for the rest of the sample, but within one standard deviation (SD=1.38). The mean for Brooke's 18-year-old age mates was 8.4, with a standard deviation of 1.44. Two 18-year-olds and one 12-year-old scored lower than Brooke, while everyone else scored equally well (two subjects) or better (17 subjects). Because the test contained only ten items, a chi-square test was used to confirm that the sample was performing significantly better than could be expected by chance (chi-square=95.23, dof=1, p<0.001).

Contrary to expectation, Nico performed very well on the intonation pattern-matching task, receiving a perfect score of 10 compared to a mean score of 8.8 among his same age 10-year-old peers. (The three adults all received perfect scores.) Nico's score fell a full standard deviation above the mean (SD=1.13).

In the task in which phrases were differentiated by stress, e.g. "Red Socks" (the baseball team) versus "red socks" (a particular color of socks), Brooke scored 3 out of 6 correct, which is indistinguishable from chance. The sample mean was 4.0, and the sample standard deviation was 1.89. Six subjects scored lower than Brooke; they included the three 8-year-olds, and one ten-, one twelve-, and one 18-year-old. Once again, because of the small number of items in the test, a chi-square was used to confirm that the sample as a whole was performing above chance (chi-square=14.03, dof=1, p<0.001).

In contrast to Brooke's relative difficulty compared to his peers with differentiating phrases by stress, Nico received a perfect score on the Spanish version of this task, which involved differentiating words that differ only by stress. To be fair, the Spanish version of the test is probably somewhat easier, as all but two of Nico's same age 10-year-old peers also received perfect scores, as did the three adults.

The most difficult forced-choice condition required subjects to integrate information about the story context with information about the speaker's intent to choose the most suitable of two differently-intoned but otherwise identical ending statements. On this test, Brooke's score fell to the fourth percentile and more than two standard deviations below the mean; only one 8-year-old scored equivalently poorly. Brooke's score was 4 out of 10; the mean for the American sample was 8.2, with a standard deviation of 1.95.

On the Spanish version of this task, Nico also performed poorly compared to his peers, receiving a score more than two standard deviations below the mean for his same age 12-year-old peers. Nico scored a 3 out of 10, compared to the 12-year-old mean of 6.6, SD=1.43. Nico's score at age 12 was also more than one standard deviation below the mean for 10-year-olds (Mean for 10-year-olds=5.2, SD=2.1, N=13). The mean for the six adults was 8.5, with a standard deviation of 1.05.

Arguably, the tests most directly approximating prosodic judgements in real-life social interactions were the story conditions involving short vignettes with two characters. In the condition that subjects encountered first, subjects heard ten short stories with either sarcastic or sincere contexts, ending with a report of one character's sarcastically ambiguous statement to the other character. Subjects were asked to decide whether the final statement had been sarcastic or sincere, and to justify their answers (see Figure 1 in Methods). Both Nico and Brooke performed equally well to their peers on this task. Nico scored a 7 out of 10, compared to a mean for his
same-age 12-year-old peers of 6.82, SD=1.60, N=10. Brooke scored a 9 out of 10, and the scores for his same-age peers ranged from 9 to 10. Given these scores, both Nico and Brooke were able to use a story context to infer the sarcastic or sincere intention of a speaker's comment.

On the complementary story condition, subjects heard sarcastically ambiguous stories that ended with one character making a statement to the other in either a sarcastic (n=4) or a sincere (n=4) tone of voice. Interspersed were items with sincerely intoned ending statements but contexts that indicated that the speaker was lying (n=5). Compared to his peers, Nico performed competently on these items, receiving a score of 9 out of 13, which fell exactly at the mean. The standard deviation among his same-age 12-year-old peers was 1.48. Nico's errors were more or less evenly spread among the three conditions; he made one error on recognizing deception, one on sincerity, and two errors on sarcasm.

Brooke, interestingly, did exceptionally well on this condition, listening carefully to speakers' tone of voice and accurately judging their intent. Brooke received a score of 12 out of thirteen; the mean for his same-age 18-year-old peers was 9.05, SD=1.75. Brooke's only mistake was in judging the speaker in a sincere item to be simultaneously joking and lying.

As described above in the methods section, in addition to making judgements about speaker's sarcastic, sincere, or deceptive intents, subjects were also asked questions to probe their reasoning or strategy. Here, Nico and Brooke performed very atypically compared to the normal boys, regardless of age. Using cluster analyses that included each subject's strategy codes by each individual item with both context and tone of voice conditions included, Nico and Brooke were compared to their same-age and younger peers as a group. In each case, the data split at the first step into two clusters, one containing the hemispherectomized boy and the other containing all of the other subjects (see Figure 3).

Not only were Nico's and Brooke's strategies very atypical, they were very different from each other. Brooke relied heavily on imitating or alluding to a speaker's tone of voice. Further, in instances where he imitated the speaker's tone of voice, he would often go on to bring his own personal experiences to bear on his judgement of the speaker's intent, sometimes going as far as to blur the boundaries between himself and the story characters. For example, in describing how he knew that a speaker was lying when she said she had scored ten soccer goals when if fact she had scored only one in the story, Brooke said,

"She didn’t want to admit she only scored one point... And you can’t even score 10 points. You can probably only score like 5, and that’s the highest you can go. Cause I can only- out of a game- I can only score like 2 or 3 and that’s if I really try."

In this example, Brooke uses his own experience with soccer to guide his judgement, even though the story had plainly stated how many goals the girl had scored.

In addition, Brooke often seemed to work from tone of voice, noting the emotion that the tone seemed to portray and the implications that that emotion would have for the story. For instance, in a story in which an older sister sarcastically tells her younger sister, "Yeah, I'm sure you have lots of homework!", Brooke responded,

"She was probably joking around. But I think she was serious at the same time. It’s like two things at once...joking around is like, “you don’t have no homework.” [said in a joking tone] That’s joking around. Serious is like, “you have homework? That’s a drag.” [said in an exaggeratedly serious tone] That’s serious. So it’s like a little mix."

Here, Brooke justifies his decision that the story character's intent was sarcastic by talking as the character would sound were she sarcastic or serious, and then explaining that the character's original statement was, in his opinion, a mix between these two tones.
Nico, on the other hand, never mentioned tone of voice or his own personal experiences in justifying or reasoning about his decisions. Instead, he tended to merely reiterate his original choice, giving answers such as, "how do I know that [she is joking]? Because I just heard it." Despite his accuracy at categorizing the statements, he showed little awareness of the source of his judgement, and gave few embellishments or explanations in his answers. (This was true despite his high verbal IQ and generally talkative nature.)

**Figure 3.** The results of two cluster analyses, one on the American and one on the Argentine prosodic data, including each of the prosodic reception codes by individual test item for each of the subjects. The top and bottom diagrams depict the American and Argentine data respectively. Number labels represent the age/subject identity of the comparison boys. Notice that Brooke's and Nico's response strategies represent the single largest source of variation in the data. In essence, they are "most different" from the rest of the groups.
Emotion

Nico and Brooke participated in two complementary assessments of emotion, a clinical-style interview about the participants' thoughts and feelings about his personal relationships with close friends and family, known as the Self-in-Relationships interview, or SIR (Fischer & Kennedy, 1997; Kennedy, 1994), and a conventional assessment of emotion discrimination on faces (Ekman & Friesen, 1975). On both tests, Nico's and Brooke's emotions were atypical; they were less accurate than normals on identifying emotions on faces, and they showed less complex representations of their feelings about close relationships. However, while the boys were atypical, their profiles were also quite distinct from each other.

The Self-in-Relationships Interview

On the SIR, Brooke showed a distinct reluctance to think or talk about his personal relationships, despite the finding that, in general, adolescents greatly enjoy this interview protocol. He described himself as "gentle and open-hearted," but provided only concrete definitions of what these constructs meant, e.g. "…open-hearted is like…you can talk to your friends whenever you want. If you have a problem or something they will understand." When asked to describe his feelings, the only adjectives he spontaneously produced were "happy" and, by way of something negative, "agitated." In talking about his surgery and hospitalization, he used words such as "psycho" (which he clarified as "angry" and produced in the context of explaining how he felt in the hospital after his surgery when he was physically restrained) and "out of control." His descriptions of personal relationships, such as with his best friend Pete, were given begrudgingly and mostly constituted an outright refusal to reflect on relationships. For example, when pushed to talk about what he and Pete enjoy doing together, he replied, "We're just friends. We're not like boyfriend/girlfriend…I don't know what Pete's real life is! I'm not like the mother of his family."

However, towards the end of the interview, Brooke revealed that he is in fact quite strategic about managing his thoughts and emotions, and keeping them exclusively positive. As the conversation worked around again to negative feelings, Brooke explained,

"I put those questions away in the back of my head… I really don't want to [pull them out]…It's like a locked door…All those things you are saying, that I don't want to do, 'cause I try to hide those things. I don't open it up. That's my theory. That's why I'm always happy."

Overall, Brooke's strategy with regard to emotion seemed to be to actively avoid negative emotions at all cost, and to effortfully cultivate positive emotional states. He explained,

"I just do things that make me happy…Just got to open up one of those boxes in your head to think about the fun thing you did. And when you are done with your happiness you close the box again to save."

In describing how he "gets out of the dumps," he stated,

"there's different kinds of methods I use to get out…I got to think of it, think of it hard, and sometimes it doesn't click 'til like two hours later."

As these statements reveal, Brooke seemed to modulate his emotions by consciously controlling the situations he allows himself to think about, cultivating positive emotions and refusing to think about negative emotions. It could be that Brooke's neurological condition has left him less able to modulate or control his own emotional states, a condition that he compensates for by strategically manipulating his thoughts.

While Brooke was quite calculated and reflective in his strategies during the SIR interview, Nico remained very concrete throughout. When asked to describe himself, he stated "I
like to swim" and "I like to travel." The only adjectives for emotional states that he used were "calm (tranquilo)" in relation to how he feels with his family and "nervous (nervioso)" in school. He seemed to find the interview exceedingly tedious and his descriptions of his friends and family were very concrete. In addition, he seemed to actively avoid discussing emotions, saying that the task was "too hard." For example, when asked how he feels with his father, he replied, "I don't know, because the truth is that I don't like to go to the cinema and he does. I don't like to go to the cinema a lot."

In this answer, rather than reflect even in a simple way on his feelings with his father (as a younger child might), Nico avoids thinking about emotions and instead turns the discussion towards the concrete, unemotional topic of the cinema.

Overall, Nico's understanding of emotional states was very rudimentary and undifferentiated, moving between a positive emotional state of "calm" and the negative state of "nervousness." Although he represented both positive and negative emotions in describing himself, he showed little willingness or ability to further differentiate his feelings.

**The Ekman Test of Facial Affect Discrimination**

In the Ekman test, Nico and Brooke scored approximately equivalently, with Brooke correctly identifying 71 of 110 photos, or about 65%, while Nico correctly identified 75 photos out of 110, or about 68%. In analyzing responses, surprise and happiness were considered positive emotions, while fear, anger, disgust, and sadness were considered negative.

Nico had two major trends in his pattern of errors. First, he tended not to notice the emotions portrayed on faces and to default towards neutrality, categorizing as "neutral" three happy, two angry and two sad faces, and as "thoughtful [his word]" three angry and two sad faces, for a total of twelve errors. Second, he tended to make errors distinguishing between negative emotions; he made twenty errors of this sort, nine of which were confusions between disgust and anger, a mistake common in patients with brain damage (Calder, Keane, Manes, Antoun, & Young, 2000). Counted among these errors were also difficulties recognizing sadness, which he correctly identified in only four out of seventeen photos. In the remaining three errors, Nico labeled "fear" as "surprise," his only confusion between a negative and a positive emotion, and a relatively easy error to make. He correctly labeled all of the surprised photos and fifteen of the eighteen happy photos. Notably, he never misattributed happiness to a face displaying a negative emotion, and his only error in identifying positive emotions was to mistake happiness for neutrality three times.

The most striking trend in Brooke's data was that he accurately attributed happiness; he labeled the eighteen happy photos and only those photos "happy." The majority of Brooke's errors were in distinguishing between negative emotions; he made twenty-one errors of this sort, fifteen of which were in miscategorizing disgust as other negative emotions, mainly anger. Overall, Brooke's errors were less easy to explain in terms of trends; except for his complete failure to recognize disgust and his perfect record in recognizing happiness, his errors were sprinkled throughout the exercise. He both labeled emotive faces as neutral five times and labeled neutral faces as emotive three times. He made four errors converting a negative emotion, fear or anger, into a positive emotion, surprise, and four errors converting surprise into a negative emotion, fear or disgust. In general, except for the instances of happiness and disgust, Brooke seemed to be less systematic than Nico in his categorization of emotions on faces.
Discussion:

In juxtaposing measures of prosodic understanding and emotion in Nico and Brooke, interesting complementary profiles emerge. These profiles provide tentative evidence for a strong developmental relationship between emotion and prosody, one in which the two neuropsychological skills seem to have remained closely associated in both boys through their cognitive and neurological compensation after brain damage. This finding has implications for future work with normal and clinically developing children, for whom this strong association between skill sets may also exist.

While Nico's and Brooke's results seem on the surface to contradict expectations based on neuropsychological findings with adults, they combine to reveal a neuropsychological compensatory logic that begins to elucidate the brain's mechanisms of change through development, at least in the extreme case of hemispherectomy. Based on past work with brain-damaged adults, we would expect Nico to have relatively poor prosodic discriminatory skills, and Brooke to have relatively strong skills in this area. In fact, in the most straightforward discriminatory conditions, including the task involving matching intonational contours on a blank syllable to the intonational contour of a previously heard statement, Nico performed as well as or significantly better than his peers, while Brooke's scores fell at or below the mean. At the same time, Brooke's ability to make inferences about a speaker's intent based on his or her tone of voice was excellent compared to his peers. Both boys fell to over two standard deviations below the mean of their peers on the hardest test, involving the integration of information from the story context and tone of voice.

Although these results may seem incongruous, interpreting them in terms of developmental neuropsychological compensatory mechanisms, rather than in terms of brain damage in adults, can provide tentative explanations. In Nico's case, tonal language speakers provide a precedent for left-hemisphere analysis of prosodic features (Gandour et al., 2000; Hughes, Chan, & Su, 1983; Moen & Sundet, 1996; Packard, 1986). In tonal languages, such as Mandarin Chinese, prosody is used to express both grammatical/lexical information and affective information. In tonal language speakers, while the right hemisphere handles affective prosodic information, the left hemisphere specializes in processing prosodic grammatical information (Gandour, Ponglorpisit, & Dardarananda, 1992; Gandour, Wong, & Hutchins, 1998). Returning to Nico, we see a boy who is very skilled at categorizing affective prosodic information, but relatively poor at explaining what this information implies for the larger social context, say the outcome of a story. I would suggest that Nico's left hemisphere, rather than working to understand the affective information as affective, has instead modified the task to suit its relative strength, grammatical or lexical categorization. In effect, Nico may be interpreting different affective tones of voice as categorical rather than emotional information. In this way, he is able to discriminate affective prosodic information quite efficiently. At the same time, it becomes quite difficult for him to bring this information to bear on the emotions in a situation.

Brooke, on the other hand, seemed very interested in both emotion and intonation, and often spontaneously brought either emotional or intonational information explicitly to bear on basic discriminatory tasks requiring only categorical judgements. For instance, in the simple task of discriminating statements from questions, he volunteered, "That's a question because it's higher." In matching intonational contours to previously heard phrases, he sometimes volunteered emotional evaluations of the two statements. For example, in matching a pitch contour to the phrase "I'm happy to see her," he said, "hmm...she doesn't sound happy to see her." In the most complex test, requiring the integration of pitch and stress information with story
context, Brooke's strategy was to explicitly describe the tone and pitch patterns in the two choices, and then base his judgement on how emotionally or socially appropriate that pitch pattern sounded to him. For example, in a story about a teacher reminding a student to write his name on his paper, Brooke responded, "One [choice] is like a phrase, and the other one is almost shouting. And you can't shout at school. So... [That's why you chose the first one?] Yeah." Other descriptions Brooke provided included, "the second choice has extra space," "she shouted at the ending," "the volume's going up," and "the first one was a little bit quieter and mellow." At times Brooke provided detailed descriptions of tonal patterns and their emotional implications, as in "Because [that choice] goes up and then down and then up again. Because it's the anger going on. It sounds meaner, but the other [choice] goes up at the last word, which is nicer."

In bringing explicit emotional judgements and detailed descriptions of prosodic contour to bear on basic discriminatory problems, Brooke was likely taking advantage of his relative neuropsychological strengths. Instead of training his right hemisphere to process linguistic information like his missing left hemisphere would have, he appears to be, like Nico, modifying the cognitive processing problem to suite the skills he has, namely prosodic and emotional ones. Paradoxically, through overly analyzing prosodic features and assigning affective information that was not necessarily relevant, Brooke may have disadvantaged himself compared to his peers on the basic discriminatory measures. At the same time, when faced with a test condition involving using prosodic information to make judgments about speaker intent, a test well matched to Brooke's strategy, Brooke was able to outperform his peers.

Nico's and Brooke's strategies also played out in the justifications for the answers in the story conditions. Both boys did well on these tasks compared to their peers, but each used strategies qualitatively different from those of their peers or each other. These strategies both support the tentative neuropsychological explanations from the discriminatory tasks, and suggest implications for Nico's and Brooke's real-life social functioning. They also highlight the parallels between the boys' emotional and prosodic functioning.

As discussed in the results section, Nico rarely offered emotional evaluations during any of the test conditions, prosodic or emotional. In categorizing emotional faces in the Ekman test, he tended to regress towards neutrality and had a difficult time distinguishing between negative emotions. In the prosodic test conditions, he quickly categorized speakers' tones of voice, but was relatively unwilling to reflect upon the emotional implications of this judgement. In addition, the majority of his errors were on sarcastic rather than sincere or deceptive conditions, suggesting that he tended toward ignoring tone of voice and instead attempting to reconcile a literal interpretation of a speaker's statement with the context of the story. Indeed, although his overall score was not significantly different from the mean of his peers' scores, some of his errors suggested a striking inability to make use of or imagine a speaker's tone, coupled with an unreasonable or unlikely evaluation of a speaker's affect. For example, in a story in which a girl tastes a completely burned cookie and declares it "the best she has ever tasted," Nico steadfastly holds to a literal interpretation, stating that the cookie-taster was sincere, "because she ate them and she thought they were good. After all, she tried them." When asked whether the cookies really tasted good, he replied that he did not know.

In this example, Nico seemed unwilling or unable to imagine that the speaker's tone may have been sarcastic and her emotion one of disgust; despite contextual evidence to the contrary, he held to a sincere interpretation. This finding may foreshadow his parents' growing concern that Nico has difficulties communicating appropriately with his social peers. According to his parents, his childhood social popularity is waning. It may be that, despite Nico's normal verbal
IQ, his inability to use prosodic information to predict emotion could have serious social consequences.

Brooke, on the other hand, was more willing than his peers to assign affective evaluations to statements, often using various permutations of tone to work around to his emotional judgement. In the SIR interview, Brooke was quite direct about his cognitive strategies for modulating his emotions. His father and guidance counselor reinforced my interpretation that to control his all-consuming emotions, Brooke physically or mentally removes himself from negative situations. Brooke thoroughly enjoyed the benign and clearly delineated prosodic story conditions, talking freely about speakers' intents, and often acting out their situations himself or recounting past experiences as evidence for his judgements. In this condition, the inherent boundaries in the design of the test allowed him to make use of his emotional and prosodic strengths. However, these same strengths may become liabilities in negotiating everyday social situations, as Brooke appears to have trouble separating his emotional feelings from his thoughts and recollections about these feelings. This condition leaves him vulnerable to violent outbursts and periods of depression, and requires that he dedicate much mental energy to actively cultivating positive thoughts and emotions.

Overall, both Nico's and Brooke's profiles on the emotional and prosodic tests suggest strong developmental parallels between emotional and prosodic processing. Nico's rule-bound, categorical approach to prosodic processing leaves him largely unable to use the prosodic information for emotional ends. Conversely, Brooke's apparent heavy reliance on prosody and emotion leaves him vulnerable to emotional regulation problems and to bringing emotional judgements to bear when they are not particularly relevant. Interestingly, while both boys' profiles present them with liabilities, each boy seems to be building directly on his comparative neuropsychological strengths, even in the face of compensation for such extreme neurological damage.

**Conclusion and Limitations**

The developmental relationship between prosody and emotion has been insufficiently explored, despite its implications for socioemotional and language development in typical and clinical populations. This study investigates this relationship in two exceptional, rare boys who have successfully compensated for the surgical removal of one of their cerebral hemispheres, and lends support to the notion that emotional and prosodic processing are heavily intertwined through development. While the exact neurological mechanism by which they are connected is beyond the scope of this study, the close neuropsychological associations found in Nico and Brooke, each of whom suffered severe brain damage, suggest shared neurological resources between the two skills.

At the same time, by their very nature, case studies such as these have inherent limitations, in that mechanisms are discovered based on the performance of only two, albeit very special, people. While we stand hugely to benefit from such cases because they reveal mechanisms that are often well hidden in normal children, their very exceptionality can make them difficult to interpret and generalize. For this reason, it is essential that the results from this study be investigated in other clinically and normally developing populations.

Especially as atypical prosody is a feature of many psychiatric disorders involving emotion, the link between emotion and prosody could have clinical implications. For example, a well-explicated neuropsychological link between emotion and prosody could be exploited to develop a screening test for prosodic discrimination skills in young children that would identify children at risk for emotional problems. Alternatively, as it is known that clinically depressed
mothers speak with less prosodic variation to their infants, the emotion-prosody link may turn out to be one of the channels by which mothers pass dysregulated affect to their infants. In normal children and adolescents, a better understanding of the developmental progression in prosodic skills could provide a new angle through which emotional development could be explored and, in cases of difficulty, remediated.

In conclusion, Nico’s and Brooke’s cases present a unique opportunity to tease apart the developmental trajectories of emotion and prosody, and, in the process, to explore the basic principles governing developmental plasticity in the brain. While their exceptional cases should be interpreted with caution, they also suggest possible developmental mechanisms in normal children. In the end, the developmental, neuropsychological link between emotion and prosody could prove a useful new vantage point from which to study emotional and linguistic development.

References


Appendix 1.

Codes for Prosodic Reception Story Condition Data

O  Uses a generalizable rule, i.e. “b/c nobody would say a beautiful cake is ugly.” Or, “b/c everyone loves pretty cakes.” [A rule is not specific to this situation, but can be generalized to similar situations.]

A₀  Restates something from the story.
A₁  Extrapolates directly from the story, based on common knowledge or assumption. (This does not include extrapolation about someone’s feelings, which is R₁).
A₂  Adds information that does not directly follow from the story, or adds embellishments that don’t really matter.

K₀  Uses self as a reference point, i.e. “b/c I would have…” or “b/c once I had a similar thing happen…” or “b/c my big sister said the same thing to me.” [Here the subject is taking on the story character’s perspective as his own by putting himself in the character’s place. He retains his own identity but imagines himself personally in the story situation.]
K₁  Uses self as a reference point by actually acting out or speaking as the person in the story, i.e. “b/c she said, ‘I don’t wanna clean my room. I can clean my room any old time.’” Or the subject pointing to his own boots to show why a 4-year-old wouldn’t fit in his father’s boots, saying “b/c these boots are size tens.” [Here the subject is taking on the story character’s perspective as his own by becoming the character in some way, and blurring the boundaries between his own identity and the character’s. He brings the character’s situation into the present and acts it out.]

R₀  The subject only considers his own perspective, not that of the story character, e.g. “How do I know that? Because that’s what I think./Because I just heard it./Considering the situation./Because it says so./I don’t know why she said that./Because he said it.” This code also includes cases where the subject says you have to take the speaker literally, as in, “she said it so it must be true.” It also encompasses the subject saying you can’t know another’s thoughts, as in, “How can I know whether she liked the cookies? It was her who tasted them.”
R₁  Interpolating by taking a 1ˢᵗ order perspective that includes something about the character’s feelings or intention, e.g. “Why did she say that to him? B/c I know he didn’t do it on purpose./B/c he at least he tried to catch the ball./Because she liked the cookies.” [Here the subject can mention his own beliefs about the character’s position, but does not put himself in the character’s position.]
R₂  Interpolating by taking a 2ⁿᵈ order perspective, e.g. “B/c she didn’t want to make him feel bad.” This can be direct or implied, as in “why did she say that? Not to hurt her sister’s feelings.” It can also be involving a second perspective on the same character’s feelings, as in, “she didn’t want to embarrass herself.” Or, “She didn’t want to make herself feel bad about losing.”

T₀  Tone of voice mentioned, described or alluded to, e.g. “he said it like a joke.” “b/c she sounded sincere.” “I know it by her tone.”
T₁  Tone of voice imitated or reproduced, e.g. “b/c she said to beat the eggs.” “B/c she said, ‘I don’t wanna clean my room. I can clean my room any old time.’” (The second example would also get a K₁ because he’s acting as the story character and reporting statements that weren’t actually in the story.)
I  Contradiction/inconsistency. The subject solves some of the questions as if one thing were true, then switches to contradict himself.

N  The answers are implausible/not possible, i.e. father’s boots fit the 4-year-old, or burned cookies taste good. The subject shows no serious awareness that these interpretations are highly unlikely.

D  The person is lying (deception).
J  The person is joking (sarcasm).
S  The person is being sincere.

U  Uncodable- unclear what the person meant, or raters disagree.