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Acknowledgements. We thank H. S. Yong, P. Reillo and M. Taper for assistance in the field; S. Bhatt, P. Reillo and D. Reames for assistance in the laboratory; and C. Boake, R. Gibson, L. Hurst, M. Kirkpatrick, R. Trivers and L. Wolfenbarger for comments on the manuscript. This work was supported by the NSF.

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Spontaneous sign systems created by deaf children in two cultures

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Deaf children whose access to usable conventional linguistic input, signed or spoken, is severely limited nevertheless use gesture to communicate[1–3]. These gestures resemble natural language in that they are structured at the level both of sentence[4] and of word[5]. Although the inclination to use gesture may be traceable to the fact that the deaf children's hearing parents, like all speakers, gesture as they talk[6], the children themselves are responsible for introducing language-like structure into their gestures[7]. We have explored the robustness of this phenomenon by observing deaf children of hearing parents in two cultures, an American and a Chinese culture, that differ in their child-rearing practices[8–12] and in the way gesture is used in relation to speech[13]. The spontaneous sign systems developed in these cultures shared a number of structural similarities: patterned production and deletion of semantic elements in the surface structure of a sentence; patterned ordering of those elements within the sentence; and concatenation of propositions within a sentence. These striking similarities offer critical empirical input towards resolving the ongoing debate about the 'innateness' of language in human infants[14–16].

We videotaped four deaf children in the USA (one in Philadelphia and three in Chicago) and four in Taiwan, Republic of China (Taipei), interacting with their hearing mothers at home with a standard set of toys. Each child was observed twice between 3 years 8 months and 4 years 11 months. Children were congenitally deaf with no recognized cognitive deficits. Cause of the deafness was unknown. Each child had at least a 70 to 90 dB hearing loss in both ears; even with hearing aids, none was able to acquire speech naturally. Children attended oral schools advocating training in sound sensitivity, lip-reading and speech production. At the time of videotaping, none could do more than produce an occasional spoken word in a highly constrained context.

None of the children had been exposed to a conventional sign system. The children's hearing parents attempted to communicate with them through speech. However, much of their interaction took place in action and gesture, a technique that worked because conversation was about the 'here-and-now'.

Although the number of subjects in the study was small, the number of observations was not. The data contain 6,614 gestural communications (an average of 455 per child, 372 per mother) made up of 10,398 individual gestures (779 per child, 531 per mother).

Unlike hearing children and adults who rarely concatenate their spontaneous gestures into strings[17,18], the deaf children in both cultures often conveyed their message through gesture sentences rather than single gestures. The sentences the Chinese and American children produced conformed closely to a structural analogue of the ergative pattern that predominates in some, but not all, natural languages[19,20]; importantly, not in English or Mandarin. This observation reduces the likelihood that the grammatical structure noted in the deaf children's gesture systems was somehow derived from the structure of the spoken languages that surrounded them.

The hallmark of an ergative pattern is that the actor in an intransitive sentence (mouse in the proposition 'mouse goes to hole') is distinguished linguistically from the actor in a transitive sentence (mouse in 'mouse eats cheese') and instead is marked like the patient (cheese). In contrast, in English, which is predominantly an accusative language, intransitive actors are treated like transitive actors and not like patients; for example, both actors precede the verb ('the *mouse* **goes** to the hole' and 'the *mouse* **eats** the cheese') whereas patients follow the verb ('the mouse **eats** the *cheese*').

Children in both cultures produced gestures for transitive actors, patients and intransitive actors at different rates (Fig. 1, dark bars; $F(2, 7) = 22.52$, $P < 0.0001$ for the groups combined; proportional data subjected to Freeman–Tukey transform before statistical analysis[21]). Gestures were produced significantly more often for patients (eaten-cheese) and for intransitive actors (moving-mouse) than for transitive actors (eating-mouse; both comparisons $P < 0.01$, Newman–Keuls). There were no significant differences between patients and intransitive actors. This production prob-

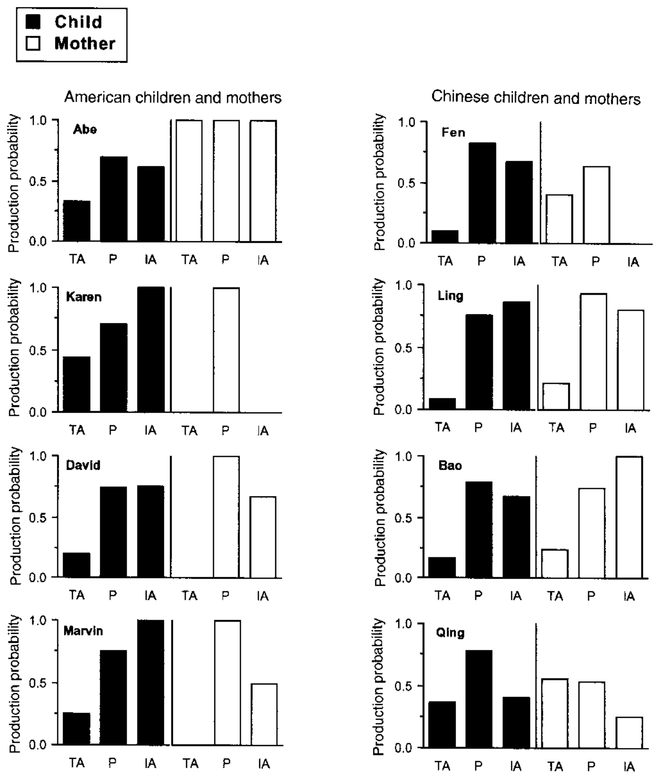

Figure 1 Probability that a gesture will be produced for transitive actors (TA), patients (P), and intransitive actors (IA) in a two-element gesture sentence. Probabilities were calculated using sentences in which three semantic elements could be gestured but only two elements actually were gestured. Deaf children (dark bars) showed significant differences in production patterns across the three elements. Gestures were produced more often for patients than for transitive actors, and more often for intransitive actors than for transitive actors, a structural analogue of the ergative pattern found in certain natural languages. Hearing mothers (white bars) were not consistent in their treatment of intransitive actors and did not display an ergative pattern.

ability conformed to an ergative pattern: gesture production was high and equal for intransitive actors and patients, and low for transitive actors. Note that production probability patterns convey information about who is the doer and the done-to in two-element sentences. If, for example, a deaf child produced the gesture sentence 'boy hit', it is likely that the boy was the hittee (patient) rather than the hitter (transitive actor) in the scene under description.

In addition to producing reliably some semantic elements at the expense of others, children were also consistent in where those elements were positioned in two-gesture strings. Children in both cultures produced gestures for intransitive actors before gestures for acts (*mouse*-go); Ling produced 14 of 15 relevant sentences conforming to this pattern, Qing 17 of 19, Bao 12 of 15, David 18 of 23, Abe 10 of 10 (P values ≤ 0.02; binomial test on each child), Marvin 4 of 4, Karen 2 of 3 (Fen was an exception, 1 of 4). Children also produced gestures for patients before gestures for acts (*cheese*-eat); Ling 11 of 12, Bao 26 of 29, Fen 9 of 11, Qing 29 of 29, Marvin 9 of 10 (P values ≤ 0.03), Abe 9 of 14, Karen 4 of 4 (David was an exception, 17 of 35; the precocious onset of a noun/verb distinction may have perturbed this pattern which was evident in his earlier sessions[22]). Thus, children in both cultures placed intransitive actors in the same position as patients, a pattern again consistent with an ergative structure.

Only two children, Qing and David, produced gestures for transitive actors often enough for order to be explored. David produced gestures for transitive actors after gestures for acts (eat-*mouse*, 5 of 6; this order has been confirmed in larger samples[23]). David thus distinguished transitive from intransitive actors, not only in production probability, but also in gesture order. Qing produced gestures for transitive actors in the same position as intransitive actors and patients: before gestures for acts (*mouse*-eat, 8 of 8, $P \leq 0.004$). However, Qing did distinguish between patients and transitive actors when the two appeared in the same string, producing gestures for transitive actors in second position after patients (cheese-*mouse*, 6 of 7, $P \leq 0.06$). Patients and intransitive actors thus consistently occupied first position in two-element sentences, again conforming to an ergative structure.

Children in both cultures produced complex sentences, concatenating more than one proposition within a single string. For example, one child produced a 'clap' gesture, a point at himself, a 'twist' gesture, a 'blow' gesture, and a point at mother to request mother to twist open the jar (proposition_1) and blow a bubble (proposition_2) so that he could clap it (proposition_3). The children did not differ significantly in their production of complex sentences ($U = 5$, NS, Mann–Whitney U Test[24]; Fen 0.54 of 65 gesture sentences; Bao 0.42 of 289; Qing 0.41 of 257; Ling 0.33 of 156; David 0.45 of 394; Abe 0.36 of 152; Karen 0.34 of 50; Marvin 0.32 of 82). Each child's gesture system thus demonstrated generative capability, an essential property of all natural languages.

We next explored a potential source of input to the children's gesture systems, analysing the spontaneous gestures produced by the hearing mothers when interacting with their children during these videotaped sessions. Like their children, mothers produced transitive actors, patients, and intransitive actors at significantly different rates (Fig. 1, white bars; $F(2, 6) = 4.20$, $P < 0.05$). Karen's mother produced no relevant intransitive sentences and was consequently excluded from statistical analysis ($n = 7$); all other blank entries in the figure reflect the fact that the mothers did not produce a semantic element when they had the opportunity to do so (on average, they had 17.3 such opportunities). Mothers produced more gestures for patients than for transitive actors ($P < 0.05$), thus distinguishing between the two, as did their children. It is, however, where intransitive actors are situated relative to transitive actors and patients that determines the typology of a language, and here mothers and children differed. Mothers showed no reliable patterning of intransitive actors, whereas children produced intransitive actors at a rate significantly different from transitive actors but not different from patients, thus displaying an ergative pattern.

Chinese mothers tended to order their gestures within sentences in the same way as their children (patient-act, mothers Bao 16 of 21, Fen 14 of 16, Ling 11 of 11, P values < 0.01; intransitive actor-act, mothers Bao 5 of 5, Fen 7 of 7, Qing 6 of 6, P values < 0.02, Ling 9 of 12, $P < 0.07$), with the exception that Qing's mother showed no patient-act order (6 of 12) and no patient-transitive actor order (2 of 5) although her child did. In contrast, American mothers each produced only 2 to 5 relevant gesture sentences in these sessions, and more extensive analyses of additional sessions[23] also failed to reveal statistically significant ordering patterns.

Across the two cultures, mothers produced proportionally fewer complex sentences than their children ($t(7) = 2.50$, $P < 0.05$ on transformed data[21]; Fig. 2; total $n = 1{,}445$ children, 629 mothers), although the gap was much wider for American dyads than for Chinese. To explore who took the lead in the production of complex gesture sentences, we looked at the developmental pattern for American mothers and children in additional videotaped sessions (Fig. 3; total $n = 1{,}364$ children, 229 mothers). In 15 of 20 sessions

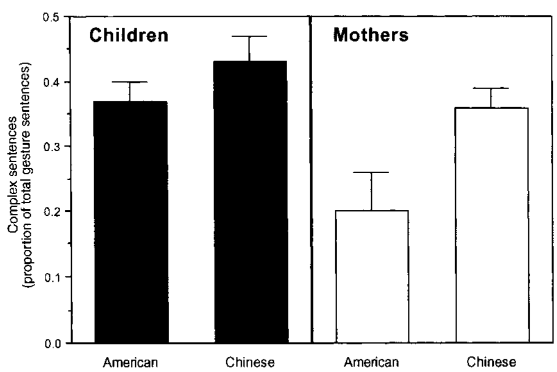

Figure 2 Mean number of complex gesture sentences as a proportion of total gesture sentences in Chinese and American deaf children and their mothers. Complex sentences contain two or more propositions. The children in the two cultures did not differ in their production of complex sentences and, as a group, produced significantly more complex sentences than their mothers. The error bars represent s.e.m.

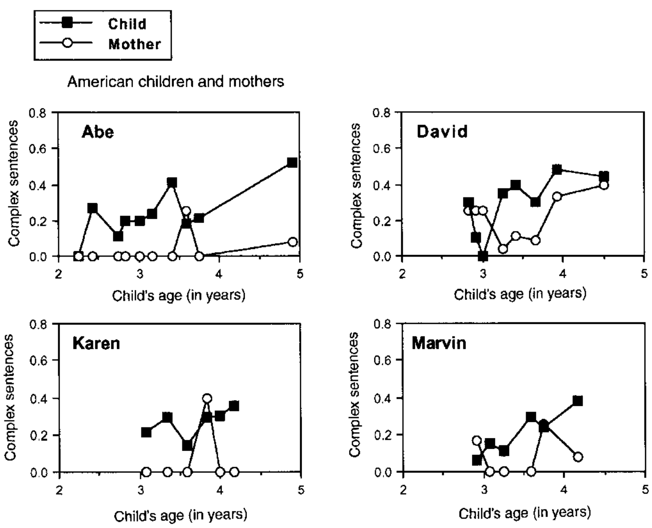

Figure 3 Development of complex gesture sentences in American deaf children and their mothers (proportion of total gesture sentences). All four children steadily increased their use of complex sentences over time. The mothers did not consistently use complex sentences until months after their children, if at all.

before age 3 years 8 months, child produced proportionally more complex gesture sentences than mother ($P < 0.02$, sign test[24]). In only 6 of the 20 sessions did mothers' production of complex sentences rise above 4%, compared to 18 of 20 for the children ($z = 3.55$, $P < 0.001$). Thus, American children were unlikely to have learned complex gesture sentences from their mothers.

Overall, American mothers' gestures did not resemble their children's. Indeed, American children's gestures had more in common with Chinese children's gestures than with their own mothers'. American children thus appear to be responsible for the structural aspects of their systems. In contrast, Chinese mothers' gestures did resemble their children's, at least in part. Chinese children may therefore have learned segments of their systems from their mothers or, more likely given that Chinese and American children's gestures follow the same patterns, the mothers may have learned them from their children. If so, we ask why Chinese (but not American) mothers copy gesture patterns from their deaf children. The answer might involve cultural differences in attitudes toward children's communications, or the languages themselves (it may be easier to produce complex gesture sentences while speaking Mandarin than while speaking English). Whatever the reason, the fact remains that American children took the lead in creating their gesture systems, a lead their mothers did not follow.

Given the salient differences between Chinese and American cultures[8–12], the structural similarities in the children's gesture systems are striking. These structural properties—consistent marking of semantic elements by deletion and by ordering, and concatenation of propositions within a single sentence—are developmentally robust in humans (but not, apparently, in chimpanzees[25]). Their development is buffered against large variations in environmental conditions and in this sense can be considered 'innate'[26]. □

Methods

Children's and mothers' gestures were coded according to a system developed previously[23]. Criteria for isolating gestures grew out of a concern that the gestures meet the minimal requirements for a communicative symbol: first, the gesture must be directed to another individual; the gesturer must establish eye contact with a communication partner, or be assured of the partner's attention, before acting; and second, gesture must not itself be a direct manipulation of some relevant person or object; it must be empty-handed[17]. Using these criteria, we isolated gestures from the stream of motor behaviour. We characterized the form of the gestures following guidelines established for coding conventional sign languages, and divided gestures into sentence strings on the basis of motoric criteria. We then characterized the meaning of the gestures, deciding how many and what type of propositions were conveyed in a sentence, and identifying individual semantic elements.

Reliability was established between two trained coders who independently transcribed a portion of the videotapes. Two native Mandarin speakers (one born and raised in Taiwan) who were bilingual in English coded the Chinese videotapes, and two native English speakers coded the American videotapes. Reliability was 87% and 89% agreement between coders (for the Chinese and American samples, respectively) for describing gesture form, 100% and 93% for identifying sentence boundaries, 87% and 85% for identifying types of propositions, and 92% and 90% for identifying semantic elements.

Received 25 April; accepted 20 October 1997.

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Acknowledgements. We thank L. Barsalou, J. Huttenlocher, B. Keysar, M. K. McClintock, P. Miller, D. McNeill and W. Wimsatt for comments; S. Duncan for help in collecting the Taiwanese data; and F. Bechter and M.-Y. Zheng for help in transcribing the videotapes. Supported by grants from the National Institute on Deafness and other Communciation Disorders and the NSF.

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Prostaglandins stimulate calcium-dependent glutamate release in astrocytes

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Astrocytes in the brain form an intimately associated network with neurons. They respond to neuronal activity and synaptically released glutamate by raising intracellular calcium concentration ($[Ca^{2+}]_i$)[1,2], which could represent the start of back-signalling to neurons[3–5]. Here we show that coactivation of the AMPA/kainate and metabotropic glutamate receptors (mGluRs) on astrocytes stimulates these cells to release glutamate through a Ca^{2+}-dependent process mediated by prostaglandins. Pharmacological inhibition of prostaglandin synthesis prevents glutamate release, whereas application of prostaglandins (in particular PGE_2) mimics and occludes the releasing action of GluR agonists. PGE_2 promotes Ca^{2+}-dependent glutamate release from cultured astrocytes and also from acute brain slices under conditions that suppress neuronal exocytotic release. When applied to the CA1 hippocampal region, PGE_2 induces increases in $[Ca^{2+}]_i$ both in astrocytes and in neurons. The $[Ca^{2+}]_i$ increase in neurons is mediated by glutamate released from astrocytes, because it is abolished by GluR antagonists. Our results reveal a new pathway of regulated transmitter release from astrocytes and outline the existence of an integrated glutamatergic cross-talk between neurons and astrocytes *in situ* that may play critical roles in synaptic plasticity and in neurotoxicity.

The release of endogenous glutamate from cultured cortical astrocytes was monitored continuously by means of an enzymatic assay[6]. Coapplication of (S)-α-amino-3-hydroxy-5-methyl-4-