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Concomitants of Success in Acquiring an Augmentative Communication System: Changes in Attention, Communication, and Sociability

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Evidence was presented that successful participation in augmentative communication intervention can foster developmental changes that extend beyond the targeted effect. Ten persons with severe mental retardation were assigned in matched pairs to a lexigram condition (graphic symbols) or a control condition (social stimulation). A coding system, developed to assess pre- versus postintervention performance in four domains, was applied to videotapes of each subject in dyadic interaction. The 3 subjects who successfully acquired lexigrams exhibited changes in attention, intentional communication, and sociability; the other subjects improved only in sociability. Supporting results were obtained using an abbreviated coding system. Application of the coding systems to additional subject populations and interventions would clarify how broadly the results generalize.

When intervention works, why does it work? Are changes limited to targeted behaviors, or does success depend upon a more complex orchestration of developmental changes that are occasioned by the intervention in ways that may not always be anticipated? In this paper, we have

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considered the case of augmentative communication. Investigators have demonstrated that for individuals who lack speech in conjunction with severe mental retardation, a change of input modality can often bring about the first success at acquiring a conventional symbolic system (for a review, see Romski, Sevcik, and Ellis-Joyner, 1984). Augmentative communication systems augment or replace speech with symbols in the visual–manual modalities, typically in the form of manual signs (e.g., Abrahamsen, Cavallo, & McCluer, 1985) or graphic symbols (e.g., Romski, Sevcik, & Pate, 1988). These interventions have had excellent outcomes, in that most participants acquire communicative use of a nonspeech symbol vocabulary. In this study we asked, what else changes? If the process of acquiring the new symbols is embedded in a causal structure of changes involving several domains, identification of these domains is the first step towards understanding what actually occurs under a particular intervention. Likely candidates include the domains of (a) unaided intentional communication (ranging from primitive gestural–vocal communication to conventional speech), (b) attention deployment, (c) task-orientedness, and (d) sociability.

There is a substantial literature on intervention effects, which is most persuasive in its documentation of change in the domain that is directly targeted by the intervention. Specifically: (a) the participants in augmentative communication programs, who are exposed to speech in conjunction with corresponding nonspeech symbols, frequently show improved speech comprehension (Bricker, 1972), speech production (Hobson & Duncan, 1979; Kahn, 1981), or both (Konstantareas, Webster, & Oxman, 1979; Linville, 1977), in addition to acquiring the nonspeech symbols. (b) Individuals with mental retardation who participate in attentional interventions show improvements in attention span (Chamberlain, 1985), visual attention in a visual–motor task (Goetz & Gee, 1987), and visual monitoring in a pattern detection task (Perryman, Halcomb, & Landers, 1981). (c) Those who are taught techniques of self-monitoring exhibit increased task-orientedness (Morrow, Burke, & Buell, 1985; Osborne, Kosiewicz, Crumley, & Lee, 1987). (d) Finally, those who participate in social intervention programs show improved social behavior (Cone, Anderson, Harris, Goff, & Fox, 1978; Twardosz & Jozwiak, 1981).

Changes in domains that are less directly related to the intervention are of greater interest but have not been as well documented. For individuals with *autism* who participate in augmentative communication programs, there are several domains for which some degree of evidence is available. Systematic observations using techniques such as time-sampling have yielded strong evidence for improvements in the social domain but inconsistent results concerning predicted decreases in off-task behavior (e.g., Benaroya, Wesley, Ogilvie, Klein, & Meaney, 1977; Konstantareas et al., 1979). Less systematic observations have suggested that participants may also show improvements in attention and unaided intentional communication (Bonvillian & Nelson, 1976; Fulwiler & Fouts, 1976).

For individuals with *mental retardation* who participate in the same types of augmentative communication programs, changes in these four domains have not been adequately demonstrated, although on occasion they have been noted incidentally (Romski, White, Millen, & Rumbaugh, 1984; Wilson, 1974). There is reason to think that changes in the attention domain would be particularly salient for this population. Odom-Brooks and Arnold (1976) have suggested that individuals with severe retardation exhibit general attentional deficits, and other researchers have specifically targeted problems with selective listening (Snyder & McLean, 1977), joint attention to a referent (Snyder & McLean, 1977; Yoder & Farran, 1986), and attentional capacity as exhibited in an auditory detection task (Nugent & Mosley, 1987). The intervention literature, however, has lacked precise quantitative measures for tracking the consequences of augmentative communication intervention in the domain of attention, as well as the domains of communication, task-orientedness, and sociability.

In recent years, measures of this sort have been developed by investigators using observational methods to characterize the behavior patterns of animals in social groups (Pearl & Schulman, 1983) and of infants interacting with their caretakers or peers (Lewis & Rosenblum, 1974; Schaffer, 1977). Sackett (1978) urged that these methods should be used to achieve a better understanding of mental retardation and brought together some of the early studies in this area. Most often, time-sampling techniques have been emphasized in these applications, but the alternative technique of continuous coding makes possible some very precise measures of infrequent events (e.g., intentional communication) and of the structural and temporal properties of more frequent events (e.g., shifts of attention).

We have selected five types of quantitative measures that can be computed from continuously coded transcripts of a target subject's interaction with a partner. These have appeared primarily in the literature on parent–infant and parent–toddler interaction, but show potential for capturing changes in individuals with mental retardation over the course of their participation in intervention. One measure of each type has been incorporated in the System for Transcript-Based Analysis for Responsivity (STAR), which is introduced in the present paper as a tool for the evaluation of intervention effects. There is one measure each for the communication, task-orientedness, and sociability domains, and two measures for the attention domain. The five types of measures and their basis in the literature are as follows.

1. In toddlers, development in the communication domain is reflected in increased usage of gestures and vocalizations (Mueller & Lucas, 1975), followed by increased usage of conventional language. The STAR system counts all such instances of communication to obtain a *communication frequency* measure.

2. Infants show increases in certain abstract measures of rate, including rate of gaze shift (Friedman et al., 1976; Messer & Vietze, 1984; Strydom, 1985) and rate of interaction cycles (Kaye & Fogel, 1980). Rate measures are obtained by performing a complete, continuous coding of behavior with respect to the dimension of interest. For example, rate of gaze shift is determined by partitioning a period of recorded behavior (e.g., 5 minutes of parent–infant interaction) exhaustively into segments on the basis of the infant's direction of gaze. A new segment is coded each time the direction of the infant's gaze changes. The number of segments relative to the total duration is the rate of gaze shift; for convenience it can be re-expressed (e.g., as *n* shifts per minute or one shift per *n* seconds). In STAR there is one rate measure, *attention shift,* that reflects changes in activity as well as direction of visual regard.

3. Infants and toddlers also show developmental increases in the complexity of their behavioral episodes, as indicated by the average number of component units per episode (Lewis & Lee-Painter, 1974; Mueller & Vandell, 1979). Computation of this type of measure requires a hierarchical coding of behavior using the levels of (a) episodes and (b) components of episodes. In STAR, periods of attention with no action are classified as attention-only episodes, and attention segments based on visual regard are the components. The average number of attention segments per attention-only episode yields the value of the *attention complexity* measure.

4. Measures of task-orientedness are frequently employed in coding the behavior of older individuals with retardation, but not of infants. These can be defined positively in terms of time-on-task (e.g., Cipani, 1982) or negatively in terms of extent of inappropriate or off-task behavior (e.g., Rose, 1981). In STAR, *task-orientedness* is the proportion of total duration that is on-task (vs. off-task).

5. Finally, certain forms of social attention have been shown to have developmental significance: mutual gaze in early infancy (Brazelton, Koslowski, & Main, 1974; Stern, 1974) and joint visual attention to caretaker and objects in the later transition to toddler status (Bakeman & Adamson, 1984; Bruner, 1983; Trevarthen, 1977). In STAR, both attention episodes and action episodes are coded as socially versus nonsocially oriented; the proportion of the total duration of these episodes that is socially oriented provides a measure of *sociability*.

The STAR system was used to evaluate the effects of a particular augmentative communication intervention, in which arbitrary graphic symbols (*lexigrams*) are used to communicate with a teacher in an interactive electronic environment. Subjects with severe and profound retardation who successfully acquired lexigrams were compared to peers who did not acquire lexigrams. The comparison group included the members of a control group as well as 2 members of the intervention group who did not succeed in acquiring lexigrams. Continuous coding of videotapes made before and after lexigram intervention provided change data for the measures of communication frequency, attention shift, attention complexity, task-orientedness, and sociability. Also, real-time coding using an abbreviated coding system provided additional change data on the first two measures. The results provide an initial picture of how one augmentative communication intervention worked by fostering a broad assemblage of developmental changes, most of which were not observed in comparison subjects and hence were distinctive to the participants who successfully acquired lexigrams.

Method

Subjects

Subjects for this study were 10 persons with severe retardation who resided at the Developmental Learning Center of Georgia Regional Hospital in Atlanta. They were randomly selected for participation from the 15 residents who met certain minimal physical and behavioral criteria. They ranged in age from 6 years, 2 months to 22 years, 8 months (mean = 16 years, 5 months). Prior to the onset of the study, an assessment battery was administered, as summarized in Table 1. Five matched pairs were formed on the basis of performance on the sorting and matching tasks, Uzgiris–Hunt stage, intentional communication level, and speech comprehension and production. The subjects were then divided into two groups by randomly assigning one subject from each pair to each group. The two groups had similar mean scores on the Table 1 variables that could not be jointly applied in the pairwise matching: CA, MA, and years in institution. Diagnosis was roughly equated across groups (e.g., one hearing-impaired subject per group), but usually not within pairs. Two subjects in each group were nonambulatory (Subjects DB, TS, PC, CS).

Intervention Conditions

For the first 3 months following the assessment period, all 10 subjects participated in daily

Table 1
Subject Characteristics Prior to Intervention

Group/ Matched pair, subject	CA[a]	MA[a]	Match-sort[b]	U-H[c]	Years in institution[a]	Diagnosis	Intentional communication[d]	Speech comprehension[e]	Speech production
Lexigram									
1, DB	17:1	5:4	100	5.7	12:5	Severe MR, cerebral palsy, spastic quadriplegia	Coordinated conventional	PPVT 3:9 Context-varied	Unintelligible speech, severe dysarthria
2, TS	19:5	1:3	88	5.2	14:11	Severe MR, seizure disorder	Coordinated conventional	PPVT* Context-bound	Two word approximations
3, SB	18:11	1:9	58	4.5	12:3	Severe MR, hearing impaired[f]	Coordinated primitive (food)	PPVT* None	None
4, JP	14:7	1:4	47	4.3	7:11	Severe MR, autism, seizure disorder	Object-oriented	PPVT* None	None
5, CD	6:2	1:3	46	4.2	0:4	Severe MR	Coordinated conventional	PPVT* Context-bound	Two word approximations
Mean	15:3	2:2	68	4.8	9:7				
Control									
1, PC	16:6	3:5	100	5.5	5:6	Severe MR, cerebral palsy, hearing impaired[f]	Coordinated conventional	PPVT 2:6 Context-varied	Unintelligible speech, severe dysarthria
2, SL	16:7	2:10	78	5.2	1:6	Severe MR, autistic-like	Coordinated conventional (food)	PPVT 2:7 Context-varied	Less than five word approximations
3, CS	15:4	1:3	41	4.5	12:10	Severe MR	Person-oriented	PPVT* None	None
4, GH	22:8	1:2	42	4.0	22:8	Severe MR, Down syndrome	Object-oriented	PPVT* None	None
5, DE	16:10	1:3	50	4.0	12:5	Severe MR	Coordinated primitive	PPVT* None	None
Mean	17:7	2:0	62	4.6	11:0				

[a] In years: months. MA was measured by the Cattell Infant Intelligence Scale (Cattell, 1940) or the Stanford-Binet Intelligence Scale (Terman & Merrill, 1973); Subjects DB, PC, and SL also had above-basal scores (4:1 to 4:10) on The Leiter International Performance Scale (Arthur, 1952).

[b] Mean percentage correct on matching and sorting tasks using objects and colors.

[c] Mean sensorimotor stage on the Uzgiris-Hunt (U-H) Scales of Infant Development (Uzgiris & Hunt, 1975), excluding Scale IIIa (vocal imitation). For Matched Pair 5, Scale IIIb (gestural imitation) is also excluded because Subject DE refused to respond.

[d] Performance level on an intentional communication task assessing coordination of attention to a referent object and an addressee (adapted from Harding & Golinkoff, 1979): (1) orientation to an object or person but not both; (2) coordination using primitive means; (3) coordination using conventional means. If level is limited to food referents, that is indicated.

[e] Receptive vocabulary age on the Peabody Picture Vocabulary Test (PPVT, Dunn & Dunn, 1981) and observed level of comprehension. Asterisk indicates subject did not achieve a basal score on the PPVT.

[f] Moderate to severe bilateral hearing impairment.

sessions designed to encourage social interaction. At the end of the 3 months, one group was randomly selected to serve as the lexigram group and the other as the control group. The 5 lexigram subjects began augmentative communication instruction using lexigram symbols. The 5 matched subjects in the control group continued their participation in the social interaction sessions, in order to provide a base of comparison for changes shown by the lexigram group during the first year-and-a-half of lexigram instruction. Changes shown by the lexigram subjects, but not by the control subjects, should reflect distinctive characteristics of the lexigram intervention itself, beyond the benefits brought by any generally enriched social environment.

Sessions for both groups occupied approximately one hour per day, 5 days per week. Teachers were randomly assigned to subjects each week (typically from a pool of five to six teachers), and each teacher worked with subjects in both groups. Teachers had, at minimum, a bachelor's degree in speech–language pathology or psychology and previous experience with mental retardation. All 10 subjects continued to participate in daily programs at their residential setting as well.

Social Interaction Condition. This intervention was designed to stimulate social interaction, but without placing specific communicative or linguistic demands on the subjects or directly teaching communicative or linguistic skills. The first activity each morning was a dyadic interaction in which each subject engaged in object-oriented activities with one teacher (e.g., sorting objects). The remainder of the morning was spent in a group activity, in which each subject had a rotating assigned task for preparing a snack, serving it, and cleaning up. Subjects were reinforced with verbal/social praise for their compliance and received edible reinforcement on an intermittent basis.

Lexigram Condition. This intervention also included both dyadic and group interactions, but the focus was on teaching the participants to use a computer-linked augmentative communication system. Arbitrary visual–graphic symbols called "lexigrams" were employed. For example, the lexigram formed by a diamond with two superimposed horizontal lines is arbitrarily defined to signify *cheese.* In contrast to speech systems, input is visual rather than auditory; output is gross-motor rather than oral (i.e., the user contacts a keyboard with a finger); and, initially, the only memory requirement is to recognize the symbols on the display rather than to recall them (Romski, Sevcik, & Ellis-Joyner, 1984).

The lexigrams, as displayed on the computer-controlled electronic keyboard, form a dynamic system. That is, even though the symbols themselves are static, the computer provides an environment of visual display and visual/auditory feedback that engages the user interactively. The interaction begins when lexigrams appear lit on the keyboard display to signal that they are available for use. The subject can then select one lexigram by contacting the touch sensitive plate beneath it. This contact results in an increase in the illumination of the activated lexigram, simultaneous display of the lexigram on a video monitor above the keyboard, and sounding of an auditory signal. Another feature of the electronic control system is that the teacher can randomly relocate the lexigrams on any given trial, thus discouraging the positional responding that is frequently a problem for persons with severe retardation. In these ways, the computer interface makes the lexigram system far more powerful than visual–graphic symbol sets used on some other types of communication boards. Hence, the term *lexigram intervention* should be understood to refer not simply to the set of symbols, but also to the computerized technology and teaching strategies employed.

The strategies for teaching the communicative use of lexigrams were adapted from language-relevant research with nonhuman primates (Romski & Savage-Rumbaugh, 1986). In the first task (requesting), subjects learned to use four different lexigrams to obtain four corresponding foods, first from a vending device and then from a person. Successful subjects were then introduced to additional lexigrams and tasks (labeling and comprehension). The tasks, technology, sequence of instructional steps, and major findings are described in detail by Romski et al. (1988). Initially, lexigram instruction occupied about one-half hour of each one-hour session; the remaining time was spent in social interaction involving one teacher and 2 subjects, usually centered around object manipulation. As learning progressed, lexigram instruction was gradually increased; by late in the second year, it occupied the entire hour.

An important milestone in the study was the division of the lexigram group into two subgroups by Month 8 of lexigram intervention. Three subjects (DB, TS, and SB) were learners: They had acquired a conditional association between symbols and foods, as exhibited in contrastive use of at least two lexigrams, and were working on adding other lexigrams to their repertoires.

Subjects JP and CD were nonlearners: They had acquired only one lexigram each and therefore did not meet the minimum criterion of contrastive use of two lexigrams. The data from these two subgroups must be considered separately because the purpose of the study was to identify the broad assemblage of developmental changes within which symbol acquisition is embedded. Mere participation in the lexigram program without success is best seen as a second kind of control or comparison condition, against which the distinctive effects of successful participation are made manifest.

Videotaped Sessions for Assessing Change

One of our goals was to gain insight into the nature of the changes fostered by the intervention, extending beyond acquisition of the lexigrams themselves. To enable investigation of changes in other developmental domains, periodic sessions that sampled subjects' behavior in four standard situations were videotaped. Session A occurred at the beginning of the 3-month baseline period that preceded the onset of lexigram intervention. Session B occurred during Month 1 of the lexigram intervention (2 to 3 weeks after lexigrams were introduced). Sessions A and B together are referred to as the baseline or preintervention sessions because they were used to obtain two different samples of behavior that would be relatively unaffected by participation in the lexigram intervention. The remaining sessions occurred during Months 4 through 18 of the intervention period. They are referred to as postintervention sessions because potentially effective amounts of intervention had occurred. These were Sessions C (Month 4), D (Month 7), E (Month 12), and F (Month 18). For the 3 learners, who participated for a longer period than did the other subjects, there was also a Session G (Month 26). Hence, Sessions E and F were the last two sessions for which the lexigram and control groups could be compared for most subjects. (The last two sessions were D and E for 2 subjects: Control Subject PC was placed in a foster home shortly after the intervention began but continued to be videotaped through Month 12; and Lexigram Subject CD, a nonlearner, was transferred to another institution during Month 12.)

There was a total of 61 videotaped sessions, of which 46 were used for the present analysis. Each session included two situations that involved dyadic interaction with a partner, who was randomly selected from the pool of teachers available on that day. For all except 3 sessions, the partner was one of five teachers who had a long-term involvement with the study. Each of these teachers participated in 9 or more sessions, distributed across both periods of study (pre- and postintervention) and both groups of subjects (lexigram and control). In the objects situation the teacher sat at a table with the subject and actively attempted to keep the subject engaged in joint interaction with a standard set of objects for 10 minutes. The objects were: cup, pitcher, spoon, book or magazine, Play-Doh, comb, brush, pillow, mirror, pencil or crayon, and blank paper. Lexigrams were not available for use. In the keyboard situation, the same teacher sat with the subject at the lexigram keyboard, and they worked on lexigram use at the subject's current level of functioning.

Sessions were videotaped using a Sony SLO-260 Betamax videocassette recorder and a single Panasonic WV-360P monochrome video camera interfaced to a date/time generator that superimposed the date and elapsed time (in .1-second increments) on the tapes during recording. The camera and operator were visibly located in the same room as the participants but were only infrequently a focus of attention. A Sony SLO-320 videocassette recorder and Panasonic CT-1320M monitor were used for playback by the coders.

Coding and Analysis of the Objects Situation Using STAR

System for Transcript-Based Analysis of Responsivity (*STAR*). No existing system was adequate to assess change in all of the domains of interest. Therefore, a new coding system was developed. The STAR system requires a transcription of each videotaped session, to which three different systems of coding categories are applied: (a) *communication coding*, a characterization of each instance of intentional communication (including modality and form); (b) *attention coding*, a second-by-second record of the subject's focus of attention (e.g., the teacher's face, the subject's own action); (c) *episode coding*, a segmentation of the videotaped interaction into episodes based on interaction states in three categories, each with subcategories: *action* (social vs. nonsocial); *attention-only* (social vs. nonsocial and single- vs. multi-focus); and *off-task* (self-stimulation, active avoidance, negative action, passive/distracted). Each of these three codings yields frequency of occurrence data for one or more sets of mutually exclusive codes; the episode and attention codings yield duration data as well. Definitions and procedures are provided in a coding manual (Abrahamsen, 1985); see Appendix A for a summary.

Coding Procedure. Changes that accompanied lexigram learning were identified by applying the STAR system to four of the videotaped sessions: the two baseline sessions preceding or closely following onset of the lexigram intervention (Sessions A-B) and the last two sessions for each subject before the control group's participation was discontinued (Sessions D-E or E-F). These four sessions, each 10 minutes in length, were coded in their entirety for intentional communication. For the episode and attention codings, only the first 5 usable minutes of each session were coded. Excluded as unusable were certain types of episodes for which the attention versus action distinction was difficult to apply (play with the mirror, magazine, or book). This procedure kept the amount of coding time required within reasonable limits, while allowing for intersession variability by pooling data from two different sessions for each period of interest.

Two coders (Coders 1 and 2) used coding sheets with space for a brief verbal transcription of each episode on the right and separate sections for each of the three sets of codes on the left; each such section had columns for indicating coding category (using numeric codes), onset time, and duration. (See Appendix B for an example; however, the actual coding sheets had separate coding category columns for the three types of episodes as a visual aid.) Following training and establishment of reliability on nontarget sessions, each coder coded half of the target sessions, with assignment counterbalanced such that any differences between coders would equally affect the pre- and postintervention results for each subject and each condition. For the communication coding, however, all sessions were coded by both coders, with disagreements resolved by discussion. This was done because intercoder agreement as well as number of occurrences were lower for communication than for the attention and episode codes. Both coders were naive regarding the design and purpose of the study. They were aware that lexigram use was being taught at the center and occasionally saw subjects arriving or leaving, but they did not know that some subjects were controls or nonlearners or that change across sessions was a focus of analysis.

Reliability. For the episode and attention codings, Coder 2 independently coded one minute from Coder 1's assigned sessions for each subject. For each second of videotape, a disagreement was scored if the two coders had assigned different codes to that second. For the communication coding, all instances identified by at least one coder prior to resolution were examined; a disagreement was scored if only one coder had identified it or if any of the three dimensions were coded differently. Kappa, a measure of proportion of agreement adjusted for agreement expected by chance (Cohen, 1960), yielded values of .852 for episodes, .836 for attention, and .728 for communication. For communication, we also calculated that the proportion of all communicative events that were identified by both coders (rather than one coder) was .953.

After the numeric codes were entered into a computer database for analysis, we checked for internal consistency by visually scanning the data and by running programs that sorted the data in several ways. By this means we identified and corrected certain coder errors and data entry errors. Considering that the labor-intensiveness of STAR coding limits the amount of data that can be obtained, procedures such as these for ensuring the integrity of the data should not be omitted.

Derivation of Measures to Assess Change. From the coding results, a variety of quantitative measures could potentially be calculated and used to assess change. Currently, five such measures are defined as part of the STAR system. The first measure, *communication frequency,* is the total number of acts of intentional communication in a 20-minute period, ranging from primitive gestures or vocalizations to conventional spoken words or phrases. The second and third measures are obtained from the attention coding. *Attention shift,* the total number of attention segments in a 10-minute period, captures the overall rate at which attention shifted to a new focus. Usually, this involved a change in the direction of visual regard or postural orientation, but initiation of an action episode without a gaze shift also was coded as a new focus of attention. *Attention complexity,* the mean number of attention segments per attention-only episode, is based on the assumption that episodes that string together a number of different attentional foci are structurally more complex than sequences with fewer foci (just as mean length of utterance is a convenient index of sentence complexity). The last two measures are based on the episode coding and reflect the subject's degree of interaction with the available objects and with the teacher. *Task-orientedness* is the proportion of total time that is on-task (vs. off-task), and *sociability* is the proportion of on-task time that is socially oriented towards the teacher (vs. nonsocially oriented), including both attention-only and action episodes. Examples of the computation of these measures are provided in Appendix B. (Corresponding frequency measures using the number of episodes rather than their duration were also calculated and yielded such similar results in the present data set that they are not separately reported.)

Coding and Analysis of the Keyboard Situation Using SOAR

System for On-Line Analysis of Responsivity (SOAR). An abbreviated system was developed following data analysis using STAR and applied to certain videotapes of the keyboard situation on an exploratory basis. The SOAR system provides a less complete characterization of each session but has the advantage that it can be performed on-line using an event recorder in real time. It includes just three codes and corresponding measures: (a) *communication frequency* is a count of the number of instances of intentional communication; (b) *attention shift* is scored each time the subject's focus of attention changes; (c) *vocalization* is a count of the number of noncommunicative vocalizations (i.e., vocalizations such as "effort sounds" that do not meet the criteria for intentional communication). The first two measures constitute a subset of the STAR system. The third measure was appended in order to capture precommunicative progress of one subject for whom intentional communication was infrequent. See Appendix C for further detail.

Procedure. The SOAR system was applied by two new coders to videotapes of the keyboard situation for the 3 learners. This situation had a duration of 10 minutes; it was included in one baseline session (Session B) and four postintervention sessions (Sessions D, E, F and G). It was selected for coding in order to establish that the results apply to the teaching situation as well as the less familiar objects situation.

The initial SOAR coding was carried out by Coder 3 (the first author, who had trained the STAR coders) using an NEC PC-8201A lap computer modified for use as an event recorder by S&K Computer Products (Toronto). The recorder was used to count instances of intentional communication, vocalization, and several types of attention shift (which were distinguished on an exploratory basis and later pooled). For most sessions all codes were applied in one pass without stopping the tape; each subject was coded separately, with sessions placed in random order. For the first subject (TS), situations in addition to the keyboard situation were coded for practice. For the other subjects (DB and SB), only the keyboard situation was coded, and the coder was blind as to which session was being coded.

At a later time, Coder 4 was trained by the first author, using a new randomized block order of the sessions in which the 3 subjects were intermixed and the coder was blind as to session. Coder 4 made separate passes for coding communication (recording each communicative form on paper, from which a count was made); attention shift (using two mechanical inventory tally counters rather than an event recorder, one for a "conservative" coding and one for a "liberal" coding); and vocalization (using a single tally counter, for SB only). Feedback and discussion of criteria were provided after each of the first 9 sessions coded (3 per subject), and half of these were coded an additional time. Then the remaining 6 sessions were coded and the initial 9 sessions recoded without interim feedback; at the end Coder 4 was informed that agreement was good for communication frequency and vocalization, but that in general her values for attention shift were higher than those of the trainer (Coder 3). On a later day, Coder 4 carried out a more conservative attention shift coding of all 15 sessions without interruption or feedback. Coder 3 independently carried out a new coding of attention shift using the new procedure in order to assess intra-coder reliability.

For data analysis, one set of coding values was selected from each coder, and these were averaged to obtain the best estimate for each measure for each session. For communication frequency and vocalization, Coder 3's original coding and Coder 4's most recent coding were used (for most sessions, there was no alternative coding). For attention shift, the two most conservative codings were selected because these were most comparable to the STAR coding. These were Coder 3's original coding and Coder 4's final conservative coding.

Reliability. The Pearson product-moment correlation across sessions was used as a measure of intercoder reliability and was computed both for all 15 sessions and for each subject's 5 sessions. The values of *r* for the sets of values used in the data analysis were as follows: communication frequency, .991 overall (.978 for Subject DB; .985, Subject TS; .997, Subject SB); attention shift, .905

overall (.583, Subject DB; .730, Subject TS; .903, Subject SB); vocalization, .910, Subject DB. If the sessions for which Coder 4 had initially received feedback are computed separately from those that had not, there is little difference in the correlations for either communication frequency (.990, feedback; .998, no feedback) or attention shift (.918, feedback; .898, no feedback). If Coder 4's initial rather than most recent coding is used, communication frequency drops to .938 and attention shift drops to .867.

Another way to measure reliability is to calculate the mean absolute discrepancy between coders' scores per session. For communication frequency there was a mean discrepancy of 3.7 on an average session score of 38.4, and for attention shift there was a mean discrepancy of 12.3 on an average session score of 110.1, placing agreement on total scores (not necessarily on individual events) in the 90% range for these measures.

For the attention shift measure, intracoder reliability was also examined. For Coder 3, despite procedural differences the original and recoded (conservative) series had an overall *r* of .997 (.867, Subject DB; .928, Subject TS; .960, Subject SB). For the less experienced Coder 4, the last two coding series had an overall *r* of .916 (.873, Subject DB; .710, Subject TS; .829, Subject SB).

Results

Lexigram Acquisition

Three of the 5 subjects in the lexigram group succeeded in acquiring lexigrams; their achievements at the time of each videotaping session are displayed in Table 2. (For a much more detailed report, see Romski et al., 1988). It can be seen that the highest functioning subject, DB, showed steady and relatively rapid progress. She acquired contrastive use of her first two lexigram symbols within the first 2 weeks of teaching that preceded Session B and acquired additional lexigrams at a rate better than one per month over the next 25 months. This rate is more impressive if one considers that time was occupied not only meeting criterion in the initial request task, but also in administering probes assessing generalization to labeling, comprehension, other referents, and other conversational partners. The other 2 learners, Subjects TS and SB, had a considerably slower rate of acquisition. They had particular difficulty when Lexigram 2 was added, and a branch teaching sequence was inserted to build in the steps towards contrastive, conditional use of two lexigrams. This milestone was passed by Subject SB at the beginning of Month 6 and by Subject TS in Month 8 (lengthened by two periods of setback from seizure episodes). Thereafter, their rates of acquisition improved considerably. Subject TS became the next fastest subject, requiring a little more than 1 month on average to acquire each additional lexigram over the next 19 months, whereas Subject SB required almost 2 months on average to acquire each additional lexigram over the next 21 months.

The milestone of contrastive use was not reached by the other 2 subjects. In Month 12, still in the process of learning Lexigram 2, Subject CD was transferred to a distant institution and his

Table 2
Lexigram Acquisition Milestones of Learners by Time of Each Videotaping Session

	Session (month of intervention)					
Subject/Milestone	B(1)	C(4)	D(7)	E(12)	F(18)	G(26)
Subject DB						
No. of lexigrams acquired	2	6	10	11	23	30
Generalization to labeling		X				
Generalization to comprehension			X			
Generalization to photos and slides				X		
Acquisition of proper names					X	
Use of lexigrams with adults & peers						X
Subject TS						
No. of lexigrams acquired	0	1	1	3	9	15
Generalization to labeling					X	
Generalization to comprehension						X
Request & retrieve invisible items						X
Subject SB						
No. of lexigrams acquired	0	1	2	4	8	13
Generalization to labeling					X	
Generalization to comprehension						X
Request & retrieve invisible items						X

Note. X = Milestone was attained by the time of this session.

participation ended. Conceivably, he would have achieved the goal but already had been working 4 months longer than the last learner, and hence was classified as a nonlearner. The other nonlearner, Subject JP, acquired Lexigram 1 but showed minimal progress towards contrastive use with Lexigram 2. He appeared to be employing a positional strategy, and his participation in the study was terminated in Month 12.

Somewhat more precise measurements of rate, which are not affected by other interspersed tasks, are provided in Table 3. These figures suggest that Subject DB brought to the task a readiness to acquire appropriate contrastive use of visual symbols and only required exposure to the system to learn. Any concomitant changes would be associated with the process of learning symbols as such. In contrast, Subjects TS and SB could not initially deploy attention to scan and choose from an array the one lexigram that matched a desired referent. For them, the early months were an extended process of building in necessary competencies, and assembling them into a procedure adequate for successful performance in the request task environment. Established step-by-step in the context of learning the first two lexigrams, that procedure could then be utilized for the efficient acquisition of additional lexigrams. In fact, once the milestone of contrastive use of two symbols was passed, their trials-to-criterion for additional symbols decreased significantly. For these subjects, concomitant changes during the early months would be connected with the preparatory process of procedure-building ("learning to learn"). Following the milestone of contrastive use, concomitant changes could be attributed to the process of utilizing that procedure to learn additional symbols. Finally, the two nonlearners had yet a different experience. They neither built nor utilized a procedure for learning lexigrams, as evidenced by their failure to master contrastive use of the first two lexigrams. Any changes connected with the symbol learning process should not be exhibited in Subjects CD or JP because they did not successfully engage in that process.

Concomitant Changes in the Learners Compared to Other Subjects: STAR Coding of the Object Situation

The data from the videotaped sessions address the question of whether successful participants in the lexigram program showed distinctive changes beyond the targeted effect that lexigrams were acquired as a communicative tool. The STAR coding system was applied to two preintervention sessions (A and B) and two postintervention sessions (E and F for most subjects). Table 4 displays the mean preintervention, postintervention, and difference scores for each subject group. The learners showed a pattern of broad improvement over several measures, whereas the nonlearners and control subjects improved only in sociability.

To evaluate whether this apparent difference in outcome was statistically reliable, we compared the scores of the learners to the scores of the

Table 3
Changes in Time Required to Acquire Lexigrams in Request Task

	Lexigram numbers						
Subject/Measure	1	2	3	4	5–9	10–14	15–19
Subject DB							
Trials-to-criterion	125	298	93	42	28.8	14.0	20.2
No. of sessions	7	14	7	4	3.4	3.8	4.4
Subject TS							
Trials-to-criterion	469	2217[a]	102	455[a]	145.0	61.0	77.8
No. of sessions	19	99[a]	5	45[a]	6.0	3.6	4.6
Subject SB							
Trials-to-criterion	903	1319	262[b]	337	146.6	38.6	45.6
No. of sessions	29	53	60[b]	27	14.6	5.2	6.0
Subject JP							
Trials-to-criterion or end	2514	5000[c]	–	–	–	–	–
No. of sessions	43	161[c]	–	–	–	–	–
Subject CD							
Trials-to-criterion or end	1137	3957[c]	–	–	–	–	–
No. of sessions	32	120[c]	–	–	–	–	–

Note. Figures shown are scores on each lexigram for Lexigrams 1 to 4, and means across sets of five lexigrams for Lexigrams 5 to 19.

[a] The time to acquire Lexigrams 2 and 4 was lengthened due to seizure episodes. [b] The time to acquire Lexigram 3 was lengthened because three different foods had to be tried to find one that was sufficiently motivating. [c] The two nonlearner subjects did not reach criterion on Lexigram 2.

Table 4
Change on Each Measure From Preintervention to Postintervention

	Target group		Comparison group					
	Learners ($n=3$)		Nonlearners ($n=2$)		Controls ($n=5$)		Total ($n=7$)	
Measure[a]	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Communication frequency*								
Pre	35	34	12	13	33	53	27	45
Post	72	70	7	8	42	69	32	60
Diff	37	37	−5	5	9	17	5	15
Attention shift**								
Pre	111	61	184	55	128	27	144	42
Post	175	100	176	48	120	22	136	38
Diff	64	43	−8	7	−8	27	−8	22
Attention complexity*								
Pre	1.88	.58	3.16	.85	2.07	.36	2.38	.70
Post	3.27	.54	3.25	.60	2.44	1.02	2.67	.95
Diff	1.39	.25	.09	.25	.37	.70	.29	.60
Task-orientedness								
Pre	.932	.070	.972	.010	.944	.058	.952	.049
Post	.910	.097	.922	.075	.949	.055	.942	.056
Diff	−.023	.033	−.050	.065	.005	.056	−.010	.059
Sociability								
Pre	.656	.179	.680	.037	.607	.128	.628	.111
Post	.803	.020	.849	.130	.770	.183	.793	.163
Diff	.147	.161	.170	.167	.163	.133	.165	.128

Note: Two-tailed probability levels are indicated on each measure for which there was a significant difference in the change shown by the target group (3 learners) versus the comparison group (nonlearners and controls), based on an analysis of covariance.
[a] Communication frequency: total number of intentional communication acts per 20 minutes. Attention shift: total number of attention segments per 10 minutes. Attention complexity: mean number of attention segments per attention episode. Task-orientedness: proportion of total time that is on-task. Sociability: proportion of on-task time that is socially oriented.
* $p<.05$. ** $p<.01$.

other 7 subjects for each measure separately. (For reasons of tradition and statistical convenience, it is usual to compare groups that are defined on the basis of which intervention was offered. Here the groups are defined on the basis of outcome instead because the focus of analysis was identification of the concomitants of success, not of mere participation. In a larger study, it would be of interest to maintain the nonlearners as a separate group in order to statistically confirm their similarity to the control group.)

Analysis of covariance, selected as the most appropriate method of between-groups analysis (Cohen & Cohen, 1975), was carried out using the SPSS REGRESSION program (Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975). By this procedure, the postintervention scores of the learners were compared to those of the other 7 subjects, using the preintervention scores as covariates to adjust for initial differences among individual subjects. Preliminary tests indicated that there were no significant differences between the two groups in their initial means and variability on each measure; also, careful attention was given to the equal-slopes, equal-variance, and normality assumptions of each analysis of covariance. For the attention and communication measures, the assumptions were best met when a logarithmic transformation was performed on the raw scores. This is a reasonable transformation for measures with a lower but not an upper bound, so it was incorporated in the analysis.

The measures for which the analysis of covariance yielded a significant group difference are marked in Table 4, with asterisks indicating the probability level. The learners showed a distinctive effect of improvement on the communication and attention measures, which differed significantly from the lack of improvement shown by the other 7 subjects. Specifically, there were significant differences for communication frequency, $F(1, 7) = 7.920, p = .03$; attention shift, $F(1, 7) = 12.957, p < .01$, and attention complexity, $F(1, 7) = 8.064, p = .03$.

For the other two measures, the summary data in Table 4 clearly show no hint of any difference between groups. The analysis of covariance was not a good instrument for verifying this, due to differences in variability and in regression slopes between learners and the other 7 subjects. An alternative analysis, comparing the two groups' difference scores using t tests with separate variance estimates, yielded no significant group differences, $p > .25$. There was, however, a difference between the measures themselves. Neither group improved on task-orientedness (proportion of total time on-task). Because measures of on-task orientation are frequently used in evaluating change under intervention, this result is noteworthy. An intervention that has substantial effect on such important domains as attention and communication may not improve measured on-task behavior levels at all, an outcome that has some precedent in previous studies (Forness & Kavale, 1985; Konstantareas et al., 1979).

The other measure showing no group difference was sociability. In this case, the lack of a difference was due to a similar degree of improvement by the learners (whose difference score of .147 represents a 22.4% increase in the proportion of on-task time that was socially oriented) and by the other 7 subjects (whose difference score of .165 represents a 26.3% increase). The increase in sociability was statistically significant, as indicated by a one-sample t test on the 10 subjects combined, $p < .01$. We note, however, that the definition of *sociability* in the STAR system is rather undemanding; simply looking at the partner or cooperating in a joint activity was sufficient to receive credit for social orientation. If only active social initiatives were credited, a group difference favoring the learners would conceivably be revealed. (This would best be investigated using a frequency count rather than attempting to set criteria for the offset of social-initiative episodes.)

In summary, the learners showed distinctive changes in communication and attention concomitant with the process of acquiring lexigrams, and it can be tentatively concluded that the changes were associated in some way with that process. Increased sociability was a more general effect that occurred in both the lexigram intervention condition and the social interaction control condition. It was a desirable outcome of participation in the lexigram intervention but could also be obtained in other ways and therefore cannot be attributed to the process of learning lexigrams as such. Finally, neither lexigram learning nor social interaction brought improvements in task-orientedness.

Additional Findings for Learners: SOAR Coding of the Keyboard Situation

There are two domains in which the 3 learners, but not the nonlearners or the control subjects, showed improvements: communication and attention. This finding is based on two preintervention and two postintervention sessions using one situation (objects). The SOAR system was developed as an abbreviated derivative of the STAR system in order to confirm and extend these findings. It includes two of the three variables that showed distinctive effects for the learners and can be rapidly applied in real time. On an exploratory basis, the SOAR system was applied by two coders to the keyboard situation for every session in which the keyboard situation was videotaped.

The mean of the two coders' values for each measure are displayed in Table 5 for each learner individually and for the 3 learners combined. For comparison, these scores from the STAR coding of the same measures in the object situation are displayed for each session as well. With few exceptions, postintervention scores (Sessions D, E, F, and G) were higher than baseline scores (Sessions B and, for the objects situation, Session A as well). Of the 13 series (rows) of data, in 7 series there was no overlap, and in 6 series the best baseline score was surpassed by all except the worst postintervention score. Nonetheless, a variety of factors contributed to intersession variability, including the brevity of sessions and whether the subject was having a "good day" or "bad day." It is therefore advisable to pool sessions to obtain the most stable data for comparing periods.

Two ways of pooling sessions to measure percentage improvement are shown in Table 5. The first uses the mean for all available baseline sessions as the denominator of the improvement ratio (A and B for the object situation; B alone for the keyboard situation) and the difference score between the baseline sessions and the mean of postintervention Sessions E and F as the numerator: (EF – (A)B)/(A)B. The difference scores EF – AB are the same ones that contributed to the mean difference scores in Table 4; Table 5 breaks down those means by session and participant. The second improvement measure uses only Session B as a baseline (to make the two situations comparable) and adds Session G to Sessions E and F in the numerator (to use more of the data): (EFG – B)/B. It can be seen that improvement ranged between 9.8% and 661.1% across the different situations, measures, and participants. On average, communication frequency improved by

Table 5
Learners' Changes Across Sessions in Two Situations

Subject/Measure/	Session							% increase	
Situation	A	B	C	D	E	F	G	(A)B-EF	B-EFG
Subject DB									
Attention shift[a]									
Objects situation	62	34	NA	NA	76	100	52	83.3	123.5
Keyboard situation	NA	61	NA	81	70	81	87	23.8	30.0
Combined situations	62	47	NA	81	73	90	69	—	64.5
Communication frequency[b]									
Objects situation	24	52	NA	NA	54	86	100	84.2	53.8
Keyboard situation	NA	8	NA	10	52	34	50	437.5	466.7
Combined situations	24	30	NA	10	53	60	75	—	108.9
Subject TS									
Attention shift									
Objects situation	94	136	NA	NA	146	160	142	33.0	9.8
Keyboard situation	NA	105	NA	119	151	118	168	28.1	38.7
Combined situations	94	120	NA	119	148	139	155	—	22.8
Communication frequency									
Objects situation	78	56	NA	NA	150	136	74	113.4	114.3
Keyboard situation	NA	56	NA	36	146	66	84	89.3	76.2
Combined situations	78	56	NA	36	148	101	79	—	95.2
Subject SB									
Attention shift									
Objects situation	154	186	NA	NA	268	300	264	67.1	49.1
Keyboard situation	NA	86	NA	137	158	145	85	76.2	50.4
Combined situations	154	136	NA	137	213	222	174	—	49.3
Communication frequency									
Objects situation	0	0	NA	NA	6	0	6	—	—
Keyboard situation	NA	4	NA	4	0	4	26	—	—
Combined situations	0	2	NA	4	3	2	32	—	250.0
Vocalization frequency									
Keyboard situation	NA	14	NA	10	16	34	52	64.3	142.9
Subjects combined									
Attention shift									
Objects situation	103	119	NA	NA	163	187	153	57.7	41.2
Keyboard situation	NA	84	NA	112	126	115	119	43.5	42.7
Communication frequency									
Objects situation	34	36	NA	NA	70	74	60	105.7	94.3
Keyboard situation	NA	23	NA	17	67	35	49	120.6	123.5

Note. Different coding methods were used to obtain data in the two situations: The STAR system was applied to the objects situation and the SOAR system to the keyboard situation. NA indicates data are not available because a session was not videotaped (keyboard situation) or was videotaped but not coded (objects situation). See text for explanation of methods of obtaining percentage improvement.

[a] Rate per 10 minutes, calculated for comparability to Table 4; actual minutes coded were 5 minutes per session for objects and 10 minutes per session for keyboard. [b] Rate per 20 minutes, calculated for comparability to Table 4; actual minutes coded were 10 minutes per session for objects and keyboard situations. Communication by means of lexigram keys was excluded by definition.

106% and attention shift by 46%, with no systematic differences in degree of change between the objects and keyboard situations.

In the following section, the data in Table 5 are supplemented by other available information on each of the 3 learners to provide a somewhat richer characterization of the changes that occurred concomitant with lexigram acquisition.

Individual Patterns of Change

Subject DB. Of the 3 learners, Subject DB was the highest functioning on the various preintervention assessments (Table 1) but had the lowest scores on the two attention measures, both pre- and postintervention. Due to cervical–thoracic kyphosis, she tended to sit hunched over, looking down at the table, and moved slowly to new foci of attention. This posture creates a somewhat misleading picture of her attentional capabilities, however; she was the only subject who learned, with only minimal training, to scan an array and select the one lexigram that was appropriate for a referent, an act that requires considerable deployment of attention resources. Although this early competence was not captured by the STAR coding, the process of acquiring lexigrams brought fairly steady improvement in the STAR measures of attention complexity (85%) and attention shift (83%).

Subject DB's improvements in communication were more straightforward. From the beginning, she was the best communicator, and more than 80% of her communicative acts were vocal (rather than gestural or bimodal). What changed was their frequency and quality. From Session A to Session G (pooling data from the two situations), she showed a substantial, near-monotonic increase on the communication frequency measure. The most impressive improvement occurred specifically in the STAR subcategories for intelligible words and partially intelligible multiword utterances, which increased from 0 in Session A to 13 in Session G. This effect of lexigram intervention on speech intelligibility was quite dramatic and is further documented in Romski et al. (1988). They reported, for example, improvement from an initially undifferentiated schwa sound to word approximations such as /gʌdɪ/ for gumdrop, /bepɑ/ for paper, and /læbo/ for lapboard. Another potential locus of improvement is in the subcategories of self-initiated communications and imitations compared to responses. Although these were more frequent in later than in earlier sessions for Subject DB, in terms of percentage of all communications, only Session E (25.9%) was substantially above the other sessions (3.8 to 8.3%). Consistent with this, Subject DB performed self-initiated lexigram communications far less frequently than did the other learners (less than once a month around the time of Session E, increasing to once or twice a day by Session F). Finally, and perhaps associated with this, she had the lowest sociability score of all 10 subjects during the baseline sessions and showed the most improvement (almost catching up to Subjects TS and SB).

Subject TS. Overall, Subject TS was the middle subject in initial abilities and in progress. Her improvement on attention complexity was the highest of any subject (103%); she also improved on attention shift (33%), though not as much as the other learners. She showed a good increase in communication frequency, but, as was the case for Subject DB, it was changes in the character of her communications that were most impressive. The percentage that were initiations (or occasionally imitations) rather than responses increased from 2.6% in Session 1 to 29% in Sessions E through G. Consistent with this, after Session F she began using self-initiated lexigram communications in her daily teaching sessions (mean frequency, 4.5 initiations per day). The form of the communications also diversified. In Session A she had a core of three gestures (nod head yes, shake head no, point) that were used alone or with /m/ or nɑ/. In Session B she used a few additional sounds (/bɛ/, /bɑ/, /mɑ/, /ɑ/) as well as certain conventional vocalizations ("yeah" was used to express agreement; "oh" was used once as a self-initiated expression of interest, and "uh" and "uhuh" accompanied gestures of response). In the later sessions, she expanded on these types of communications; by Session G she had the following repertoire. In the manual modality, she displayed approximately 15 different gestures, several used alone as self-initiated communications, a few used primarily as responses simultaneous with a vocalization, and a few used in both ways. Particularly notable was the increased sociability of the gestures (e.g., touching the teacher's hand and showing or offering an object to the teacher). In the vocal modality, she initiated "oh" as an expression of interest of interest in several different contexts, frequently used "uh" and /m/ to respond alone or with a gesture, and frequently used a variety of one- or two-syllable sounds, initially alone but increasingly with gestures (initial sounds were /b/, /m/, /n/, or /d/).

We note that Subject TS had a tendency to exhibit a "rising sawtooth" pattern across sessions, in which quantitative improvements were often followed by declines partway or fully back to baseline levels in a later session, which in turn could be followed by recovery or further improvement. What increased was her upper range of performance; whether she performed in that upper range was unstable even within a session. This same kind of instability also characterized her lexigram performance.

Subject SB. Overall, Subject SB was the lowest functioning learner at onset. She had impaired hearing and extremely limited communicative abilities; however, she had the highest initial attention and sociability scores among the 3 learners. She improved her attention scores during the intervention (including a 49% increase in attention complexity) but not her sociability score (possibly a ceiling effect). In all except the last session, her communication was limited to two or three primitive gestural acts in one or the other of the two situations (the rates in Table 4 must be halved to obtain raw totals per 10-minute session). These communications were usually self-initiated and involved guiding the teacher's hand towards a desired object or activity. In Session E, she indicated a desire to eat the Play-Doh by looking at it, sticking out her tongue, and looking at the teacher (repeated three times). She also used noncommunicative vocalizations, such as "effort" sounds and affective sounds, that increased in frequency in Session F and again in Session G (see Table 5). Beginning by Session E, and increasing to an average of 10 times per day by the time of Session G, she produced self-initiated lexigram communications during her daily teaching sessions. These increases in vocalization and initiation may have been a precursor to what happened to her communication in the keyboard situation in Session G: an increase to 14 acts of gestural communication, which were somewhat more varied than those of previous sessions. Included were reaching toward the teacher or a desired object, flicking or pushing the teacher's hand away, and pushing away an offered object. She also continued using her gesture of guiding the teacher's hand in the objects situation and, for the first time, used it in a third situation as well. None of these improvements in Subject SB's communication were reflected in the statistical analysis of the data in Table 4, because the relevant session and situations were not included there. However, they do buttress the argument that improvements in communication are concomitants to successful participation in the lexigram intervention.

Discussion

The acquisition of lexigrams occurred as part of a larger package of developmental changes in this study, which is suggestive that the process of acquiring the new symbols is embedded in a causal structure of changes involving several domains. Successful participation in the lexigram intervention brought improvements in intentional communication, rate of attentional shift, attention complexity, and sociability. Participation in a control condition of social intervention, however, brought improvements only in sociability, an effect expected from existing studies of social intervention. Unsuccessful participation in the lexigram intervention was indistinguishable in effect from the control condition. Hence, a cross-domain assemblage of developmental changes was fostered specifically in those subjects who successfully engaged in a communication intervention that emphasized the use of lexigram symbols in a dynamic, computer-controlled environment.

The differences on the quantitative measures were large and statistically significant and buttressed by supplemental information on attendant qualitative improvements. The number of subjects involved was quite small, however, and the number who actually acquired lexigrams was smaller still. The limitations imposed by small sample size are unavoidable when the focus of study is an intensive, long-term program of intervention involving subjects with severe retardation. What exactly are those limitations, and how do they affect the interpretation of the data offered in this report? If we understand the limitations, that helps to clarify what opportunities for a deeper account of intervention effects can be pursued in future work.

The first limitation is the risk of making a Type II error (i.e., missing a real effect). The smaller the sample, the larger an effect must be to emerge as significant against the background of error variance. In the present study, this undesirable state of affairs was averted: The effects were large enough relative to the intersubject variability that statistical significance was achieved for every measure that showed any hint of a difference between groups. In fact, on those three measures, the distributions of improvement scores for the 3 learners showed almost no overlap with those of the other 7 subjects. Regardless of whether difference scores or percentage improvement scores were used, only 3 of the 21 comparison scores overlapped with any of the 9 learners' scores. Even with groups of only 3 and 7 subjects, such a small degree of overlap would only rarely be achieved by chance alone; that is why the group differences were statistically significant.

(The only exceptions were as follows: First, Control Subject PC, who was placed in a foster home shortly after intervention began, showed increases in the same range as the learners on communication frequency and attention complexity [but virtually no change on attention shift]. Conceivably, family life and personal attention were responsible, by a different mechanism, for bringing some of the same benefits as the process of learning lexigrams. Second, Subject CS, the matched control subject for Subject SB, showed a slightly greater improvement than did Subject SB on communication frequency. It is not known whether Subject CS would have matched Subject SB's communication spurt in Session G because control subjects were no longer being videotaped, but that appears unlikely.)

The second limitation imposed by small sample size is an inability to precisely characterize the population to which the result applies. The achievement of statistical significance indicates that the difference in outcome for the 3 learners versus the other 7 subjects is reliable and that the finding generalizes to the population from which they were drawn as a sample. But what is that population? Is it all nonspeaking persons with retardation, a subpopulation, or an overlapping population that would include, for example, children with autism? If it is a subpopulation, is it best defined by traditional measures such as chronological age, developmental age, and IQ, or (as is weakly suggested in our results) by more specialized criteria such as good matching and sorting abilities but poor preintervention attention deployment? This dilemma is made worse by the fact that 5 subjects had the opportunity to become learners, but only 3 succeeded. Those 3 learners must represent a different population than the 2 nonlearners, and it would be useful to characterize that difference. There may also be a population of individuals who could learn to use lexigrams but would not show all of the concomitant changes in attention and communication. This population could easily have been missed if it is small or if it represents a different subpopulation than our sample. Much less likely, the sample could also have missed nonlearners or control subjects who would exhibit improved attention and/or communication by some nonobvious mechanism. Hence, we know only that at least some of those who learn lexigrams show concomitant changes in attention and communication; there is no way of knowing how prevalent these changes would be nor which types of learners (or even nonlearners) would show them.

There is a third limitation imposed by small sample size. We have tentatively suggested, on the basis of 3 learners, that the process of acquiring lexigrams is embedded in a causal structure of changes involving several domains. We have identified three measures that exhibit concomitant change with lexigram learning for at least one subpopulation of learners. Given that particular assemblage of changes, it would be most desirable to arrive at an account that actually specifies the pattern of causal pathways that link the measures of change with aspects of lexigram learning (i.e., the kind of account for which path analysis is sometimes used as a tool of evaluation). The data from 3 subjects cannot confirm any such account, but they can be examined to determine whether they point more towards one kind of account than another on an exploratory basis.

To illustrate, two of the many possible causal structures linking the same five constructs are shown in Figure 1. The simplest (but most unlikely) causal structure (Figure 1a) would have a direct causal chain from the process of learning to learn, to the process of efficiently learning lexigrams, to the outcome of knowing and using

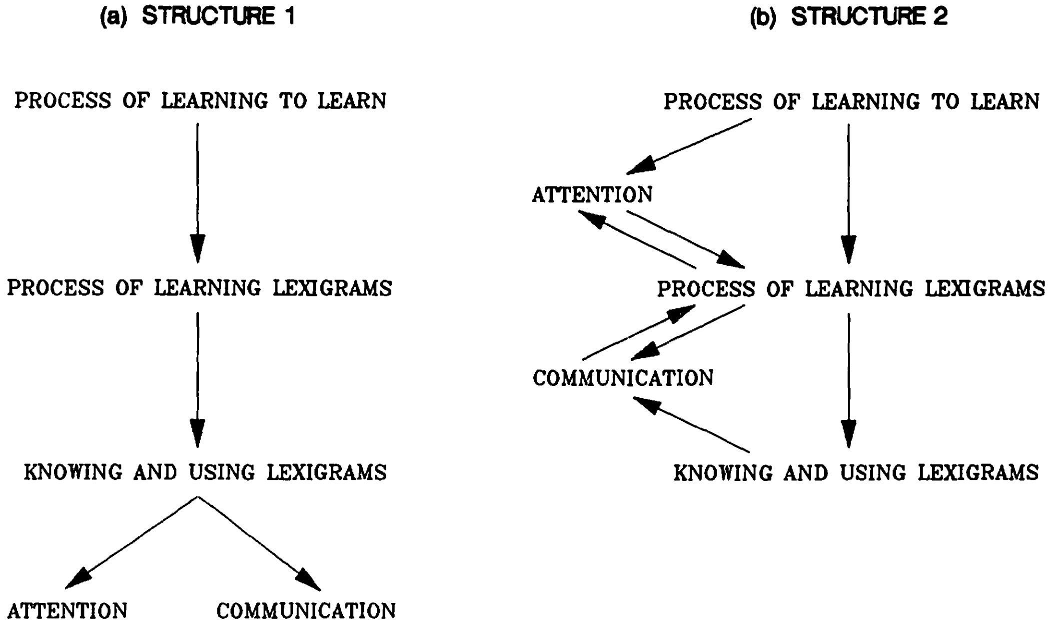

Figure 1. Two hypothetical causal structures.

some number of lexigrams, to the aspects of attention and communication that are captured by our measures. In a more likely, though somewhat oversimplified, structure (Figure 1b), the early process of constructing a procedure for learning lexigrams ("learning to learn") fosters changes in attention. This effect might even begin prior to achieving criterion on contrastive use of lexigrams and be attributed in large part to the attention-directing functions of differential lighting and feedback in the interactive electronic display. The attentional improvements may then play a causal role in the acquisition of lexigrams. With "learning to learn" accomplished, the subject may increasingly be able to coordinate attention to the lexigram keyboard with attention to the vocal, gestural, and other guiding behavior of the teacher, resulting in improvements in the subject's own communication. Again, these improvements may feed back to make the process of learning lexigrams even more efficient and efficacious. At the most advanced level of effects on communication (upwards arrow at the bottom of the figure), the repeated pairing of lexigrams that are successfully acquired with corresponding words may foster improved comprehension and even improved production of those words.

Causal structures are best evaluated using data on patterns of correlation among variables. It is reasonable to expect, however, that if the causal structure in Figure 1(b) is approximately correct, attentional gains should begin fairly early in intervention, and communicative gains should begin somewhat later. The small number of subjects in the present study limits us to the tentative observation that the data are generally consistent with this prediction. Combining across situations in Table 5 (for stability), we found that 2 of the learners (Subjects DB and SB) appear to have shown most of their increase in attention shift during Sessions D through F but did not increase in communication frequency until Sessions E through G (Subject DB) or Session G alone (Subject SB). The third learner (Subject TS) showed most of her increase on both variables at Session E. All 3 learners continued to make qualitative improvements in communication through Session G.

Hence, there are certain limitations in the present study, but these point the way to opportunities that can be taken by future researchers using the methods provided. There is one last area in which other intervention programs have often shown limitations but in which our results are quite encouraging. That is the question of generalization to contexts other than the intervention context itself. In the case of lexigram intervention, at least some effects appeared to show substantial generalization. The most direct evidence for this is the fact that the objects situation provided data on change that occurred outside of the lexigram context; that is, changes brought about in the electronic, symbolic environment of the lexigram boards generalized to a situation of object-mediated social interaction. Although that situation was familiar to the subjects from the nonlexigram portion of the teaching sessions, and involved familiar teachers, the situation had not itself been sufficient to bring changes in communication and attention for the control subjects. These effects were due to what happened in the daily lexigram sessions and were reflected in the keyboard situation data, but it is most encouraging that they also generalized to the object situation.

(Also relevant are the comments of a naive observer who was asked to observe and compare the lexigram [KB] and control [SI] groups during one daily session, without being told which group was which. She wrote: "My main impression was that there was less communication occurring within the SI group. There seemed to be less responsiveness to interactions initiated by the E, that is, smiling, making utterances, looking at E's face. There also seemed to be less apparent awareness, interest or involvement in what was happening; that is, during Snack, there seemed to be less eyes following (the teacher) getting food from the cupboard and reacting to receiving some.")

Evidence concerning generalizability to situations even further removed from the teaching context was available from professional and direct-care staff members at the subjects' living unit, who gave unsolicited reports of positive behavioral changes for the 3 learners. For example, Subject TS's physical therapist observed an increase in her attention span and duration of working on a task, and Subject SB improved enough that she was moved to a less restrictive living unit.

Of the domains of change that have been identified in this study, the one that should be pursued most vigorously is attention. Precise measures of attention have usually not been incorporated in assessments of the effects of interventions, but the importance of attentional phenomena in mental retardation has long been recognized (e.g., Das, 1973; Finkelstein, Gallagher, & Farrian, 1980; McCollum, 1987; Zeaman &

House, 1963), and in the present study the attention measures very clearly differentiated the learners from the other 7 subjects. The ability to measure attentional changes makes it possible to determine which types of intervention foster those changes and which types of subjects would benefit. The incorporation of attention-directing techniques may be a crucial design feature in intervention programs for individuals, such as those in the present study, who at onset show poor attention deployment. In lexigram intervention, differential lighting of portions of the lexigram panel is used to draw attention to the search set of candidate lexigrams and to provide feedback following a response. The use of illumination or contrast has been shown to facilitate the performance of children with mental retardation in a visual discrimination learning task (Meador, Rumbaugh, Tribble, & Thompson, 1984) as well as in a complex memory task (McLeskey, 1982). It is a reasonable hypothesis that this technique was an important factor in the learners' success at symbol acquisition as well as their attentional changes.

The present results, though limited in some respects, give initial support to the idea that targeted changes are embedded in a broader assemblage of changes that can and should be studied and provide an initial description of those changes for the case of lexigram intervention. At least some nonspeaking persons who acquire the use of visual–graphic symbols show concomitant changes in attention and communication as well as changes in sociability that are more generally achievable with other types of intervention as well. It has raised, but left unanswered, the questions of the generality of the outcome and the actual form of the causal nexus in which the various changes are embedded when they do occur. It is important to determine which particular interventions produce which changes in which participants and when. Answers should gradually emerge if the occurrence of broad, generalizable changes of this kind become one of the criteria by which language intervention programs are judged for effectiveness. The SOAR coding system provides a preliminary, efficient tool that can be used for this purpose by researchers and educators, whereas the STAR coding system can be applied to the longer term goal of precisely characterizing the changes that effective programs foster.

APPENDIX A
Abridgement of the Coding Manual
System for Transcript-Based Analysis of Responsivity (STAR)

Attention Coding

The session is exhaustively partitioned into attention segments, with onset time and duration for each segment recorded to the nearest second. Attention segments usually are shorter than episodes and nested within them. A new attention segment begins each time Subject's (S's) focus of attention changes. Focus of attention is based on the direction of S's visual regard, as determined by gaze and/or upper body orientation, and by the character of the object of visual regard as listed below. (Exception: Off-task segments are defined as for episodes.) In addition to focus, the type of unit is coded (e.g., passive lapse, new on-task focus). (E = experimenter)

Social foci	*Nonsocial foci*	*Off-task*
11. E's or joint object	31. Own object	51. Self-stimulation
12. E's face	32. (Merged into code 35)	52. Active avoidance
13. E's hand	33. Own hand	53. Negative action
14. E's or joint action	34. Own action	54. Passive down
15. E's action—passively cooperate	35. Vaguely shifting, other or can't tell	55. Passive up/out
		56. Distracted

Episode Coding

Each session is divided into a sequence of episodes, with episode boundaries determined by change from one type of interaction state to another. There are four types of off-task episodes, four types of attention-only episodes, and two types of action episodes. In determining episode boundaries, observers should ignore brief lapses (4 seconds or less) into a lower level behavior; for example, in an action episode, S may stop acting and look at a new object without terminating the episode, provided S resumes the action within 4 seconds. Also, if S looks at an object for 1 to 2 seconds before acting on it, the preliminary looking is regarded as part of the action episode (and is not a separate segment in the attention coding). Definitions are as follows:

- 1.00 Off-task episode: S is actively or passively avoiding the task of interacting with the E or the toys.
  - 1.10 Self-stimulation: S exhibits a stereotypic, repetitive behavior that is specific to that S.
  - 1.20 Active avoidance: S takes active, direct action to try to avoid E or the situation. Do not use this code if S is trying to resist a particular goal of E's but is otherwise staying in the situation.
  - 1.30 Negative action: S is acting in a negative or destructive manner.
  - 1.40 Passive or distracted: S is looking down at the table, is looking up or out "into space," and/or S is distracted (blowing nose, rubbing face, etc.). Do not use this code if there is a definite focus of attention, or for self-stimulatory acts.
- 2.00 Attention-only episode: S is attending but not acting. Attention episodes have an inclusion relation to a series of one or more attention segments as defined in the attention coding section above.
  - 2.10 Social attention, one focus: One type of social attention segment (one of the attention codes 11–16), plus any lapses that may occur (attention codes 54 through 56); by definition, each lapse is followed by an additional social attention segment.
  - 2.20 Social attention, multifocus: More than one type of social attention segment (two or more of the Attention Codes 11 through 16), plus any lapses that may occur (Attention Codes 54 through 56).
  - 2.30 Nonsocial attention, one focus: One type of nonsocial attention segment (one of the Attention Codes 31 through 35), plus any lapses that may occur (Attention Codes 54 through 56); by definition, each lapse is followed by an additional nonsocial attention segment.
  - 2.40 Nonsocial attention, multifocus: More than one type of nonsocial attention segment (two or more of the Attention Codes 31 through 35), plus any lapses that may occur (Attention Codes 54 through 56).
- 3.00 Action episode: S performs one or more actions alone or jointly with E. An action is a movement that at least minimally involves an act of will and goal-directedness but is not an act of intentional communication. Passive cooperation with E, fiddling, etc., are coded as attention-only episodes.
  - 3.10 Social action: A social action episode begins when S initiates an action under E's influence and terminates when S stops acting, or 4 seconds after S's action is no longer under E's influence.
  - 3.20 Nonsocial action: Nonsocial action episodes begin when (a) S initiates an action that does not meet the criteria for social action or (b) S continues an action that no longer meets the criteria for social action.

Communication Coding

Each act of intentional communication is coded in this division, without affecting the episode coding. (Direction of regard, however, is reflected in the attention coding). The coding is on an occurrence rather than duration basis. A gesture and/or vocalization is an act of intentional communication if it is directed at E to accomplish a goal (generally indicated by S looking at E at least briefly and/or repeating the communicative act if E does not respond) or to respond to a communication by E. Self-communications (e.g., naming an object or expressing interest by saying "oh!") are also counted. Smiling and vocalizations with minimal form and meaning are disregarded. Three categories of exhaustive, mutually exclusive subcodes are applied, as follows.

Nonvocal Form

- 0.00 None
- 0.20 Gaze + manually indicate object (help)
- 0.30 Gaze + manually indicate object (show)
- 0.40 Gaze + hold out object (offer)
- 0.50 Touch socially (e.g., shake hands)
- 0.60 Point (unless .20 or .30)
- 0.70 Touch–point (unless .20 or .30)
- 0.80 Other nontouch gesture (e.g., wave, nod)

Discourse Type

- 1.00 S-initiated
- 4.00 Nonimitative response
- 5.00 Partly imitative response
- 6.00 Complete imitation
- 7.00 Reduced imitation

Vocal Form

- 0.00 None
- 0.01 Jargon (multisyllabic, unintelligible, sentence-like intonational contour)
- 0.02 Idiosyncratic vocalization (word length, nonconventional, characteristic)
- 0.03 Conventional nonlinguistic vocalization (e.g., "yeah," "uh huh")
- 0.04 Single word, unintelligible (some resemblance to target form, but context is needed to identify the word)

0.05 Single word, intelligible (context is not needed to identify the word)
0.06 Multiword utterance, unintelligible in part (construction of two or more words, including at least one intelligible and one unintelligible word)
0.07 Multiword utterance, intelligible (construction of two or more words, all of which are intelligible without context)

APPENDIX B

An Example of the Transcription, Coding, and Computation of Measures in STAR

Intentional communication				Attention focus			Episode			
Transcription	Type	Nonvocal	Vocal	Code	Onset	Dura	Code	Onset	Dura	Description
Point & 'bah'	1	6	4	4.11	2'38"	4	2.2	2'38"	7	Look at brush
				6.55	2'42"	1				Look up (lapse)
				4.12	2'43"	2				Look at E face
				4.11	2'45"	3	3.1	2'45"	25	Pick up Play-Doh at E's request
				4.13	2'48"	2				Look at E hand expectantly
				4.16	2'50"	20				Pound Play-Doh jointly
				9.52	3'10"	8	1.2	3'10"	8	Try leave table
				4.31	3'18"	5	2.3	3'18"	5	Look at cup
				4.34	3'23"	7	3.2	3'23"	7	Pretend to drink
'Yeah'	4	0	3	4.12	3'30"	2	2.1	3'30"	2	Respond to E's "You like to drink?"
				8.54	3'32"	6	1.4	3'32"	6	Passively look down

Communication Frequency: 2
Attention Shift: 11 / 1 minute = 111 per 10 minutes
Attention Complexity: (3 + 1 + 1) / 3 episodes = 1.67 segments per episode
Task-orientedness (7 + 25 + 5 + 7 + 2) / (7 + 25 + 5 + 7 + 2) + (8 + 6) = 46/60 = .767
Sociability: (7 + 25 + 2) / (7 + 25 + 2) + (5 + 7) = 34/46 = .944

APPENDIX C

System for On-Line Analysis of Responsivity (SOAR)

The SOAR system is derived from STAR as follows.

1. An act of intentional communication is transcribed or simply counted every time the STAR criteria are met; no subcodes are recorded. The total number of acts provides the value for the communication frequency measure.

2. An attention segment is scored every time the criteria from the attention coding division of STAR are met. For the keyboard situation redirecting attention to a different area of the keyboard counts as a new segment. The total number of attention segments provides the value of the attention shift measure.

3. A vocalization is scored every time S vocalizes without meeting the criteria for communication. The total number of vocalizations provides the value for the vocalization frequency measure. This measure can be omitted for subjects who show sufficient intentional communication.

Several considerations are relevant to obtaining stable values of the attention shift measure. First, different situations and materials produce different rates of attention shift, so it is best to use a well-specified situation with relatively few attention foci (e.g., the keyboard situation is easier to code in real time than is the objects situation because the main sites of action are simply E's location, the food's location, and the areas of the keyboard). Second, situation-specific rules need to be developed (e.g., if food is moved from the food bin to a table, is the food on the table a new focus of attention?) Third, strict application of the STAR criteria can be difficult because in real time it is easier to simply count gaze shifts than to track the more complex criteria for attention shift (e.g., if E tosses an object across the table and retrieves it, and S maintains attention to E's action by shifting gaze to the new location, there is only one attention segment; however, coding two segments is easier). Fourth, strict adherence to the STAR criteria yields the most conservative real-time coding. Greater emphasis on gaze shift alone as a criterion produces more liberal coding; for us, the most liberal coding was 40 to 50% higher than the most conservative coding for each subject. Nonetheless, the pattern across sessions tended to be consistent, based on correlations between conservative and liberal codings within and across coders. If this receives further verification, it may be sufficient to train coders to a reasonably consistent use of gaze shift rather than training the more complex rules for attention shift. Fifth, coders should be blind as to the preintervention versus postintervention status of sessions.

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