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Critical Properties in the Assembly Call of the Common American Crow

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CRITICAL PROPERTIES OF THE ASSEMBLY CALL OF THE COMMON AMERICAN CROW

by

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(With 6 Figures)
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The communication system of the common American crow has traditionally been said to consist of a definite set of diverse utterances or "caws", each of which occurs in a particular context and has a predictable effect upon the behavior of other crows. Hunting manuals which accompany crow calling devices dictate precisely which call is to be used for which context and for which hoped for reaction of the crows. Old time animal story writers such as Ernest SETON-THOMPSON (1898) assigned to the various cawing patterns of the crow such meanings as "All is well, come right along", and "Great danger — a gun!" Hubert & Mabel FRINGS (1957) in their classic study on the language of the American crow assembled and dispersed crows through the use of two calls recorded under circumstances appropriate to assembly and dispersal. Dwight CHAMBERLAIN (1967) has placed in the archives of the Laboratory of Natural Sounds at Cornell a catalogue of crow sounds, many of which he identifies with specific contexts and responses. In short, scientific and non-scientific tradition alike has interpreted the crow's communication system in terms of different kinds of caws, each of which signifies a particular opportunity or hazard at hand (GOOD, 1952).

Evidence is gradually accumulating that this traditional account of the crow's communication is incomplete. The evidence is the result of a program of field observations and recordings of the vocalizations of crows engaged in a variety of functional activities (THOMPSON, 1968, 1969a, 1969b). These observations and recordings have been made in several locations in the eastern United States and at all seasons of the year. The contrary evidence these observations have generated is of two kinds. One kind is evidence that the same crow utterance produces different reactions in its listeners depending on the time of year, location, and circumstances of the hearers, and most importantly depending on the syntactical context of the utterance. The second kind of contrary evidence is that markedly different caws often occur in quite similar circumstances and produce quite similar reactions from listening crows.

An important source of this contradictory evidence has been the study of "ordinary" or "structured" cawing. The term, ordinary cawing, was employed by CHAMBERLAIN & CORNWALL (1971) to refer to a loosely defined collection of vocalizations which produced no readily identified reaction in its hearers. We use the term, structured cawing, to refer to this same class of vocalizations emphasizing a characteristic organizational feature. THOMPSON (1968, 1969a, 1969b) showed that a sequence of structured cawing is characterized by the repetitiousness of its caw units and by its discontinuous pattern of emission (Figure 1). Such sequences consist of several bursts of 1 to 9

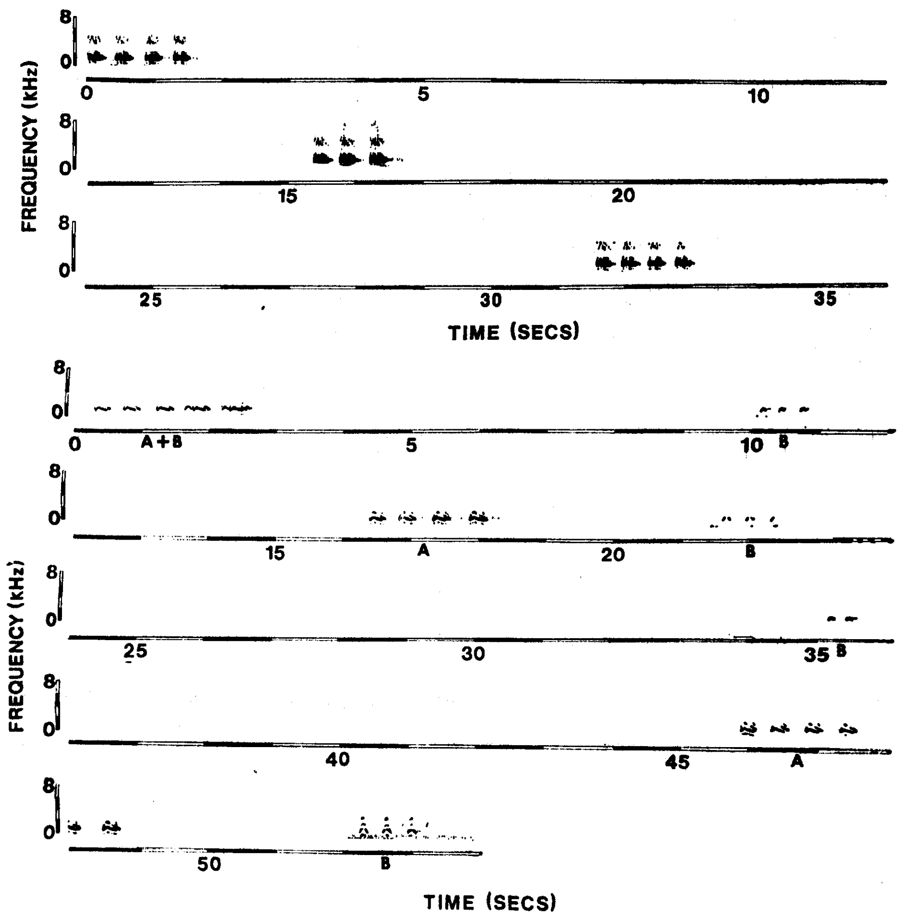

Fig. 1. Examples of structured cawing. (a) A single crow. (b) Two crows, "A" and "B" giving overlapping sequences of structured cawing.

similar caws separated from each other by pauses of 10 or more seconds. Each sequence is uniform within itself both in the caw units of which the bursts are composed and in the temporal and numerical properties of the bursts, such as number of caws per bursts, caw direction, and inter-caw interval. However, different sequences of cawing are commonly diverse in these same respects.

The use of ordinary cawing by crows presents an interesting challenge to the traditional view of crow communication. Two different crows, sitting perched in the same tree and subject, presumably, to the same circumstances, often give radically different patterns of ordinary cawing. The same crow, as he moves from tree to tree, from preening to feeding, from solitude to joining a group, often persists in giving a particular pattern of ordinary cawing. On the other hand, such a single crow may dramatically and without warning alter his ordinary cawing pattern to a pattern different in pitch and temporal organization from the pattern in which he has been persisting. Such shifts may occur in response to no discernible social or environmental circumstance. Nor need they be accompanied by any discernible reactions in crows within hearing. Thus, the use of ordinary cawing appears to violate the "tradition" that each different caw in a crow's repertoire has a particular meaning, occurs in a particular context, and is responded to by a particular limited set of behaviors on the part of other crows.

Another source of challenge to the traditional account of the crow's communication is the study of the relationship between unstructured cawing and ordinary, structured cawing. The term "unstructured cawing" we use to refer to vocalizations of the common crow which do not display the temporal pattern typical of ordinary or structural cawing (*e.g.*, Figure 2). CHAMBERLAIN (1967) has documented the broad range of functional contexts in which unstructured vocalizations occurred, including care-soliciting behavior, courtship, individual defense, and flock defense. He has shown that each of these functional contexts has its own typical caw units with characteristic timbre, inflection, duration, and pitch. On the basis of preliminary field observations of our own, we believe that a common analogic patterning is used in all instances of "unstructured" cawing. The general rule of this patterning is that the vocalizations become more variable, more frequent, with fewer and shorter breaks in the stream of sound as the situation of the bird becomes more urgent. Sequences of unstructured cawing seem to differ from structured cawing in that they are highly variable within a sequence both in the properties of the caws and used in the temporal properties of the sequences. The different types of unstructured cawing appear to occur in highly predictable contexts and elicit highly predictable behavior from crows within hearing.

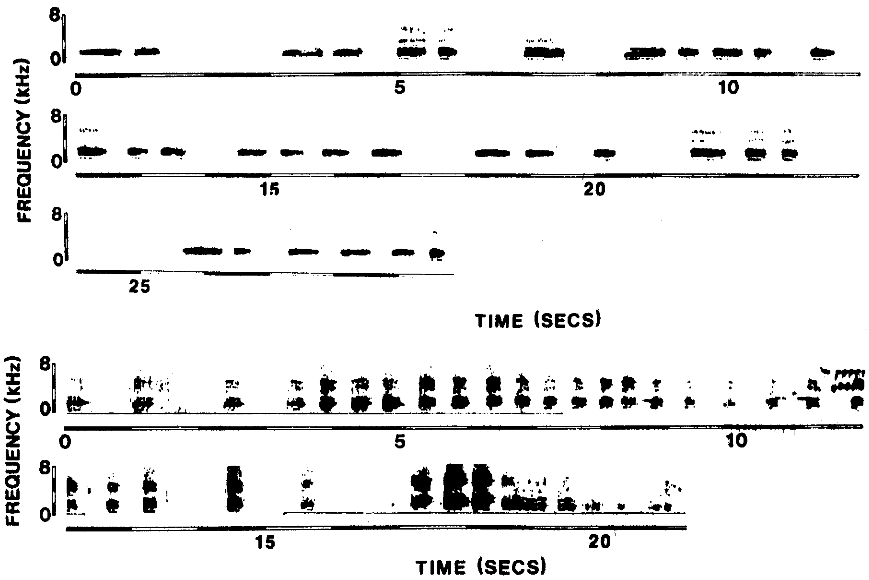

Fig. 2. Examples of unstructured cawing. (a) Tame crow responding to his first encounter with a model. (b) Young crow begging food from its parent.

Analogic variations within a sequence of unstructured cawing are apparently preceded by recognizable changes in the environment and followed by recognizable responses on the part of listening crows.

Auditory and sonagraphic comparisons of the broad types of cawing reveal an extensive overlap in the caws of which the two types of sequences are composed. Both types of structural arrangements may include caws that are high pitched or caws that are not inflected, caws with a raucous, grainy note quality, or caws with a smooth, clear note quality, long caws or short caws, *etc.* What appears to differentiate the two kinds of cawing is thus not the caws themselves but the manner in which the caws are assembled into sequences. In structured cawing, the caws are assembled into repetitive discontinuous sequences; in unstructured cawing the caws are assembled into sequences of caws of broadly similar vocal quality but within these broad types, the caws are variable, their timing is variable, and the stream of caws is emitted continuously, without marked breaks. In contrast to the traditional view, these observations suggest that much of the meaning of cawing in crows arises not from the caws themselves but from the manner in which these caws are assembled into higher order patterns.

The critical prediction of this hypothesis is that an experimenter should be able to alter the meaning of a sequence of cawing without changing the caws of which it is composed. The experimenter need only alter the way in which the caws are put together. For instance, if he were to take a caw from an unstructured sequence which elicits mobbing from crows in the wild, and arrange them in sequences like structured cawing, then these caws should cease to cause crows to assemble. Contrariwise, if he takes caws from a structured sequence of cawing which falls within the range of cawing typical of the assembly call and arranges these caws in the unstructured format, the new sequence should now assemble crows where before it didn't. Note that the hypothesis does not predict that *any* structured call can be made into an assembly call; only those structured calls whose call units fall within the broad range of note qualities typical of assembly calls.

The next several pages report the results of a series of experiments designed to show that one can make and unmake assembly caws by electronically rearranging caws into the structured and unstructured formats. The "assembly call" was chosen for analysis because of the universal agreement among scientists, hunters, animal story writers, and naturalists concerning its meaning and proporties. This unanimity suggests that a relatively clearcut evaluation of the relative importance of note quality properties and organization properties is possible using the assembly call.

GENERAL METHODS AND MATERIALS

Subjects.

The subjects of these investigations were natural populations of Common crows (*Corvus brachyrhynchos*) observed at all seasons of the year from roadsides in Central Massachusetts.

Apparatus.

The stimulus presentation apparatus consisted in either a Sonocaster 8 ohm 30 watt speaker driven by a Claricon Model 44-110 amplifier, or a Bogen HFS 30 watt speaker driven by a Bogen BT35A field amplifier, and a Sony TC800 monaural tape recorder.

Procedure.

The basic procedure was to drive along a country road until a good site for stimulus presentation was located. A good site had sufficient open land along the roadside to permit the observation of approaching crows and far enough from dwellings so that the broadcast would not disturb the residents. The experimenter then presented the stimulus in accordance with a randomized schedule.

The experimenter made notes on the general configurations of the land, the number of crows, if any, visible or within hearing at the beginning of the presentation, the direction and mode of approach of any crows during or after the presentation, and the vocalizations and behavior of any crows which responded to the presentation. These data were divided after the fact into four categories of response: grainy responding, responding with high-pitched (non-grainy) cawing, no cawing and a remaining category, "not discernible", for presentations in which responses were ambiguous, or otherwise unreported. After the second experiment a fifth category was introduced, "mixed", which

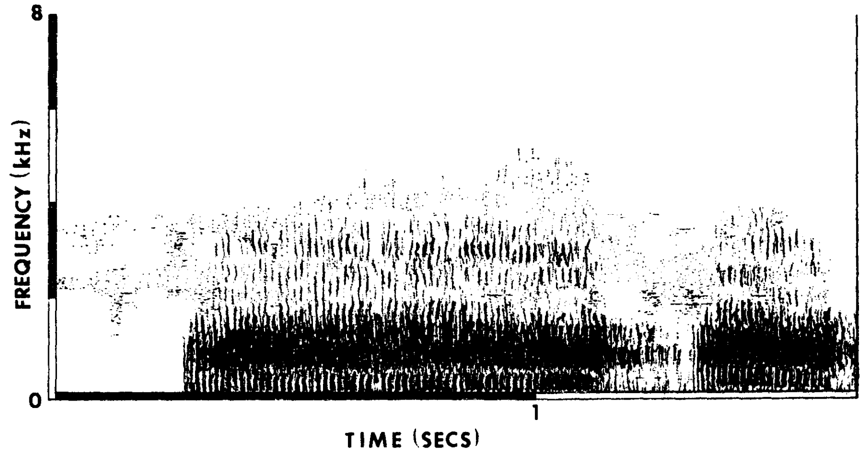

Fig. 3. A segment of the assembly call from which stimuli were constructed.

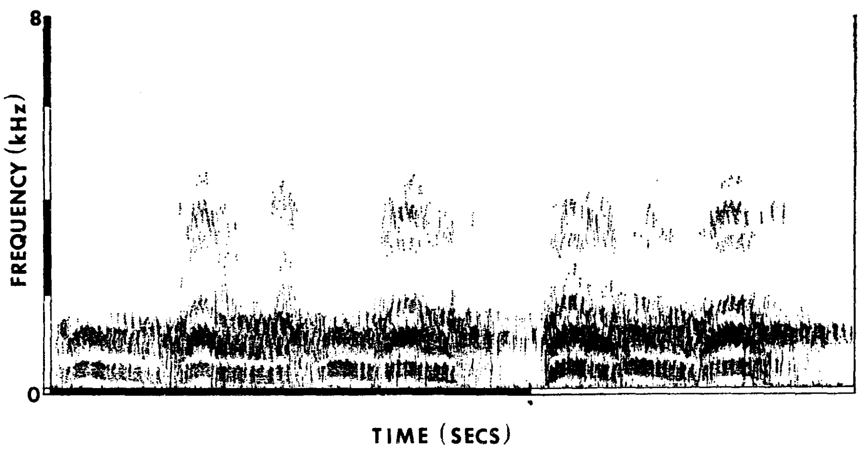

Fig. 4. A segment of the dispersal call.

was used when the responses of the crows were *both* grainy and high-pitched. The use of this category reduced the need for the "not discernible" category.

Each stimulus tape of 30 sec. duration was played three times with 5 sec. intervals between playings, giving a total stimulus presentation of 100 sec. If no crows responded by the third presentation, the trial was scored "unsuccessful". A successful trial was defined as one in which one or more crows responded to the playing of the stimulus by approaching on a direct line to the speaker. The ideal positive response was a direct flight in which the crow overflew the speaker once or a number of times. Also classified as a positive response was one in which the crow flew directly toward the speaker but veered off before overflying it. Not classified as a positive response was one in which

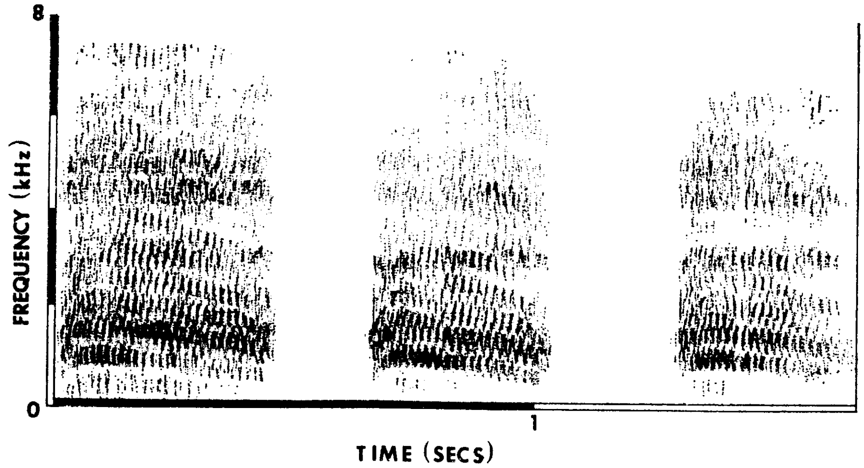

Fig. 5. A segment of grainy ordinary cawing from which stimuli were constructed.

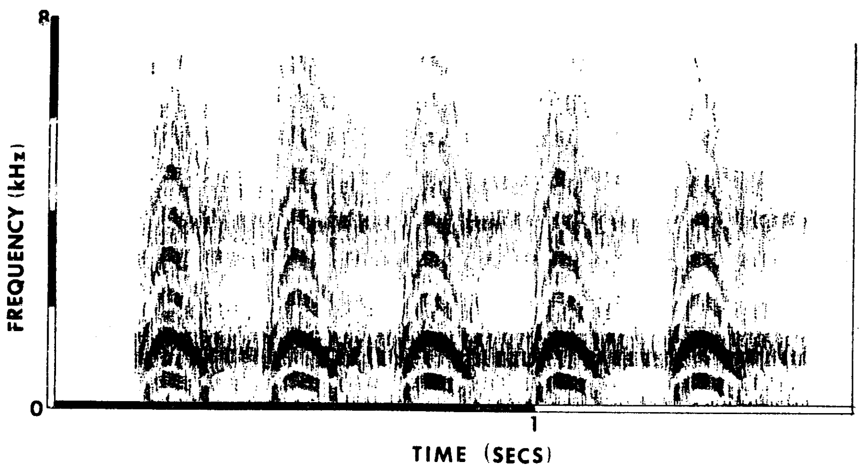

Fig. 6. A segment of high-pitched ordinary cawing from which stimuli were constructed.

the crows flew by in the distance or merely perched nearby in a tree. Over all experiments the average number of crows which assembled on a given trial was 3.8. No more weight was given to a trial in which 10 or 20 crows assembled than to a trial in which only one bird assembled. The number of birds assembling was thought to be as much a reflection of the number of crows in the vicinity as of the effectiveness of the call.

After each presentation, whether successful or unsuccessful, the experimenter drove to the next suitable location where the next stimulus on the schedule was used. Each new site was selected so as to be out of hearing of the previous site. The distance driven between sites depended upon the terrain and the amount of vegetation separating a potential new site from the previous one and also upon the direction in which the two calls were broadcast. In no case was the distance between two presentation sites less than 400 meters. Distances were usually greater than 800 meters and sometimes several miles. The occasionally short (400 meters) distance between presentation was made possible by a forested and hilly terrain.

Manufacture of stimuli.

All stimuli from all studies reported in this paper were manufactured from natural calls recorded from crows in the field. Stimuli were manufactured by splicing out larger and/or smaller sections of the natural tapes and in some cases resplicing these sections in a new order. Stimuli manufactured from "Assembly" and "Dispersal" (Figures 3 and 4) calls and some manufactured from ordinary cawing (Figure 5) were taken from the tracks so designated in the tape recording which annotates CHAMBERLAIN (1967). Stimuli (Figure 6) were also manufactured from ordinary cawing tapes collected and described by THOMPSON (1968, 1969a, 1969b).

EXPERIMENT 1

The purpose of the first experiment was to identify critical aspects of the assembly call for later, more systematic experimental study.

Four experimental variables by which the assembly call collectively differs from ordinary cawing sequences were examined. These were the assembly call's (1) lack of phrase repetitiveness, (2) the graininess or raucousness of its caws, (3) its phrase continuity, and (4) its high degree of caw-to-caw variability. These four characteristics were analyzed with two sets of recordings: a subtractive set and an additive set. In the subtractive set, the various characteristics which appeared to set the assembly call apart from structured cawing were subtracted from the assembly call. In the additive set, these same characteristics were added to a natural ordinary cawing sequence.

Stimuli presented.

In the subtractive series, 6 calls were tested, of which all but one were derived in some way from the assembly call (CHAMBERLAIN, 1967). These calls were: (1) *Assembly Call* (grainy, variable, continuous, non-repetitive); (2) *Repetitive Assembly Call* (grainy, variable, continuous, *but* repetitive); this call was constructed by taking a single 5-caw phrase from the assembly call, repeatedly recording and then splicing these segments together; in the final form, this phrase was repeated 7 times with no marked periods of silence occurring between repetitions; (3) *Discontinuous Assembly Call* (grainy, variable, non-repetitive, *but* discontinuous); segments of blank tape were inserted between the groups of the caws making up the assembly call, thereby creating a stimulus tape in which 5 bursts of cawing alternated with 3 sec. periods of silence; this tape was thus temporally structured in the same manner as an ordinary cawing tape; (4) *Non-variable Assembly Call* (grainy, non-repetitive, continuous, *but* not variable); a single, representative caw was selected from the assembly call and repeatedly recorded; these caws where then spliced together in such a way as to create a stimulus tape in which one caw was continuously repeated with variable inter-caw intervals; (5) *Non-grainy Assembly Call* (variable, non-repetitive, continuous, *but* non-grainy); the assembly call contains no non-grainy caws; several non-grainy caws were taken from an ordinary cawing sequence and were arranged in an assembly call format; that is, these caws were interspliced to form a continuous stream arranged in a temporal pattern characterized by variable inter-caw intervals and the lack of pronounced bursts of cawing; (6) *Non-variable,* *Repetitive Assembly Call* (grainy and continuous, *but* non-variable and repetitive); this call was constructed in exactly the same manner as the *Non-variable Assembly Call* except that the caws making it up were separated by a constant inter-caw interval.

In the additive series, 5 calls were tested, all of which were derived from a grainy ordinary cawing sequence: (1) *Grainy Ordinary Cawing* (non-variable, repetitive, discontinuous, *but* grainy); this stimulus tape was constructed from an unaltered burst of ordinary cawing (Figure 5) taken from the recording which annotates CHAMBERLAIN (1967); in this stimulus tape, 7 repeated bursts of cawing were separated by 3.1 sec. periods of silence; (2) *Grainy Variable Ordinary Cawing* (repetitive and discontinuous, *but* grainy and variable); the first caw in each 3-caw burst of the grainy ordinary cawing tape just described differed slightly in quality from the remaining two notes; however, in this particular ordering of these 3 notes, this difference was not readily apparent to a listener; to create a new stimulus tape with a greater degree of caw-to-caw contrast, the longer, louder first caw of the old tape was *alternated* with the other two caws in a 5-caw burst; this new stimulus tape was composed of 5 repeated bursts separated by 3.2 sec. periods of silence; (3) *Grainy Continuous Ordinary Cawing* (repetitive and non-variable *but* grainy and continuous); the periods of silence between the bursts of cawing in the grainy ordinary cawing tape were removed creating a new tape in which cawing occurred continuously; (4) *Grainy, Variable, Continuous Ordinary Cawing* (repetitive *but* grainy, variable and continuous); the periods of silence between the bursts of cawing in the *Grainy Variable Ordinary Cawing* tape were removed to make a continuous version of that tape; (5) *Grainy Variable, Non-repetitive, Continuous Ordinary Cawing* (grainy, variable, continuous and non-repetitive); segments of the tape (# 4) above were rearranged in order to eliminate the phrase repetitiveness characteristic of that tape. Experiment 1was carried out entirely within the month of July.

RESULTS

The assembly effectiveness of both the additive and subtractive sets of calls are reported in Table 1. While most of the differences in both series were not statistically significant, certain trends were suggested. First, in the subtractive series, making the ordinarily continuous assembly call discontinuous seemed to *lower* its effectiveness. Like-wise, in the additive series, making the discontinuous ordinary cawing sequence continuous seemed to *increase* its effectiveness. Second, subtracting caw variability from the assembly call seemed to lower its effectiveness, whereas in the additive series, making grainy ordinary cawing more variable had no effect and making the continuous version of the ordinary cawing tape more variable appeared to increase its effectiveness slightly. Third, the simulation of the assembly call made up of non-grainy rather than the normally grainy caws was apparently less effective in assembling birds. Finally, the phrase repetitiveness variable did not seem to be important in either the additive or subtractive sets.

EXPERIMENT 2

The second experiment examined in greater detail the three general qualities of the assembly call which the previous experimental indicated might be responsible for its greater effectiveness in assembling crows than ordinary

TABLE 1

The assembly effectiveness calls varying in caw quality, variability, repetitiveness and continuity (Experiment 1)

Call name	Call characteristics				Number of presentations	
	Grainy	Non-repetitive	Continuous	High caw variability	Successful	Unsuccessful
Stimuli						
(1) *Subtractive series* (23 replications):						
Assembly call	yes	yes	yes	yes	8	15
Repetitive assembly call	yes	no	yes	yes	6	17
Discontinuous assembly call	yes	yes	no	yes	5	18
Non-variable assembly call	yes	yes	yes	no	2	21
Non-grainy call	no	yes	yes	yes	3	20
Non-variable repetitive, assembly call	yes	no	yes	no	4	19
(2) *Additive series* (20 replications):						
Grainy, ordinary cawing	yes	no	no	no	3	17
Grainy, variable, ordinary cawing	yes	no	no	yes	3	17
Grainy continuous ordinary cawing	yes	no	yes	no	6	14
Grainy, variable, continuous ordinary cawing	yes	no	yes	yes	8	11
Grainy, variable, non-repetitive, continuous ordinary cawing	yes	yes	yes	yes	9	12

cawing sequences: (1) the graininess or raucousness of its caws, (2) its continuity (lack of burst structure), and (3) its high degree of caw-to-caw variability. These three variables, (1) grainy *vs* non-grainy caw quality, (2) continuous *vs* non-continuous pause structure, and (3) high *vs* low caw variability, were examined in a factorial design. A set of eight artificial tapes representing each possible combination of these variables were made up from two ordinary cawing tapes.

Stimuli presented.

The calls were: (1) *Non-grainy Ordinary Cawing* (non-grainy, low caw variability, non-continuous); this call was constructed from an unaltered burst of non-grainy ordinary cawing (Figure 6); each burst consisted of 5 caws separated with pauses of approximately

3.2 sec. duration; (2) *Variable Non-grainy Ordinary Cawing* (non-grainy, high caw variability, non-continuous); a non-grainy ordinary cawing sequence was recorded at two volume levels; a given caw from one tape was occasionally substituted for a caw in the other, creating a new tape characterized by more caw-to-caw variability; the near absence of caw variability within the non-grainy ordinary cawing sequence made the production of increased caw-to-caw cariability through artificial means necessary; (3) *Continuous Non-grainy Ordinary Cawing* (non-grainy, low caw variability, continuous); the periods of silence between the burst of cawing in the non-grainy ordinary cawing tape were removed creating a new stimulus tape in which caws were not clustered together in bursts; (4) *Continuous and Variable Non-grainy Ordinary Cawing* (non-grainy, high caw variability, continuous); the periods of silence between the bursts of cawing in the *Variable, Non-grainy Ordinary Cawing* tape were removed to make a new continuous tape; (5) *Grainy Ordinary Cawing* (grainy, low caw variability, non-continuous); this stimulus tape was identical to the natural grainy ordinary cawing tape tested in Experiment 1; (6) *Variable Grainy Ordinary Cawing* (grainy, high caw variability, non-continuous); a grainy ordinary tape was recorded at two volume levels; caws from one recording were occasionally substituted for caws in the other recording creating a new tape of higher caw-to-caw variability; (7) *Continuous Grainy Ordinary Cawing* (grainy, low caw variability, continuous); the periods of silence between bursts of cawing in the grainy ordinary cawing tape were removed creating a continuous stream of cawing; (8) *Continuous and Variable Grainy Ordinary Cawing* (grainy, high caw variability, continuous); the periods of silence between bursts of cawing in the *Variable Grainy Ordinary Cawing* tape were removed creating a new call which was both continuous and of high caw-to-caw variability.

In addition, two more calls were added as controls: (9) *Dispersal Call* (non-grainy, high caw variability, continuous); (10) *Assembly Call* (grainy, high caw variability, continuous). Experiment 2 was carried out during the months of October, November, December, January, and April.

RESULTS

Among the three variables examined only caw quality and continuity appeared to affect the assembly rate (see Tables 2 and 3) in the second experiment. Grainy calls elicited significantly higher rates of assembly than non-grainy callls. Only the most effective of the non-grainy stimuli approached the assembly power of the least effective grainy stimulus. Overall, continuous calls elicited higher rates of assembly than discontinuous calls, but this effect was not as dramatic as the grainy/non-grainy effect. There was broad overlap in the rate of assembly to continuous and discontinuous calls and the significance of the differences between them was marginal. Finally, variable calls did not differ from non-variable calls. The pattern of vocal responding to stimulus calls closely paralleled assembly patterns (see Table 4). The grainy calls and continuous calls which elicited higher rates of assembly than non-grainy, and non-continuous calls also elicited higher proportions of grainy responding than did less successful calls. Calls of high caw variability did not elicit significantly different assembly rates than calls of low caw variability nor did they elicit differential vocal responding. Thus, the second experiment suggested that the graininess of an assembly call's caws and its continuity were the primary characteristics responsible for its assembly power and for its capacity to elicit grainy calls from responding crows.

TABLE 2

The assembly effectiveness of artificial calls differing in caw quality, variability and continuity (Experiment 2)

Call name	Call characteristics			Number of presentations	
	Grainy	High caw variability	Continuous	Successful	Unsuccessful
Non-grainy ordinary cawing	no	no	no	6	44
Variable non-grainy ordinary cawing	no	yes	no	2	48
Continuous non-grainy ordinary cawing	no	no	yes	1	49
Continuous and variable non-grainy ordinary cawing	no	yes	yes	8	42
Grainy ordinary cawing	yes	no	no	10	40
Variable grainy ordinary cawing	yes	yes	no	10	40
Continuous grainy ordinary cawing	yes	no	yes	20	30
Continuous and variable grainy ordinary cawing	yes	yes	yes	14	36
Dispersal call	no	yes	yes	5	45
Assembly call	yes	yes	yes	15	36

TABLE 3

The influence of graininess, continuity and variability upon the assembly effectiveness of the calls in Experiment 2

Call type	Presentations	
	Success	Non-success
Grainy	54	146
Non-grainy	17	183
	Chi-square=22.192	$p < .001$
Continuous	43	157
Non-continuous	28	172
	Chi-square=3.356	$p = .07$
Variable	34	166
Non-variable	37	163
	Chi-square=.068	$p = .79$

TABLE 4

Vocal responses to stimuli of grainy vs non-grainy caw quality, continuous and discontinuous pause distribution, and high vs low caw variability tested in Experiment 2

	Responses			
Call type	Grainy	High-pitched	No cawing	Not discernible
Grainy	27	4	2	36
Non-grainy	8	8	8	17
		Chi-square = 15.966		p<.01
Continuous	10	7	7	29
Discontinuous	22	4	3	24
		Chi-square = 7.390		p = .06
Variable	15	7	6	25
Non-variable	20	5	4	28
		Chi-square = 1.474		p = .69

EXPERIMENT 3

The second experiment left ambiguous the exact nature of the temporal factors underlying the marginally greater assembly rates to the continuous calls. Confounded in the experimental variable "continuity" were two variables: caw density and caw continuity. Caw density refers to the amount of sound to silence in the stimulus tape, caw continuity to the extent to which the caws are scattered evenly through the silence, or clustered together in bursts. Because of the confounding between these two variables, the results of Experiment II provided no way of determining which of these organizational factors was responsible for the assembly call's effectiveness.

A third experiment was therefore designed in order to investigate in greater detail the relationship between the different ways in which cawing can be structurally organized. All calls were made from a single repetitively recorded grainy caw taken from an ordinary cawing sequence and differed only in the way they were temporally organized.

Two basic structural variables analyzed: (1) phrase continuity and (2) caw density. Continuous and non-continuous calls were each made up at two caw densities, high and low. Moreover, the continuous and non-continuous calls were further subdivided to reflect some of the natural variance in temporal organization shown in sequences of structured and unstructured cawing in the wild.

The set of continuous calls was subdivided into calls with either orderly or disorderly spacing. "Orderly" calls were made up of repeated cycles of gradually lengthened pauses between the caws, a characteristic of pause arrangements typical of ordinary cawing. "Disorderly" calls incorporated the same pauses as the "orderly" calls but these pauses

TABLE 5

A schematic illustration of the temporal arrangement of the calls tested in Experiment 3

Call designation	Notes/34 sec.	Bursts notes (number)	Bursts intervals (seconds)	Internote intervals	Schematic representation of the temporal patterning of notes (x's) in the first 15 sec of each call
High density Continuous Orderly	36	no bursts		variable 0.1-0.4 increasing	xx x x x x x xx x x xxx x x xx
High density Continuous Disorderly	36	no bursts		variable 0.1-0.4	x x x xx xx x x x x xx x x x x x
High density Discontinuous Short bursts	36	3	0.9	non-variable 0.2	xxx xxx xxx xxx xxx xxx
High density Discontinuous Long bursts	36	6	0.9	variable 0.1-0.3 increasing	xxxxxx xxxxxx xxxxxx
Low density Continuous Orderly	12	no bursts		variable 0.9-3.6	x x x x x x
Low density Continuous Disorderly	12	no bursts		variable 0.9-3.6	x x x x x x
Low density Discontinuous Short bursts	12	3	8.7	non-variable 0.2	xxx xxx
Low density Discontinuous Long bursts	12	6	26.0	variable 0.1-0.3 increasing	xxxxxx

occurred in an unpredictable order. This arrangement was more typical of unstructured cawing. The set of non-continuous calls was subdivided into calls made up of the short bursts (3 caws) characteristic of a great many ordinary cawing sequences or calls made up of longer bursts (6 caws), which are less common in natural ordinary cawing. See Table 5 for a schematic illustration of the temporal arrangement of these calls. All calls of high density had 36 caws per 30 seconds and all calls of low density had 12 caws per 30 seconds. The density of discontinuous calls was decreased by decreasing the number of bursts per 30 seconds. The density of continuous calls was decreased by lengthening the pauses between each note. For reference, two calls which had been used in the previous studies were added: (9) *Assembly Call* and (10) *Ordinary Cawing*. Experiment 3 was carried out in the months of July, August and September.

RESULTS

Four attributes of temporal organization were analysed in the third experiment: caw density, caw continuity, burst length (for discontinuous calls only) and pause orderliness (continuous calls only). The results indicate that density, rather than continuity, is the critical factor for assembly and for eliciting grainy responses from approaching crows (see Tables 6, 7 and 8). High density calls elicited significantly more frequent assembly ($<.001$) than did low density calls. This generalization holds whether high and low density continuous calls are being compared (chi-square=6.013, p=.01) or high and low density non-continuous calls are being compared (chi-square= 4.745, p=.03). Vocal responses to the high density stimuli were predominantly in the grainy response category, whereas vocal responses to the low density were predominantly in the mixed response category (chi-square=13.092, $p<.01$). In contrast no significant difference was observed in the frequency of assembly or vocal responses to continuous versus non-continuous calls.

The results also suggest that at high densities pause orderliness is a critical

TABLE 6

The assembly effectiveness of artificials differing independently in caw density and continuity (Experiment 3)

Caw density	Continuity	Spacing	Presentations Successful	Presentations Unsuccessful
High	Continuous	Disorderly spacing	21	29
		Orderly spacing	7	43
	Discontinuous	Short bursts	13	37
		Long bursts	8	42
Low	Continuous	Disorderly spacing	6	44
		Orderly spacing	7	43
	Discontinuous	Short bursts	7	43
		Long bursts	2	48
Assembly call			7	43
Grainy ordinary cawing			8	42

TABLE 7

The influence of caw density and continuity upon the assembly effectiveness of the calls tested in Experiment 3

	Presentations	
Call type	Successful	Unsuccessful
High density	49	151
Low density	22	178
	Chi-square = 11.576	p<.001
Continuous	41	159
Discontinuous	30	170
	Chi-square = 1.712	p = .19

TABLE 8

Vocal responses to the high and low density, continuous and discontinuous stimuli tested in Experiment 3

	Responses			
Call type	Grainy	High-pitched	Mixed grainy and high-pitched	No cawing or not discernible
High density	28	1	11	8
Low density	6	1	13	0
		Chi-square = 13.092		p<.01
Continuous	22	1	11	4
Discontinuous	12	1	13	4
		Chi-square = 2.197		p = .53

factor in eliciting assembly. When orderly and disorderly high density continuous calls were compared, the disorderly version elicited significantly more responding than did the orderly version (chi-square = 8.383, p<.01). These calls had identical pauses between the notes, only the ordering of the pauses differed. The disorderly call elicited the highest response rate of any call tested, significantly better (chi-square = 8.383, p<.01) than that given to the natural assembly call.

EXPERIMENT 4

Results of the third experiment suggest either than orderly pause structures are less exciting than disorderly pause structures or that the particular order chosen was particularly unexciting to the crows. To resolve this ambiguity the disorderly and orderly calls of Experiment 3 were tested against a third stimulus which was orderly and arranged in cycles of *increasing* caw density (accelerated order). This new ordered call consisted of repeated cycles of gradually shortened pauses between the caws in contrast to the old call which consisted of repeated cycles of gradually longer pauses between the caws. Thus, the new call provided an accelerated counterpart to the decelerated ordered call tested in the third experiment.

Stimuli presented.

Three calls were tested: (1) *High Density-Continuous-Disorderly Spacing,* (2) *High Density-Continuous-Ordered, Decelerated Spacing,* (3) *High Density-Continuous-Ordered, Accelerated Spacing.* The new call was made in the same manner as the calls of Experiment 3 using the same caw, the same inter-caw pauses, and the same tape recorders for construction. Experiment 4 was carried out in the months of September and October.

TABLE 9

The effect of pause distribution upon assembly effectiveness (Experiment 4)

Call type	Presentations Successful	Unsuccessful
High density disorderly spacing	8	17
Accelerated high density orderly spacing	15	10
Decelerated high density orderly spacing	5	20
Accelerated orderly spacing vs Decelerated orderly spacing	Chi-square = 6.75	$p < .01$
Accelerated orderly spacing vs Disorderly spacing	Chi-square = 2.899	$p < .10$
Disorderly spacing vs Decelerated orderly spacing	Chi-square = .416	$p > .10$

RESULTS

The results of this small experiment (see Table 9) show that the lack of reaction in Experiment 3 to the orderly decelerated call was due to its deceleration, not to its orderliness. The crows found the orderly accelerated call to be by far the most attractive call of any that they had encountered before. They approached this call more than three times as often as they approached the orderly decelerating call and almost twice as often as they approached the call with disorderly pauses. Thus, the most effective call for assembling crows appears to be a grainy call of high temporal density which is accelerated, *i.e.*, arranged in cycles of increasing density.

DISCUSSION

The four experiments reported here have shown that one can alter the assembly power of natural crow caws by altering the manner in which these caws are organized into sequences. In fact, one can take a grainy call which does not commonly assemble crows and by altering some of its temporal characteristics cause it to assembly; similarly, one can take a grainy call which naturally assembles crows and by altering its temporal characteristics cause it not to assembly. The critical temporal characteristics which promote assembly appear to be a rate of emission of the calls which is both high and increasing. A call artificially constructed to maximize these two characteristics elicits assembly responses from crows within hearing in a higher proportion of tests than the assembly call itself.

The results require at least some adjustment in the commonly held conception of the crow's communication. They are inconsistent with the traditional hypothesis that each particular caw in the repertoire has a different stable meaning. The results do not prove but are consistent with the hypothesis that the structure of a sequence of cawing indicates to hearers how to interpret the caw qualities of the caws contained in the sequence. A listening crow cannot simply assemble to every grainy call; he must wait to ascertain that the call is given in the proper format.

Finally, the results suggest that the crow is worthy of further study by those interested in the evolution of higher communication processes. If the hypothesis described above is correct, then the crow's communication system is an example of duality of patterning in the organization of an animal communication system. The term "duality of patterning" was introduced by HOCKETT (1959) and employed by ALTMANN (1962), THORPE (1972), and others to describe the characteristic hierarchical organization of human language. In human language, the basic interchangeable units (syllables) do not become meaningful until they are assembled into higher order units such as words and sentences. If our hypothesis is correct, then the caws of the crows do not themselves have unambiguous meaning until they are assembled into bursts and sequences. Thus, further study of corvid communication may reveal that the crow's communication system challenges basic assumptions concerning what can and cannot be accomplished by subhuman communication processes.

SUMMARY

According to tradition, the communication system of the American crow, *Corvus brachyrhynchos*, consists of an assortment of distinct sounds each of which is used in a particular context and has a unique meaning. Despite this traditional view, we have made field observations which suggested that the sounds employed in various different functional contexts overlap considerably. These observations further suggested that each sound does not have a single unique meaning, but that its meaning varies depending upon how it and similar sounds are temporally organized into calling sequences. In order to investigate this idea, a series of experiments were performed in which the temporal properties of natural sounds recorded from crows in the field were changed. These experiments were concerned primarily with the vocalization known as the assembly call. The assembly call consists of series of sounds which are low, harsh, and variable in pitch and timing.

Broadcast to crows in the field, recorded assembly calls provoke an aggregation of crows to the sound source about twenty-five percent of the time. The recordings broadcasted were of two sorts: sequences made up by modifying the temporal properties of a natural assembly call and sequences of sounds derived from calls given in other functional contexts which were then rearranged to approximate the temporal properties of an assembly call. These calls were tested on wild crows in the field. A presentation of a call was counted successful if at least one crow approached the sound source on a direct line. Different calls were compared with respect to the proportion of successful presentations.

The results show that not all types of crow sounds can be manufactured into effective assembly calls. A high pitched call, even when arranged to approximate the temporal properties of the assembly call does not assemble crows at rates approaching the rate of assembly to natural assembly calls. On the other hand, the results also show that a sound need not be derived from an assembly call in order to be arranged into an effective assembly call. A call recorded in another functional context, but which has a harsh, grainy quality will assemble crows as well as or better than an assembly call if it is presented in the proper temporal arrangement. In fact, the highest rates of success were provoked by a sequence of such sounds having a high rate of emission and organized into short cycles of increasing rate. Such a call is two to four times more effective than a natural assembly call.

These results are inconsistent with the traditional view that each particular caw in the repertoire of a crow has a discrete stable meaning. An alternate hypothesis is suggested in which the meaning of a sequence of crow sounds is thought to depend not only on the properties of the caws but upon the temporal properties of the sequence as well.

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RÉSUMÉ

Selon la tradition, la système de communication du corbeau americain, *Corvus brachyrhynchos*, consiste en un assortiment de sons distincts qui sont employés dans un contexte particulier et avec une signification unique. Malgré cette tradition, nous avons fait des observations en nature qui suggèraient que les sons employés dans des contextes fonctionels variés se dépaissaient beaucoup. Ces observations suggèraient de plus que l'organisation rythmique était importante. Pour examiner cette idée, nous avons mis en exécution une série d'expériences dans laquelle nous avons changé les propriétés rythmiques des sons naturels des corbeaux enregistrés en nature. Ces expériences se concernaient surtout avec la vocalisation qu'on peut appeler "l'appel de convocation". Ceci consiste en un enchaînement de sons approfondis, grinçants, et variés. Diffusés aux corbeaux en nature, les appels de convocation provoquent une fois en quatre une agregation des corbeaux près du point de diffusion. Les enregistrements que nous avons diffusés se divisent en deux sortes: des enchaînements fabriqués d'un appel de convocation naturel dont des propiétés rythmiques ont été modifiés, et des enchaînements fabriqués de sons qui se faisaient en nature dans un autre contexte mais que nous avons remis ensemble pour limiter quelques propiétés rythmiques de l'appel de convocation. Ces enregistrements ont été mis à l'épreuve avec des corbeaux sauvages dans la nature. Nous avons appelé un enregistrement réussi quand au moins un corbeau s'approchait du point de diffusion. Les résultâts montrent que pas toute sorte de sons ne peut être employée dans un appel de convocation fabriqué. Un son aigu, même si rythmé pour imiter l'appel de convocation n'effectue pas l'agregation des corbeaux si bien que l'appel de convocation naturel. Un enchaînement de sons grinçant et approfondis que se dérivent d'une autre contexte est au moins aussi efficace qu'un appel de convocation naturel si les sons sont enchaînés d'une manière à propos. En effet, l'enregistrement le plus efficace s'était composé des sons d'un autre contexte avec une émission rapide et organisée en petits cycles de rapidité croissante. Un tel enchaînement était deux à quatre fois plus efficace qu'un appel de convocation naturel.

Ces résultâts n'accordent pas avec l'idée traditionelle selon laquelle chaque son dans le repertoire d'un corbeau a une signification unique. Nous avons proposé une hypothèse alternative que la signification d'un enchaînement de sons de corbeau depend non seulement des propriétés des sons mais aussi des propriétés rythmiques de l'enchaînement.