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11. Linguistic theory has even entertained the possibility, in certain contact situations, of the relexification of a language, that is, the replacement of the bulk of its vocabulary with words from another language while retaining much of the original phonology, syntax, and semantics.
12. Supported in part by Canada Council grant S72-0988 and National Research Council of Canada grant A8867. We thank P. Bratley and F. Ouellette for the use of their text-handling system JEUDEMO.

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Auto-Shaping in Rats to the Presentation of Another Rat Predicting Food

Abstract. *Rats direct social rather than eating behavior toward a stimulus rat that predicts the imminent delivery of food. This result suggests that a predictive stimulus does not become a substitute for a reward, but its characteristics elicit and support a particular subset of the responses commonly related to that reward.*

Brown and Jenkins (*1*) discovered that pigeons exposed to repeated pairings of a lighted key with food began to peck the lighted key. They termed this phenomenon auto-shaping because the pigeons pecked even though food delivery was always independent of their behavior. Hearst and Jenkins (*2*) summarized subsequent studies showing that auto-shaping is a robust phenomenon which occurs with rewards other than food and in species other than pigeons.

The parallels between auto-shaping and classical conditioning led many investigators to analyze examples of auto-shaping from the viewpoint of stimulus substitution, an explanation proposed by Pavlov for classical conditioning of the salivary reflex in dogs (*2–4*). According to the stimulus substitution hypothesis, the subject responds to the predictive stimulus (CS) as if it were a substitute or surrogate for the reward (US). Support for the stimulus substitution explanation of auto-shaping was provided by experiments showing that the topography of behavior directed toward the predictive stimulus closely resembles that of behavior elicited by the reward. For example, male pigeons direct brief, hard pecks at a key which signals food, soft "sipping" pecks at a key which signals water, and court a key which predicts access to a receptive female pigeon (*2, 4*). Rats bite and lick a bar which predicts food (*3*).

However, in other experiments behavior elicited by the predictive stimulus did not resemble behavior elicited by the reward (*2–5*). Most recently, Wasserman (*5*) found that baby chicks in a refrigerated chamber approached, pecked, and "snuggled" at a lighted key which predicted the onset of heat, although the chicks' behavior in the presence of heat consisted of immobility and wing extension. Hogan (*6*) accounted for the chicks' behavior by noting that in a cool environment chicks approach, peck, and "snuggle" at a mother hen, thereby inducing her to brood them.

Hogan's explanation suggests a systematic exception to the stimulus substitution hypothesis. Behavior elicited by a predictive stimulus will resemble behavior elicited by the reward only to the extent that the predictive stimulus is compatible with and supports such behavior. If the predictive stimulus elicits and supports other behavior commonly related to the reward, conditioning will occur, but the behavior elicited by the predictive stimulus will differ from that occurring in response to the reward. From this viewpoint, Wasserman's results contradicted the stimulus substitution hypothesis, because the key light, set in a wall, most adequately supported those aspects of thermoregulatory behavior in chicks commonly directed toward the mother hen.

Table 1. Median number of trials on which subjects showed different social contact behaviors over the last 5 days of acquisition (days 7 to 11). The maximum score on any day was 30. Only subjects in groups CS$^+$ and CS^s are included because, with the exception of one animal, the median scores of subjects in the CS^r and CS^w groups were zero for all behaviors.

Subject	Social contact behaviors			
	Paw	Groom	Crawl-over	Ano-genital sniff
		Group: CS$^+$		
1	25	18	21	0
2	23	20	3	4
3	26	21	10	1
4	19	16	4	0
5	20	14	6	5
Mean	*22.6*	*17.8*	*8.8*	*2.0*
		Group: CS^s		
1	0	0	0	0
2	4	0	0	0
3	0	0	0	0
4	14	8	1	2
5	6	2	0	0
Mean	*4.8*	*2.0*	*0.2*	*0.4*

In the present experiment we examined another case in which the predictive stimulus and the reward supported different, although potentially related, behaviors. We employed a live rat fastened to a platform as a predictive stimulus for food. If the stimulus substitution hypothesis is correct, subject rats should treat the predictive rat as food, gnawing or biting it. However, social behavior elicited and supported by the predictive rat is also potentially related to feeding in the rat. Rats feed together, follow each other to food, and, both as pups and adults, learn feeding locations by approaching other rats (*7*). On this basis, the subjects would be expected to incorporate the predictive rat into a social feeding pattern, increasing their frequency of approach and social contact.

To test these hypotheses we compared the behavior of an experimental group with that of three control groups. Each group consisted of five male Wistar albino rats, 90 days of age. During acquisition each rat received 30 10-second presentations of the predictive stimulus (CS) on a variable time schedule with a mean interstimulus interval of 60 seconds (VT 60 seconds). The stimulus platform, driven by a synchronous motor and cam assembly, was presented sideways through a flap door adjacent to the wall containing the food tray. For the experimental group (CS$^+$ group) each presentation of the predictive rat was followed by one 45-mg food pellet. The CS^s (social) group received the same pattern of presentation of the stimulus rat, but no food was ever delivered. Since rats are highly social (*8*), this group served as a baseline of social reactivity to the stimulus rat. The CS^r (random) group was presented with the stimulus rat and food randomly on two independent variable-time 60-second programs. The purpose of this group was to determine the importance of the pairings of the stimulus rat and food (*9*). The CS^w (wood) group was subject to the same procedures as the CS$^+$ group, except that the predictive stimulus was a rat-sized block of wood fastened to the platform. The purpose of this group was to separate the social and predictive effects of the stimulus rat. Rats in the CS$^+$ group might approach the stimulus rat because of its predictive quality and then engage in social contact because of their proximity to the stimulus rat.

All rats were housed alone during the experiment. After adaptation to a 23-hour feeding schedule, each rat received 22 days of training: 3 days of pretraining, 11 days of acquisition, and 8 days of extinction. On the first day of pretraining we exposed each subject to the experimental chamber for 30 minutes; on the next day we trained them to approach and eat rapidly from the food tray when food was delivered. On the third day of pretraining, each subject received 30 10-second presentations of the stimulus rat. No food was delivered on this day. After the 11 acquisition sessions, all subjects received eight extinction sessions during which the predictive stimulus was presented as in acquisition, but no food was delivered.

The behavior of the subjects in the presence of the predictive stimulus was recorded by an observer using a coding scheme modified from Peterson (*10*) and Grant and Mackintosh (*8*). On each presentation of the predictive stimulus the observer noted several behaviors, including: Orient, Approach, Sniff, Bite, and Social Contact (paw, groom, crawl-over, and anogenital sniff) (*11*). A reliability check of this coding scheme with a naive observer produced an average interobserver reliability of .99.

The four panels of Fig. 1 show the median percentage of trials on which each group of five animals performed behaviors in the different categories. The group data adequately reflect the scores of the individual subjects. Figure 1A shows that the CS$^+$ animals successively increased the frequency of Orient, Approach, Sniff, and Social Contact during the 11-day acquisition period, and successively decreased the frequency of these behaviors during extinction. The incidence of Bite was zero over all trials.

The CS^s animals also engaged in considerable behavior directed toward the stimulus rat, but their performance stabilized at a lower level than that of the CS$^+$ animals (see Fig. 1B). Over the last 5 days of acquisition the median scores of the animals in each group showed no overlap in Social Contact, Approach, and Sniff, and only a single common score in the case of Orient. During extinction, the scores of the animals in the CS$^+$ and CS^s groups overlapped considerably.

The CS$^+$ animals showed greater diversity of social contact than did the CS^s animals. Table 1 shows the median individual scores over the last five acquisition trials for paw, groom, crawl-over, and anogenital sniff. All five CS$^+$ animals showed paw, groom, and crawl-over behaviors, and three showed anogenital sniff. Of the five CS^s animals, three showed paw, two showed groom, and only one showed crawl-over and anogenital sniff. Video tapes of a randomly selected animal in each group showed additional social postures for the CS$^+$ animal, such as sideways and head-over postures (*8*).

In comparison to both the CS$^+$ and CS^s groups, the CS^r groups showed a marked inhibition of approach behavior during acquisition (see Fig. 1C). With one exception, the animals oriented on less than 10 percent of the trials and all animals remained by the food tray during the presentation of the stimulus rat. No animal ever engaged in Social Contact. During extinction all behaviors except Social Contact appeared to recover and increase toward overlap with the scores of the CS^s group.

The CS^w group showed an increase in Orient equivalent to that of the CS$^+$ group, but little increase in Approach or Sniff, and no Social Contact score (see Fig. 1D). These results appear to reflect a low level of conditioning to the block of wood. The relative absence of Approach in this group shows that Approach to the predictive rat in the CS$^+$ group was not based on its predictive value alone. Conditioned Approach evidently depends on the social as well as predictive aspects of the stimulus rat.

Several animals in the CS^w group moved toward the predictive stimulus but appeared cautious, crouching slightly and sniffing from a distance of several inches (1 inch = 2.54 cm). The stimulus attributes of the platform and wood block may not have provided adequate support for approach and contact behaviors within the feeding system of the rat. The block and platform provided no social cues and were probably too large to elicit behavior related to food objects. In a natural setting, this stimulus combination would be more likely to elicit caution and avoidance.

These results show that rats can be conditioned (auto-shaped) to approach and contact a live rat, although not a block of

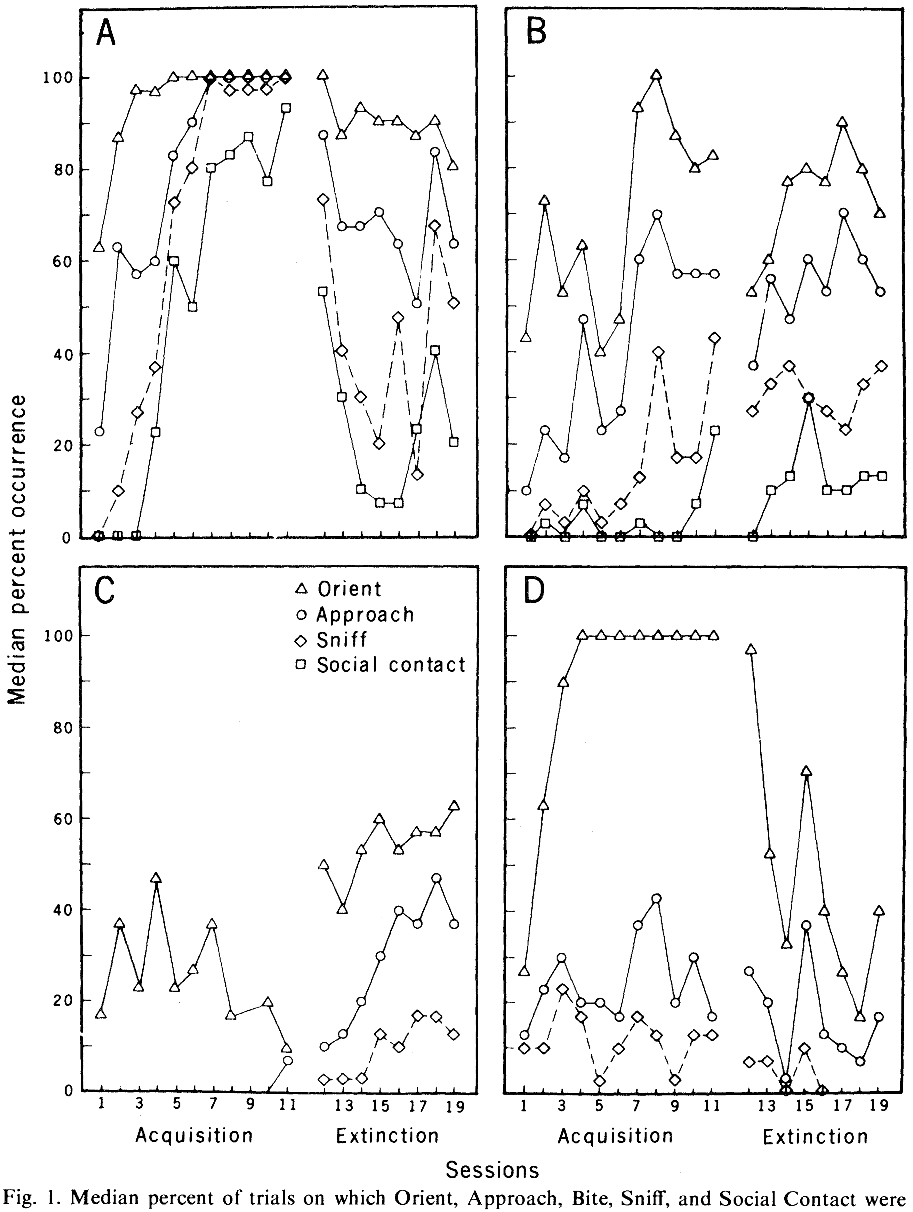

Fig. 1. Median percent of trials on which Orient, Approach, Bite, Sniff, and Social Contact were shown during acquisition (days 1 to 11) and extinction (days 12 to 19). (A) CS$^+$ group; (B) CS^s (social) group; (C) CS^r (random) group; (D) CS^w (wood) group. Since Bite never occurred it is not indicated in the graphs.

wood, which predicts the delivery of food. The form of contact with the predictive stimulus cannot be predicted from the stimulus substitution hypothesis (*12*), but appears to depend upon the nature of both the predictive stimulus and the reward. As an alternative to stimulus substitution, we offer the hypothesis that auto-shaped behavior reflects the conditioning of a system of species-typical behaviors commonly related to the reward. The form of behavior in the presence of the predictive stimulus will depend on which behaviors in the conditioned system are elicited and supported by the predictive stimulus (*13*).

The present approach may have implications for the interpretation of traditional classical conditioning phenomena as well (*2*). Lorenz (*14*) suggested a related hypothesis to explain Liddell's unpublished observations on salivary conditioning in dogs. While working in Pavlov's laboratory, Liddell unharnessed a dog from the conditioning apparatus and allowed it to approach the predictive stimulus. On the basis of Liddell's description, Lorenz identified the dog's behavior toward the predictive stimulus as food begging in the genus *Canis*. Lorenz used this illustration to suggest that an entire behavior system was conditioned by the procedures of classical conditioning, not just an isolated reflex. Our results support this viewpoint.

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11. Orient: point nose at predictive stimulus for at least 1 second; Approach: move nose to within ½ inch (1.3 cm) of predictive stimulus; Sniff: rhythmically move vibrassae and nose within ¼ inch (0.6 cm) of predictive stimulus; Bite: contact predictive stimulus with open mouth and teeth; Social Contact: paw: contact the stimulus with one or both forepaws; groom: lick and comb the fur of the stimulus using the mouth and paws; crawl-over: climb on top of the stimulus with at least three legs off the floor of the cage; anogenital sniff: sniff directed at the anogenital region of the stimulus rat, typically with the head oriented sideways. For a more complete description of the last three categories see Grant and Mackintosh (*8*). Grant and Mackintosh also coded "investigate" and "nose" as social contact behaviors. We lumped these as Sniff and did not count them as Social Contact because we felt the rat looked the same sniffing the platform, the wood, and the stimulus rat. In retrospect, the orientation of "nose" to the head of the stimulus rat potentially made it a distinct category.
12. We do not intend to argue that stimulus substitution effects were absent in the present experiment. Some behaviors shown by the CS^+ animals are readily interpretable as stimulus substitution. Two animals occasionally bit and pulled at the fur of the predictive animal while grooming it [although so did two CS^S animals; see aggressive groom in Grant and Mackintosh (*8*)]; one CS^+ animal bit the platform 12 times, and another animal bit it once (out of 330 acquisition trials). Further, it might be argued that some movements in normal groom and paw resemble components of feeding behavior, thus, some of the increase in these behaviors might be attributable to stimulus substitution. However, even a broadly conceived concept of stimulus substitution does not appear sufficient to explain all behavior in the present experiment. On the basis of stimulus substitution it is difficult to account for the failure of the CS^W animals to bite the wood, the failure of the CS^+ animals to bite the predictive rat, the low incidence of aggressive groom and platform biting in the CS^+ animals and their marked differential increase in crawl-over, a behavior sharing almost no topographical features with feeding. We feel that effects interpretable as stimulus substitution and these apparent exceptions all can be explained within the behavior system approach outlined in the text and the note in (*13*).
13. A system of behavior may be viewed as a collection of species-typical sensorimotor mechanisms potentially sharing common causal factors [see, for exemple, G. P. Baerends, R. H. Drent, P. Glass, H. Groenwald, in *The Herring Gull and Its Egg*, G. P. Baerends and R. H. Drent, Eds. (Brill, Leiden, 1970) or J. A. Hogan, *Behaviour* **39**, 129 (1971)]. The concept is similar to a species-typical central motive state [C. T. Morgan, in *Psychology: A Study of a Science*, S. Koch, Ed. (McGraw-Hill, New York, 1959), vol. 1, p. 644; D. Bindra, *Psychol. Rev.* **82**, 199 (1974)]. Bindra also discussed the importance of characteristics of the CS in supporting behavior typically elicited by the US, as did Mackintosh [N. J. Mackintosh, *The Psychology of Animal Learning* (Academic Press, New York, 1974), p. 108].
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Effects of Long-Term Corn Consumption on Brain Serotonin and the Response to Electric Shock

Abstract. *Rats fed tryptophan-poor corn diets have reduced levels of brain serotonin and show increased responsiveness to electric shock. This diet-induced hyperalgesia can be reversed by feeding the animals diets with adequate amounts of tryptophan, or by systemic injections of the amino acid.*

Protein-calorie malnutrition experienced early in life may cause long-term deficits in learning and other behavioral capacities of humans and animals. The general behavioral sequels to extreme kwashiorkor or marasmus are well documented; however, the specific alterations in brain function that underlie behavioral changes induced by malnutrition are poorly understood. Our report is one of the first to describe an animal model that relates these behavioral changes induced by malnutrition to the effects of the diet on a brain neurotransmitter.

The concentration of the putative brain neurotransmitter, serotonin, appears to be related directly to the brain and plasma concentrations of the amino acid precursor tryptophan (*1*). Mammals cannot synthesize tryptophan; hence, all of the amino acid must be derived from dietary protein. The quality of dietary protein ingested is important for the maintenance of normal blood tryptophan levels, and ultimately for normal concentrations of brain tryptophan and brain serotonin. For example, plasma and brain tryptophan, and brain serotonin, are greatly diminished in animals fed a diet in which corn, a poor source of tryptophan, is the only protein (*2, 3*).

Changes in brain serotonin after various surgical or pharmacological manipulations

Table 1. Effects of long-term corn consumption and tryptophan injection on brain tryptophan and 5-hydroxyindole levels. Rats were placed on corn (tryptophan deficient) or 18 percent casein control diets for 42 days beginning at weaning. Then, different groups of rats were fasted for 18 hours, injected intraperitoneally with the H_2O vehicle or one dose of L-tryptophan, and killed 1 hour later. All values are means ± the standard error (N = 4 to 7).

Diet	Vehicle		L-Tryptophan at:		
	Free access	Fasted	62.5 mg/kg	125 mg/kg	250 mg/kg
			Brain tryptophan (μg/g)		
Casein	3.8 ± 0.2	5.1 ± 1.1	27.4 ± 2.6	47.8 ± 7.4	102.1 ± 9.9
Corn	1.8 ± 0.1†	5.5 ± 0.7	57.5 ± 0.9†	81.1 ± 12.2†	164.2 ± 8.5†
			Brain serotonin (μg/g)		
Casein	0.32 ± .01	0.32 ± .01	0.44 ± .02	0.50 ± .03	0.50 ± .02
Corn	0.25 ± .02*	0.31 ± .02	0.50 ± .02	0.53 ± .03	0.52 ± .01
			Brain 5-hydroxyindoleacetic acid (μg/g)		
Casein	0.27 ± .01	0.31 ± .01	0.55 ± .03	0.53 ± .04	0.66 ± .02
Corn	0.23 ± .02	0.43 ± .02*	0.79 ± .05†	0.81 ± .05†	0.88 ± .03†

*$P < .05$. †$P < .01$ compared to the appropriate casein-fed group.