Complex contingencies

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Four rats were each fixed with two chronically indwelling bipolar electrodes for intracranial stimulation (ICS). ICS with one bipolar electrode was rewarding, and ICS with the other was aversive. After demonstration of the efficacy of ICS, rats were placed in a chamber with a retractable lever. A depression of the lever yielded four trains of ICS. All possible combinations of positive and negative ICS within the constraint of four events were then tested with high intensities of both rewarding and aversive ICS at intertrain intervals of .125, .25, and 1.0 sec, and with different intensities of ICS. It was found that the rats pressed more for the contingencies containing the greater number of positive ICS. The sequence of rewarding and aversive ICS was also shown to be an important variable in determining pressing rates. It was concluded that knowing the net positiveness of complex contingencies and knowing whether the first event was rewarding or aversive was sufficient to predict closely the acceptability of a contingency.

Behavior is frequently followed by more than one or two affective events. Available laboratory data, however, are limited to parametric studies using a single positive reinforcer, a single aversive event, or a combination of the two. The demonstrations that intracranial stimulations (ICS) can control behavior as conventional affective stimulations (Buckwalter, Gibson, Reid, & Porter, 1967; Gibson, Reid, Sakai, & Porter, 1965; Hunsicker & Reid, 1974; Olds, 1969; Reid, Hunsicker, Kent, Johnson, & Gallistel, 1973) opens the way to using ICS as a tool for studying more complex contingencies. This study, consequently, employed ICS to determine how leverpressing was controlled by sequences of affective events. Rats fixed with bipolar electrode for rewarding, positive ICS and an electrode pair for aversive, negative ICS were allowed to press a lever for four ICSs in all possible combinations of positive and negative, e.g., positive-positive-negative-negative and negative-negative-positive-positive were among the 16 sequences tested.

METHOD

Subjects

Four experimentally naive adult male Sprague-Dawley rats were each fixed, in standard ways, with two chronically indwelling bipolar electrodes. The electrodes were stainless steel and insulated except at the cross section of their tips. The tips of each electrode of an electrode pair were separated only by the width of each electrode's insulation. Histological analyses of frozen sections of the brains of the rats, following behavioral testing, confirmed that ICS with one electrode pair stimulated the medial forebrain bundle of the lateral hypothalamus. ICS with the other electrode pair stimulated an area near the geniculates and the geniculates themselves. Other studies have shown previously that these sites of stimulation are, respectively, rewarding and aversive (Olds, 1962; Buckwalter et al, 1967). Prior to testing in the apparatus, it was confirmed that the

medial forebrain bundle ICS supported high rates of leverpressing for the ICS. The posterior, "geniculate" ICS resulted in rapid escape and avoidance of the side of a shuttlebox where the ICS occurred. Preliminary procedures, then, yielded four rats each with two bipolar electrodes allowing either ICS-induced positive affect or ICS-induced aversiveness.

Apparatus

The experimental chamber was a 25 x 30 x 35 cm box enclosed within another sound-attenuating box having its own ventilation system and light source. A standard retractable rat lever (Leigh Valley) was mounted on one wall, 7 cm above the floor. A depression of the lever, when it was fully extended into the chamber, led to lever retraction and a series of four ICS. The offset of the last ICS was programmed to activate the lever's return to the chamber.

ICS was 60 Hz, sine waves of .25-sec duration. ICS was delivered to the rat by way of light-flexible leads connected to a swivel in the ceiling of the chamber allowing ICS delivery without hampering rat's movements.

Procedure

Following recovery from surgery, in a box different from the experimental chamber, an intensity of positive ICS which sustained the highest rates of leverpressing was determined for each rat. These intensities of 25, 30, 35, and 70 microA, for each rat, respectively, were used throughout most of the subsequent procedures. Also, an intensity of negative ICS was selected which sustained high levels of escape avoidance in a shuttlebox. These intensities were 50, 50, 75, and 40 microA, respectively.

After selection of intensities of ICS, each rat was trained in the experimental chamber with the contingency that a single press of the extended lever produced a sequence of four positive ICSs. Each ICS was .25 sec with an interval of .25 sec between. With the contingency of a sequence of four positive ICS, all rats pressed such that they received nearly the maximum number of ICS allowable by the retraction of the lever. The contingency was then changed so that a leverpress yielded four negative ICSs with the same temporal parameters. Under this condition, all rats stopped pressing after taking two or three sequences. These preliminaries demonstrated, for each rat, that the contingency of four positive ICSs was highly positively reinforcing and that the four negative ICSs were highly aversive.

With these preliminaries concluded, each rat began tests of all possible combinations of positive and negative ICS within the limits of four events per contingency. There were 16 contingencies, including the contingencies of all positive and all negative. Each test of a particular contingency was 4 min long

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and was always preceded by a warm-up period of 4 min. If a rat did not self-deliver at least five sequences of the ICS during the warm-up period, five sequences of the ICS were imposed upon it by the experimenter to insure acquaintance with the newly introduced contingency.

Daily test sessions were about 90 min long. At the beginning of each daily session, there were tests to confirm that rats continued to maximize ICS when the contingency was all-positive ICS and that the introduction of the all-negative contingency led to abrupt cessation of responding. At the conclusion of a daily session, rats were again tested with the all-positive contingency to confirm that they still maximized ICS.

The order of sequences tested for each rat was randomly determined by consulting a table of random numbers. Daily testing continued until each rat was tested for 4 min with each of the 16 sequences at least twice.

Data collected for each 4-min test session included total number of barpresses, number of sequences of ICS taken, and number of seconds the lever remained in the chamber. Leverpresses do not correlate perfectly with number of sequences taken because all depressions of the lever were counted and the rats frequently pressed the lever as it was moving in and out of the chamber. The three response measures, however, did correlate highly with one another. Kendall's coefficient of concordance, W , was calculated with the ranks from these three measures and the resulting $W = .98$. This high W allows us to use only one of the response measures for further analyses of the data and we chose leverpresses because that measure had the greatest range.

Following tests with .25-sec interstimulus intervals, two rats continued testing as before but with .125- and 1.0-sec interstimulus intervals. One rat was tested with all 16 sequences, first with an interstimulus interval of 1.0 sec, then twice with an interval of .125 sec, then again with an interval of 1.0 sec. For the other rat, the tests with different interstimulus intervals were in the reverse order.

There were also tests with the complex contingencies as the intensities of both positive and negative ICS were changed, including a considerable number of tests of just one set of intensities. Only those intensities with at least two measurements are reported here.

RESULTS

The first series of tests were with the selected intensities of positive and negative ICS and used an interstimulus interval of .25 sec. The results of these tests appear in Table 1. Kendall's W calculated with the ranks based on mean presses for each subject = .81, $\chi^2 = 49$, $df = 15$, $p < .001$, indicating that the data of subjects agree with one another. According to Hays (1963), such an obtained result suggests that 81% of the variance of the ranks is accounted for by the separate contingencies, leaving only 19% of the variance to be accounted for by such factors as individual differences, ICS sites, day of testing, and other sources of "error."

It is apparent from inspection of Table 1 that the density of positive ICS (or lack of negative ICS) is a primary determiner of the acceptability of a particular contingency. When the contingency contained three positive ICSs, rats pressed rapidly. When the contingency contained three negative ICSs, rats hardly pressed. Also, it is apparent that sequentialness of the

Table 1
Ranks and Presses for Contingencies

Rank	Contingency	Mean Presses	Rank	Contingency	Mean Presses
1	++++	192.1	9	-+--+	53.5
2	+++-	188.0	10	+---	48.4
3	++-+	184.9	11	---++	41.1
4	+--+	126.4	12	-++-	31.1
5	+-+-	104.6	13	-+--	6.9
6	+--+	82.0	14	--+-	6.2
7	-+-+	76.1	15	----+	.4
8	-+++	73.5	16	-----	.0

Note—Mean presses used to rank contingencies are based on two measures with each contingency across four rats.

ICS is an important factor in determining pressing, e.g., + + + - is pressed for more than - + + +, and + + - - is pressed for more than - - + +.

Results with different interstimulus intervals appear in Table 2. The data of .25-sec intervals from the first series of tests for the two rats included in these tests also appear in Table 2. Regardless of interstimulus intervals, the resulting rank orders for the different contingencies were very similar. Kendall's W for ranks across the interstimulus intervals = .94 ($\chi^2 = 44$, $df = 15$, $p < .001$). Even though there is remarkable similarity among ranks across intervals, there are some differences. Sequentialness within a complex contingency seems a more potent variable with the longer interstimulus intervals because, with the 1.0-sec intervals, the eight highest ranked contingencies all begin with a positive ICS; whereas with the shorter intervals, contingencies beginning with a negative ICS are among the eight highest ranked.

Direct comparisons of mean presses at .125 sec and 1.0 sec with data of .25 sec are potentially confounded by the variable of continuance of testing and passage of time. Since, however, pressing for the all-positive contingency at the first tested intensity and intervals was nearly the same at the beginning and end of all testing, it may be concluded that continuance of testing had but minor, if any, effects. Since time of measurement session remained constant, but time the lever remained in the chamber was potentially longer when interstimulus intervals were .125 sec, it was possible for rats to press more with .125sec intervals than with the longer intervals; however, they did not. The rats might have pressed less with .125 sec because the positives combined to produce something approaching a continuous train of positive, and it is known that rats tend to prefer short discrete train durations (Reid, 1967).

Results of tests with different intensities of ICS appear in Table 3. Only those contingencies consistently shown to be among the last 12 ranks in previous tests were tested twice or more, and therefore only results with those contingencies appear in Table 3. Also included in Table 3 are data of tests with contingencies

Table 2
Ranks and Mean Presses With Different Interstimulus Intervals

Ranks and Mean Presses with Directional Signs						
Rank	.125-Sec Interval		.25-Sec Interval		1.0-Sec Interval	
	Contingency	Presses	Contingency	Presses	Contingency	Presses
1	++++	197	++++	267	++++	117
2	+++—	106	+++—	260	+++—	91
3	++—+	100	++—+	255	++—+	82
4	—+++	54	+—++	162	+—++	76
5	+—++	52	—+++	129	+—++	74
6	+—++	42	++—	115	++—	71
7	++—	41	+—++	108	+—+	61
8	—++—	37	+—+—	67	+—+—	45
9	+—+—	34	—++	39	—++	30
10	+—+—	23	—++—	30	—++—	24
11	—+—+	15	+—+—	29	—+—+	21
12	—++	12	—+—+	27	—++	19
13	—+—	5	—+—	9	—+—	13
14	—+—	3	—+—	1	—+—	11
15	—++	2	—++	0	—++	5
16	—+—	2	—+—	0	—+—	3

Note—Ranks of separate contingencies by mean leverpresses for Rats 554 and 557 with three interstimulus intervals at the intense values of positive and negative ICS (25 microA positive and 50 microA negative for Rat 554 and 35 microA positive and 50 microA negative for Rat 557).

of three positive ICSs with a negative intensity of zero. There are slight differences in ranks of contingencies if only one set of intensities are considered; however, the average ranks across tests with different intensities are essentially the same as the average ranks at the originally selected intensities. When zero intensity of "negative" ICS was programmed, the rate of pressing for the contingency was inversely related to the position of the blank stimulation, i.e., ++0 was pressed for most and 0+++ was pressed for least.

All raw data were inspected to compare the pressing generated in any one testing session in which $++--$ and $--++$ were tested, in which $+-$ and $-+$ were tested, in which $++$ and $--$ were tested, and in which $+-$ and $-+$ were tested.

were tested, and in which +++- and -+++ were tested. There were no instances in which --++ was pressed for more than +- --, nor was ---+ pressed for more than +---, and only one instance where -+++ was pressed for more than +++-, an instance with very low intensity of negative ICS.

Siegel (1956, p. 238), citing Kendall (1948), suggested that the best estimate of the "true" ranking of N objects is provided, when W is significant, by the order of the sums of ranks given that one accepts the criterion used to make the original ranks. Acceptance of the criterion with these data is easy because ranks are based on mean leverpresses which correlate highly with other measures

Table 3
Results With Different Intensities of ICS

[illegible]

of responsiveness and because measurements across rats correlate highly. Consequently, to get a "true" ranking of the contingencies, the mean rank was determined by averaging all rankings with the originally tested intensities regardless of interstimulus intervals. Each rank order was based on the mean pressing of at least two measurements for each contingency. The data of the four rats with .25-sec intervals and the data of two of those rats with .125- and 1.0-sec intervals make a total of eight rankings each, based on at least two measures for each of the 16 contingencies. Kendall's W for these ranks was .94 ($\chi^2 = 113$, $df = 15$, $p < .0000001$). The "true" ranks are changed only a little by averaging in data from results with different intensities (Table 4).

DISCUSSION

It is suggested that the ranks and values of the ranks are relatively stable across parameters of stimulation. Shifting the time between stimulations between .125 sec and 1 sec did not result in radical modification of the ranks. Manipulation of the intensity of the positive and negative stimulation, including some postexperimental and unsystematic changes of intensities, resulted in few dramatic shifts in preferences. Sometimes, for example, with a given test with different intensities of ICS, $-+++$ might yield higher pressing than $++--$, but the pressing rates were also very similar. In general, the pressing rates will approach one another as the negative intensity is lowered to zero, but the order of the contingencies will remain the same.

Data of Miller et al (1967) suggest that reducing the interval between stimulations to near zero would result in greater rejection of the predominantly negative stimulation. With zero intervals, supposedly, sequentialness would be of less importance (Miller et al, 1967). Along the same lines, as the interstimulus interval would become longer the more the first event would control pressing (Miller et al, 1967).

Since this was the first study of complex sequences as contingencies, there is little with which to compare the data. The data fit some common sense notions about how complex events would control behavior, i.e., it would be anticipated that the more positive the entire consequence, the more the pressing for the complexity. Knowing that there is a gradient of delay of reinforcement, one would anticipate that the first event would be more potent than subsequent events of the sequence. In general, the data coincide with common sense and with data of one and two affective events as contingencies (Miller et al, 1967). Inasmuch as ideas derived from results of studies of one and two affective events are widely generalizable, it is anticipated that these results also have generality.

The data are seen as an extension of the work of Young (1967) and N. E. Miller (1959). These data complement Young's in that hedonic values are derived

Table 4
Summary of Data

Contingency	Mean Rank	Mean Rank With Data of Varied Intensities
++++	1.5	
+++—	2.2	
++—+	2.9	
+—++	4.6	
++—	5.9	5.1
+—+	6.1	6.5
—+++	7.6	7.5
+—+	7.8	7.7
—++	8.8	9.0
—++	9.8	9.9
—+—	10.6	10.0
+—	11.2	11.2
—+—	13.8	13.7
—+—	14.2	14.2
—+—	14.6	14.5
—+—	15.2	15.4

Note—The left column of average ranks is based on the data of first tests with four rats, plus the additional data of tests with .125-sec and .25-sec interstimulus intervals, making a total of eight "judgments" of each contingency, with each judgment based on the mean of two measurements. Data of right column include tests with different intensities, hence some values are from 11 judgments.

for sequences of affective events. These data can be thought of as extensions of Miller's conflict model but with more than just one positive and one negative event as consequences for a bit of behavior. Applied contingency management is frequently criticized because the applied rules are said to be derived from paradigms that are too simple. This study, however, suggests that increasing the complexity of the contingencies does not invalidate the general principles of assessing and manipulating the net positive or negative events that closely follow a behavior as methods for understanding and controlling the frequency of that behavior.

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