SHRIMP - BEHAVIOR STUDIES UNDERLYING THE DEVELOPMENT OF THE ELECTRIC SHRIMP-TRAWL SYSTEM

by

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ABSTRACT

Observation of how shrimp react to different amounts of electrical energy and repetition rates of pulsating direct current in the laboratory and the field provided information on the electric characteristics needed for an effective electric shrimp trawl.

The laboratory studies showed the electric threshold voltage of shrimp oriented at different positions to the electrodes and the effect of different voltages on the shrimp's responses. Threshold voltages were affected by the animal's position relative to the electric field, and the shrimp's reaction increased with an increase in voltage.

The field studies provided information on the electrical output needed to force burrowed shrimp out of the substrate. Capacitor-discharge pulses of 4 per second with a potential of 3.0 volts or more across 100 millimeters parallel to the electric field were best for forcing shrimp out of the types of bottom on some of the commercial shrimping grounds in the Eastern Gulf of Mexico.

CONTENTS

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INTRODUCTION

Commercial fishing for brown and pink shrimp, *Penaeus aztecus* and *P. duorarum*, is now restricted to trawling at night because these species stay in their burrows during the day. This restriction causes the fleet to remain idle during daylight, or roughly one-half of the time. If shrimp could be caught during the daytime, manpower, vessels, and equipment could be used more efficiently.

Higman (1956) found that pulsating direct current caused a pink shrimp to hop at each pulse. A sharp vertical jump was caused by an involuntary contraction of the shrimp's abdominal muscle. In laboratory studies, Kessler (1965) found that shrimp could be effectively stimulated with pulsating direct current of low voltage. Because of the low-energy drain of pulsating direct current in sea water, as compared with that of alternating current, the use of an electric trawl system to harvest burrowed shrimp appeared possible.

Before a practical electric shrimp-trawl system could be designed and developed, however, information was needed on the optimum electric characteristics required to force shrimp out of the substratum to a height suitable for capture with trawls. The purpose of the studies reported in this paper, therefore, was to determine the optimum electrical requirements necessary for the development of an electric shrimp-trawl system. To achieve this purpose, I carried out two studies: one in the laboratory; the other in the field.

I. LABORATORY STUDIES

The laboratory studies were concerned with determining threshold voltages and the effect of high- and low-voltage stimulation.

A. DETERMINING THRESHOLD VOLTAGES

Kessler (1965) studied the minimum voltage necessary to produce a hopping response in pink shrimp positioned parallel or perpendicular to the electric field. His findings indicated that threshold voltage varied according to the temperature of the water, size of the shrimp, width of the pulse, and position of the experimental animal relative to the electric field.

1. Procedure

Experimental animals were caught by trawling in St. Andrews Bay, Florida. The trawl tows were about 10 minutes long to minimize injury to the shrimp. After capture, the shrimp were held in tanks of circulating sea water before being transported to the laboratory. At the laboratory, they were held in live cages for at least 24 hours prior to experimentation to allow for detection and elimination of injured animals. Random samples of shrimp in "good physical condition" (that is, not injured; not obviously infected with protozoan microsporidians; and not confused or disoriented) were used in each experiment. These animals ranged from 73 to 110 millimeters total length.

The laboratory studies were carried out in 190-liter plexiglass aquariums containing water at 20° C. and at salinities ranging from 28 to 30 parts per thousand.

An electric system similar to that described by Kessler (1965) was used because this type of system provided a uniform electric field in the aquariums. This system has a capacitor-discharge stimulation pulse that can be monitored from the center of the aquarium. A pulse generator produced electric pulses that were applied through two Monel-metal electrodes[1], 46 centimeters square by 1 millimeter thick, mounted at opposite ends of the aquarium. Pulse characteristics were tested by means of a pair of pickup probes made from two 3-millimeter-diameter bronze rods, spaced 5 centimeters apart and insulated so that only

[1] Trade names are mentioned merely to simplify the description of the experimental equipment; no endorsement is implied.

the bottom 10 millimeters of each rod was exposed. These pulse characteristics were displayed on an oscilloscope showing a graph of voltage versus time.

To determine threshold voltages, I held the shrimp immobile in a predetermined position relative to the electric field. Each shrimp was placed in a nylon-mesh tube in the center of the aquarium, and the tube was positioned at 0°, 15°, 30°, 45°, 60°, or 75° in relation to the electrodes. The voltage was increased slowly until the shrimp hopped. The voltage at the time of the hop was called the threshold voltage — it was read from the oscilloscope and recorded.

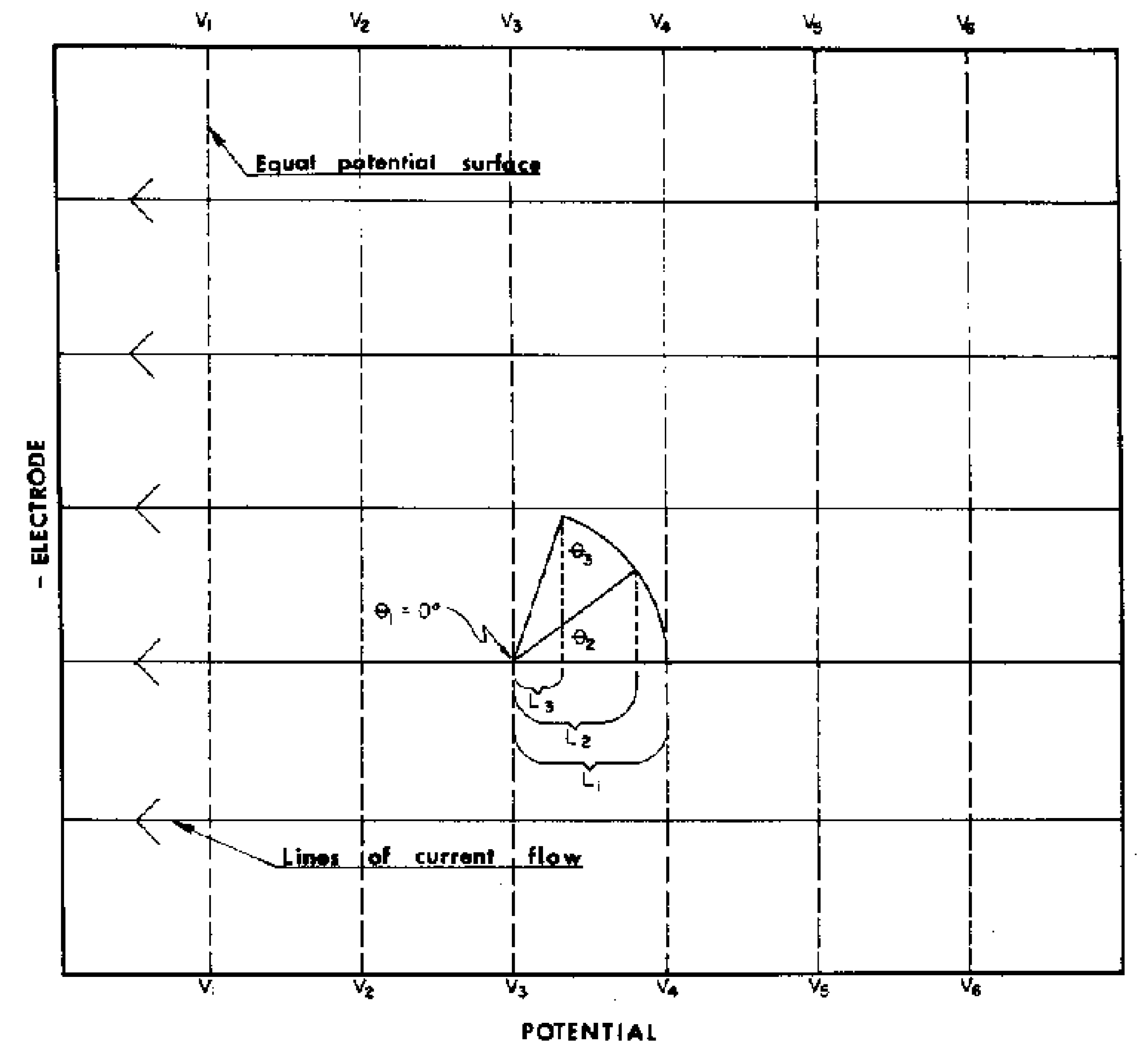

Figure 1.—Uniform electric field showing hashed lines of equal potential surfaces, solid lines of current flow, angle of theta, and the relation between L length of an object at various angles of theta and lines of equal potential (V = voltage).

2. Results

Figure 1 shows the relation between length of shrimp at various angles of theta and lines of equal potential or, in other words, the voltage drop across the length of the animal's body perpendicular to the equal potential surfaces. These findings indicate a direct relation between threshold voltages or lines of equal potential and positions of the shrimp in the electric field (Table 1). Slightly more voltage is required to produce a response in shrimp facing the negative electrode as compared with that required to produce a response in shrimp facing the positive electrode. This polarity effect was observed for all angles of theta tested.

Threshold voltages are lowest when shrimp are parallel to the electric field (theta equals zero) and are facing the positive electrode. As the angle of the animal increases from 0° to 75°, the threshold voltage increases. Average response voltages for shrimp oriented at various angles to the field are up to four times greater than are threshold voltages for shrimp parallel to the field. Shrimp at 45° to the field require only 1.4 times as much voltage to elicit a hopping response as those parallel to the field, whereas those at 75° to the field require about four times as much voltage to be stimulated. This relation can be expressed as:

$$\text{Threshold voltage at angle } \theta = \frac{\text{threshold voltage at } 0^\circ}{\text{cosine } \theta}$$

where 0° is an angle parallel to the electric field and perpendicular to the electrodes.

The theoretical voltages for shrimp oriented at angles of 0°, 15°, 30°, 45°, 60°, and 75° were calculated by the above formula

Table 1.—Threshold voltage for pink shrimp

Orientation of shrimp in relation to electrodes	Data for shrimp facing positive electrode				Data for shrimp facing negative electrode			
	Shrimp in sample	Potential difference			Shrimp in sample	Potential difference		
		Mean	Standard deviation	Theoretical		Mean	Standard deviation	Theoretical
Degrees	*Number*	*Voltage drop per 5 cm. sea water*			*Number*	*Voltage drop per 5 cm. sea water*		
0	30	0.16	0.04	0.16	20	0.20	0.04	0.29
15	30	0.17	0.04	0.17	20	0.31	0.05	0.30
30	30	0.18	0.04	0.18	20	0.35	0.06	0.33
45	30	0.23	0.06	0.23	20	0.42	0.09	0.41
60	30	0.34	0.09	0.32	20	0.60	0.13	0.58
75	30	0.56	0.15	0.61	19	0.96	0.24	1.12

(Table 1). The agreement between the actual and theoretical threshold voltages justified acceptance of the above relation for the different positions tested.

This relation is identical to the physical law of electricity (Brophy, 1966) that states that the voltage drop between two points in an electric field depends upon the distance between these points as measured along the lines of current flow (Figure 1). In this instance, the lines of current flow are perpendicular to the electrodes. As the angle of the shrimp relative to the lines of equal potential increases, the voltage drop across the animal decreases with the cosine of the angle, which implies that electric stimulation occurs from one end of the shrimp's body to the other. We can, therefore, conclude that the voltage felt by shrimp varies not only with its orientation but also with its total length. Hence, as the length of the animal increases, the amount of voltage felt also increases, according to the following:

$$L \cos \theta = \Delta V$$

where L = total length of the animal and Δ V = voltage drop across the animal.

B. DETERMINING EFFECT OF HIGH- AND LOW-VOLTAGE STIMULATION

Further laboratory studies were made to ascertain how different voltages would affect the reactions of shrimp.

1. Procedure

Experimental animals were caught and handled in the same manner as was described in the preceding experiment on the determination of threshold voltages.

To determine the effect of different voltages on the hopping response of electrically stimulated shrimp, I first applied the threshold voltage and then applied 7.0 volts to each experimental animal. The height each shrimp jumped was measured with a ruler and recorded.

2. Results

This laboratory study to ascertain the effect of voltage on the response of shrimp indicates that the height jumped above the bottom is greater when the shrimp are stimulated at 7.0 volts than when they are stimulated at the threshold voltages (Table 2).

Table 2.—Relation between length of shrimp and their response to electric potential

Length of shrimp	Shrimp in sample	Average height shrimp jumped when stimulated at:	
		0.16 volt	7 volts
Millimeters	*Number*	*Centimeters*	*Centimeters*
70- 79	20	6.0	8.1
80- 89	45	8.9	12.2
90- 99	24	7.9	11.4
100-109	11	7.6	14.1
Total	100	---	----
Average	---	7.9	11.4

Also a direct relation appears to exist between shrimp size and height jumped for animals stimulated with high voltage — the larger the animal, the higher it jumps. At threshold voltage, however, no such relation appears to exist; the height jumped does not increase with an increase in the length of the shrimp.

II. FIELD STUDIES

In the field studies, which were to provide the engineering staff at the Base with sufficient data to enable them to design an electric shrimp-trawl system, it was desirable to determine the optimum electric stimulus necessary to "deburrow" (to evacuate the burrow) shrimp from the major kinds of bottom found on commercial shrimp grounds in the Eastern Gulf of Mexico. These studies were divided into two parts: The first determined the optimum pulse rate and voltage needed to force brown and pink shrimps out of white sand. The second evaluated the efficacy of the optimum combination of electric characteristics necessary for deburrowing shrimp from substrata found on the Cape San Blas, Florida;

St. Andrews Bay, Florida; Dry Tortugas, Florida, grounds; and fishing grounds of the State of Mississippi.

A. RESPONSES OF ELECTRICALLY STIMULATED SHRIMP BURROWED IN SAND

Part A of the field studies was carried out at Panama City, Florida.

1. Procedure

Shrimp used in the experiments were caught with trawls towed for less than 10 minutes. The shrimp were measured, placed in a tank of circulating sea water, and held for at least 24 hours. Shrimp in "good physical condition," ranging from 90 to 200 millimeters total length, were transferred from the tank to a wire cage on the floor of the sea, where they were held until needed.

SCUBA divers placed individual shrimp in the bottomless cages in which the shrimp could burrow into the sea bottom. The burrowed shrimp were then covered with an electrode array that was powered by a surface pulse generator through a No. 14-gage wire covered with neoprene. This generator provided pulses of the capacitor-discharge type. The array had a pair of bronze electrodes, 10 centimeters long by 1.9 centimeters wide, spaced 28 centimeters apart. Attached to the electrodes was a timing-event light, which came on simultaneously with the electric current. A pair of adjustable pickup probes, which were made of 3-millimeter-diameter bronze rods insulated except for the center 10 millimeters of each, was located between the electrodes. The probes were placed at the head and tail of each animal to check the pulse characteristics. Pulse rate, pulse width, and voltage applied to the shrimp were displayed on an oscilloscope on the vessel that was being used. Because Kessler (1965) found that a pulse width of 140-microseconds was satisfactory for stimulating shrimp, this pulse width was used in all the field experiments. Pulse rate was held constant during each experiment. Since the voltage for each shrimp is a function of its length, each animal could not be subjected to an exact predetermined voltage. Thus, an average voltage is given for each experimental group (Table 3).

Table 3.—Summary of experiments in which burrowed shrimp were stimulated electrically

Group	Shrimp tested		Location of test	Type of sediment	Electrical stimulation data		
					Electrode toward which shrimp faced	Pulse rate	Average potential across shrimp's body
No.	*No.*	*Species*				*Pulses/sec.*	*Volts*
1	52	Pink	Panama City	Sand[1]	+	3	0.7
2	55	Pink	Panama City	Sand	+	3	3.8
3	54	Pink	Panama City	Sand	+	4	5.8
4	50	Pink	Panama City	Sand	+	5	3.2
5	49	Pink	Panama City	Sand	+	4	3.2
6	50	Brown	Panama City	Sand	–	4	5.2
7	47	Brown	Panama City	Sand	–	4	3.3
8	64	Brown	Panama City	Sand	–	6	3.7
9	21	Brown	Panama City	Sand	–	3	0.9
10	59	Brown	Panama City	Sand	–	4	1.1
11	34	Brown	Panama City	Sand	–	5	1.1
12	27	Brown	Panama City	Sand	+	5	1.1
13	48	Brown	Panama City	Sand	+	6	0.9
14	52	Brown	Panama City	Sand	+	5	1.6
15	62	Brown	Cape San Blas	Sand[2]	+	4	3.6
16	63	Brown	Cape San Blas	Sand[3]	+	4	3.6
17	10	Brown	Cape San Blas	Sand[3]	+	5	3.2
18	59	Brown	St. Andrews Bay	Silty sand	+	4	3.6
19	24	Pink	Dry Tortugas	Sand	+	3	4.4
20	20	Pink	Dry Tortugas	Sand	+	3	0.8
21	89	Pink	Dry Tortugas	Sandy silt	+	4	3.3
22	34	Pink	Off the State of Mississippi	Sand-silt-clay	+	4	3.3

[1] 98 percent sand and 2 percent silt and clay.
[2] 99 percent sand and 1 percent silt.
[3] 83 percent sand, 11 percent silt, and 6 percent clay.

Owing to the difficulty in obtaining accurate measurements under water, motion picture photography was used to record the escape reactions of stimulated shrimp. A SCUBA diver operated a hand-held 16-millimeter movie camera in a watertight housing to record the action (Figure 2). The timing-event light provided the time base for each observation. When used in combination with the motion-picture film speed of 32 frames per second, the data obtained by means of the timing-event light permitted the escape reactions of stimulated shrimp to be measured with an accuracy of 0.03 second. The checkered grid shown in Figure 2 was used for measuring the lateral and vertical escape movements of the shrimp. Film analyses of the escape sequences provided data on the time required for shrimp to evacuate

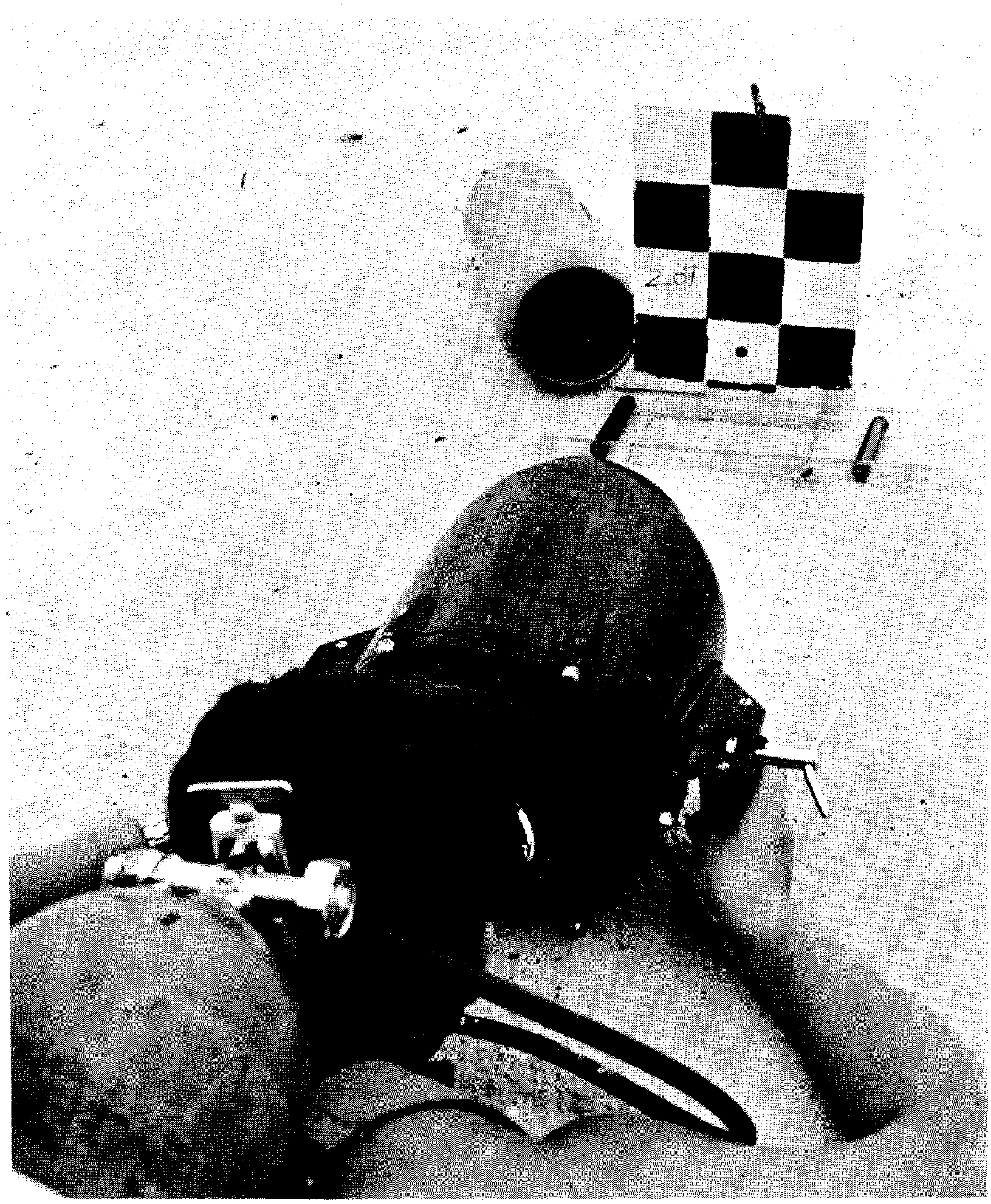

Figure 2.—SCUBA diver filming electrically stimulated shrimp for time and motion studies.

their burrows and jump to heights of 75, 150, 225, or 300 millimeters above the bottom.

Before the optimal stimulation pulse rates and voltages for use with an electric trawl could be determined, knowledge on specific characteristics of the trawl design and performance was needed. The width of the electric field at the center of the net opening, as shown in Figure 3, and the speed at which the net travels over the bottom will determine the minimum time required to force shrimp out of the substratum, whereas the height of the footrope above the bottom will be the minimum height the shrimp must jump to be captured by the trawl. I anticipated that the electric field of the prototype trawl would range in width from 2.1 to 2.4 meters, at the center of the trawl, and that the footrope would not be higher than 75 millimeters above the bottom when traveling at a speed of 4.6 kilometers per hour. Between 1.66 and 1.90 seconds is needed for a trawl with a 2.1- to 2.4-meter wide electric field to pass a given point when traveling at this speed. Thus, if shrimp could be forced out and off the bottom to a height of 75 millimeters within 1.66 or 1.90 seconds, they would probably be captured by the trawl.

To evaluate the effectiveness of the pulse characteristics tested, I measured, by means of film sequences, the reaction times for the shrimp to deburrow and jump heights of 75 and 150 millimeters. I compared pulse characteristics with the following responses: (1) proportion of shrimp deburrowing; (2) proportion of shrimp jumping heights of 75 and 150 millimeters, respectively, within 1.66 and 1.90 seconds; (3) average height shrimp jumped within 1.90 seconds; and (4) rate at which shrimp jumped a height of 75 millimeters.

Optimum pulse characteristics for shrimp burrowed in sand were determined by combinations of pulse rates and voltages inducing the greatest percentage of shrimp to perform the above-mentioned escape reactions in the shortest time.

Also determined were the physical characteristics of the various sea bottoms on which the studies were made. Soil from various sub-

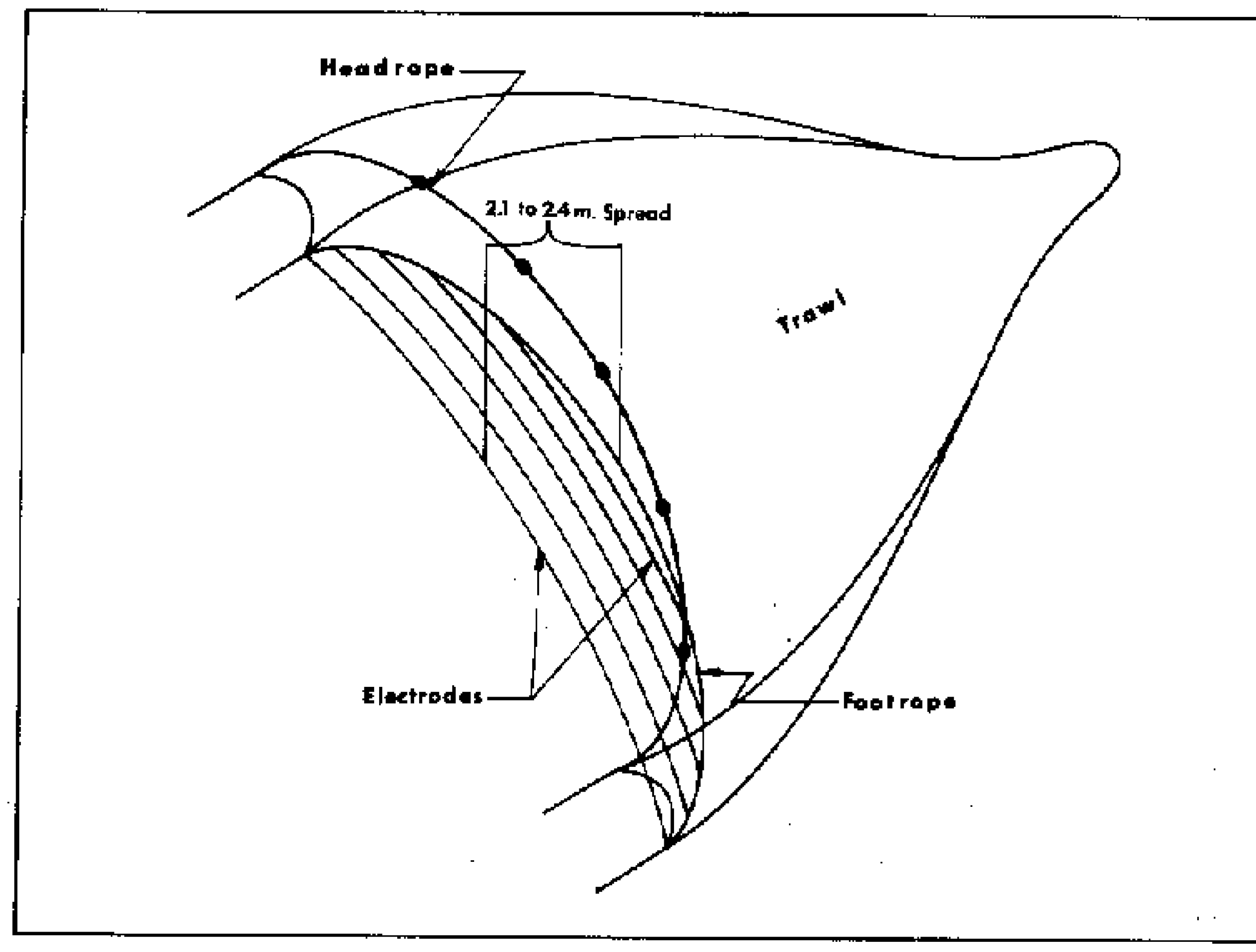

Figure 3.—Diagram of shrimp trawl rigged with the electric system, showing terms used.

strata was sampled and analyzed for particle size composition, by use of sieves and soil hydrometers (Krumbein and Pettijohn, 1938). The Wentworth scale of particle type and Shepard's (1954) sand-silt-clay terminology were followed. Bottom salinities and temperatures were taken with a portable salinometer at each station.

2. Results

Analysis of the escape reactions of the study animals provided information on the optimum electric characteristics necessary to deburrow shrimp from a bottom classified as sand (that is, 98-percent sand) near Panama City (Table 3). The time-frequency distributions of specific escape reactions for Groups 1 to 14 in Tables 4, 5, and 6 yielded data on the optimum pulse rate and voltage for forcing brown and pink shrimps out of white sand.

The escape reactions of brown and pink shrimps from a sand substratum were compared to determine whether or not these species behaved differently when stimulated electrically. By the chi-square contingency test, analyses were made of the proportion of animals of each species that deburrowed within 1.66 seconds and the numbers of brown and pink shrimps that jumped 75 millimeters high within the same time limit. The results showed that the responses of the two species were essentially the same (Table 7). Therefore, I concluded that the escape responses for these

Table 4.—Time-frequency distribution of burrowed shrimp deburrowing when stimulated electrically

Response time	Shrimp that deburrowed in Group:																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	1	4	3	4	3	11	4	11	1	4	1	2	4	5	17	3	1	53	1	--	82	21
0.31-0.59	5	8	23	11	12	16	6	23	1	10	4	2	5	6	37	10	--	4	5	--	5	11
0.62-0.90	9	8	7	23	16	11	14	15	5	18	10	5	4	9	6	16	2	1	4	1	--	2
0.94-1.22	5	10	12	6	11	7	7	5	6	9	3	3	6	9	1	7	1	--	2	3	--	--
1.25-1.53	7	7	4	6	3	1	7	3	1	6	3	4	7	1	--	6	4	--	3	2	--	--
1.56-1.84	6	2	2	--	3	4	3	1	1	3	3	--	1	3	--	5	2	--	3	1	1	--
1.87-2.15	5	4	2	--	1	--	1	1	3	1	3	2	2	3	--	7	--	--	3	2	--	--
2.18-2.46	2	1	--	--	--	--	3	1	--	1	--	3	3	3	--	5	--	--	2	1	1	--
2.50-2.78	1	5	--	--	--	--	--	1	1	1	--	3	2	1	--	--	--	--	--	3	--	--
2.81-3.09	1	--	--	--	--	--	--	--	--	1	--	--	3	1	--	--	--	--	1	2	--	--
3.12-3.40	--	--	--	--	--	--	--	--	--	--	--	2	1	--	--	--	--	--	--	--	--	--
3.43-3.71	--	1	--	--	--	--	--	--	1	2	1	--	3	--	--	--	--	--	--	1	--	--
3.74-4.02	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--
4.06-4.34	2	1	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--
4.37-4.65	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
>4.96	1	1	--	--	--	--	--	2	--	--	1	--	2	1	--	--	--	--	--	--	--	--
Number responding	45	52	54	50	49	50	45	63	20	56	29	26	44	44	61	59	10	58	24	16	89	34
Number not responding	7	3	0	0	0	0	2	1	1	3	5	1	4	8	1	4	0	0	0	4	0	0
Total shrimp	52	55	54	50	49	50	47	64	21	59	34	27	48	52	62	63	10	58	24	20	89	34
Percent responding within 1.66 seconds	56	69	91	100	92	96	85	91	71	80	65	59	56	60	98	70	90	100	71	30	98	100
Percent responding within 1.90 seconds	67	71	96	100	98	100	89	91	81	86	71	59	63	63	98	78	100	100	79	35	99	100

Table 5.—Time-frequency distribution of burrowed shrimp jumping 75 millimeters high when stimulated electrically

Response time	Shrimp that jumped 75 millimeters in Group:																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	1	2	2	2	2	7	2	10	1	2	--	1	3	3	10	2	1	43	1	--	71	12
0.31-0.59	3	6	23	7	10	19	6	18	1	8	2	2	3	7	40	5	--	14	3	--	17	15
0.62-0.90	8	7	5	25	11	11	9	17	2	12	9	1	2	7	9	16	1	1	4	1	--	6
0.94-1.22	3	9	10	7	10	6	12	7	2	15	2	3	3	6	--	10	2	--	2	2	--	--
1.25-1.53	4	6	7	5	7	2	7	2	1	4	4	5	3	2	1	5	3	--	1	3	--	--
1.56-1.84	2	5	3	1	3	3	5	--	4	5	2	--	3	5	--	7	2	--	3	1	--	1
1.87-2.15	7	2	1	--	3	1	1	--	3	4	1	1	2	6	--	5	1	--	6	2	1	--
2.18-2.46	4	1	--	--	--	--	3	1	1	1	--	1	3	--	--	8	--	--	--	1	--	--
2.50-2.78	1	1	--	--	--	1	--	--	--	--	1	--	2	--	--	1	--	--	2	1	--	--
2.81-3.09	--	2	--	--	--	--	--	--	1	1	--	1	--	1	--	--	--	--	--	1	--	--
3.12-3.40	--	--	--	--	--	--	--	--	1	--	--	1	2	--	--	--	--	--	1	1	--	--
3.43-3.71	--	--	--	--	--	--	--	--	1	1	--	1	2	--	--	--	--	--	--	--	--	--
3.74-4.02	1	1	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 5—Continued

Response time	Shrimp that jumper 75 millimeters in Group:																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
4.06-4.34	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4.37-4.65	1	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--	--
>4.96	--	2	1	--	--	--	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--
Number responding	36	46	52	47	46	50	45	57	18	53	22	17	29	38	60	59	10	58	23	14	89	34
Number not responding	16	9	2	3	3	0	2	7	3	6	12	10	19	14	2	4	0	0	1	6	0	0
Total shrimp	52	55	54	50	49	50	47	64	21	59	34	27	48	52	62	63	10	58	24	20	89	34
Percent responding within 1.66 seconds	38	60	87	94	86	92	79	84	52	71	50	44	31	54	97	70	90	100	63	40	99	100
Percent responding within 1.90 seconds	50	64	89	94	90	98	87	84	52	79	55	44	35	60	97	75	100	100	71	45	99	100

Table 6.—Time-frequency distribution of burrowed shrimp jumping 150 millimeters high when stimulated electrically

Response time	Shrimp that jumped 150 millimeters in Group:																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	--	--	--	1	--	4	1	5	--	--	--	--	1	--	3	1	--	16	1	--	29	--
0.31-0.59	1	1	15	2	8	12	5	14	--	2	1	--	--	3	31	4	--	21	2	--	23	19
0.62-0.90	1	6	6	13	1	10	3	10	1	7	--	2	4	1	7	3	1	5	2	--	5	4
0.94-1.22	1	5	6	7	6	9	6	5	1	5	1	--	--	5	5	4	1	2	3	1	2	3
1.25-1.53	--	5	5	2	6	3	6	1	1	5	3	--	--	2	1	7	1	--	2	1	2	2
1.56-1.84	1	3	2	1	2	1	1	--	--	1	--	--	3	2	1	8	--	--	3	2	--	--
1.87-2.15	1	5	3	1	2	2	--	--	3	2	--	--	--	4	--	4	2	--	5	2	--	1
2.18-2.46	4	--	--	--	1	--	2	--	2	4	1	--	--	--	--	2	--	--	--	--	--	--
2.50-2.78	--	2	--	--	--	1	--	1	--	--	--	--	1	1	--	1	--	--	3	--	1	--
2.81-3.09	--	1	--	--	--	--	--	--	--	--	--	1	--	--	--	1	--	--	--	--	--	--
3.12-3.40	2	1	--	--	--	--	--	--	--	--	--	--	--	3	--	--	--	--	--	--	--	--
3.43-3.71	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
3.74-4.02	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	--
4.06-4.34	1	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--
4.37-4.65	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
>4.96	--	--	1	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	1	--	--
Number responding	12	30	38	27	26	42	24	37	8	27	6	3	10	22	48	35	5	44	21	9	62	29
Number not responding	40	25	16	23	23	8	23	27	13	32	28	24	38	30	14	28	5	14	3	11	27	5
Total shrimp	52	55	54	50	49	50	47	64	21	59	34	27	48	52	62	63	10	58	24	20	89	34
Percent responding within 1.66 seconds	6	33	63	50	45	76	45	55	14	32	15	7	13	23	77	40	30	76	50	10	69	82
Percent responding within 1.90 seconds	8	38	63	52	47	76	45	55	14	36	15	7	17	25	77	43	30	76	54	20	69	82

Table 7.—Comparison between responses of brown and pink shrimps when stimulated with more than 5 volts at 4 pulses per second

Shrimp response	Shrimp that:			
	Evacuated burrow within 1.66 seconds		Jumped 75 millimeters high within 1.66 seconds	
	Pink	Brown	Pink	Brown
	No.	*No.*	*No.*	*No.*
Responded	49	48	47	46
Did not respond	5	2	7	4
Total shrimp	54	50	54	50
Chi-square	1.143		0.676	
Degree of freedom	1		1	
Probability	0.25-0.10		0.50-0.25	

Note: These data are from Groups 3 and 6 (Table 3).

two species were sufficiently similar so that such information could be pooled.

A comparison was made of the escape reactions of shrimp burrowed in sand facing either pole, because Kessler (1965) found that threshold voltages for shrimp facing the anode were different from those for shrimp facing the cathode. Analysis by the chi-square contingency test showed no significant difference at the 5-percent level of probability in the escape responses (Table 8). This finding

Table 8.—Comparison between responses of shrimp facing positive or negative electrode when stimulated with 1.1 volts at 5 pulses per second

Shrimp response	Shrimp that:			
	Evacuated burrow within 1.66 seconds when they faced the:		Jumped 75 millimeters high within 1.66 seconds when they faced the:	
	+ electrode	—electrode	+ electrode	—electrode
	No.	*No.*	*No.*	*No.*
Responded	16	22	12	17
Did not respond	11	12	15	17
Total shrimp	27	34	27	34
Chi-square	0.273		0.186	
Degree of freedom	1		1	
Probability	0.75-0.50		0.75-0.50	

Note: These data are from Groups 11 and 12 (Table 3).

permitted combining experimental groups facing either electrode. The animal's position relative to either pole was not considered important in altering the behavior of the experimental shrimp.

To facilitate analyses, I combined Groups 1 and 9; 3 and 6; 5 and 7; and 11, 12, and 14 because of their similarity in the stimulation pulse rates and voltages. Time-frequency distributions of the three escape criteria for these combined experimental groups are listed in Table 9.

Analysis of the escape responses from the first 14 groups indicates that pulse rate and voltage affect the time required for shrimp burrowed in white sand to deburrow and jump heights of 75 and 150 millimeters. The percent activity (that is the proportion of animals deburrowing within 1.90 seconds) is greater for groups exposed to high-voltage stimulation (more than 3.0 volts) than for those exposed to low-voltage stimulation (Figure 4). With high-voltage stimulation, activity was highest at 5 pulses per second, slightly less at 4 and 6 pulses per second, and lowest at 3 pulses per second. With low-voltage stimulation, the best pulse rate was 4 pulses per second because activity was much more depressed at repetition rates of 3, 5, and 6.

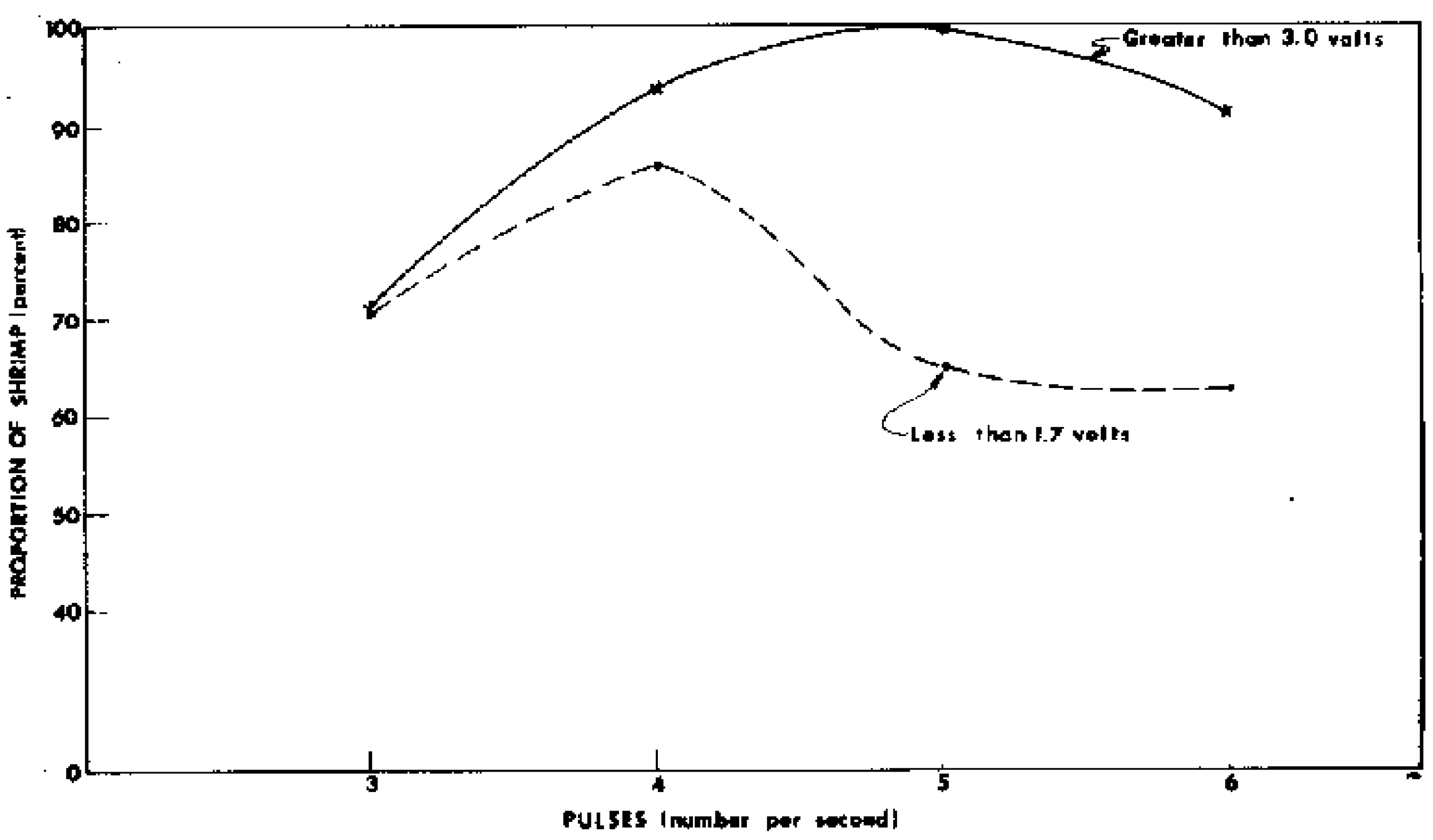

Figure 4.—Relation between pulse rate and percentage of shrimp deburrowing from white sand within 1.90 seconds.

The proportion of shrimp jumping 75 millimeters high within 1.90 seconds indicates the optimal characteristic to be high voltage at 4 or 5 pulses per second (Figure 5). The percent activity was more than 80 percent for these pulse characteristics but was less than 80 percent for other stimulation pulse rates and voltages.

A similar relation can be seen for the proportion of shrimp jumping 150 millimeters high within 1.90 seconds (Figure 6). The

Table 9.—Time-frequency distribution of combined groups depicting rate of deburrowing and jumping 75 and 150 millimeters high

Response time	Shrimp that: Deburrowed in:				Jumped 75 millimeters in:				Jumped 150 millimeters in:			
	Groups 1 & 9	Groups 3 & 6	Groups 5 & 7	Groups 11, 12, & 14	Groups 1 & 9	Groups 3 & 6	Groups 5 & 7	Groups 11, 12, & 14	Groups 1 & 9	Groups 3 & 6	Groups 5 & 7	Groups 11, 12, & 14
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	2	14	7	8	2	9	4	4	--	4	1	--
0.31-0.49	6	39	18	12	4	42	16	11	1	27	13	4
0.62-0.90	14	18	30	24	10	16	20	17	2	16	4	1
0.94-1.22	11	19	18	15	5	16	22	11	2	15	12	6
1.25-1.53	8	5	10	8	5	9	14	11	1	8	12	5
1.56-1.84	7	6	6	6	6	6	8	7	1	3	3	2
1.87-2.15	8	2	2	8	10	2	4	8	4	5	2	4
2.18-2.46	2	--	3	6	5	--	3	1	6	--	3	1
2.50-2.78	2	--	--	4	1	1	--	1	--	1	--	1
2.81-3.09	1	--	--	1	1	--	--	2	--	--	--	1
3.12-3.40	--	--	--	2	1	--	--	1	2	--	--	3
3.43-3.71	1	--	--	1	1	--	--	1	--	--	--	--
3.74-4.02	--	--	--	--	1	--	--	--	--	--	--	--
4.06-4.34	2	--	--	2	1	--	--	--	1	--	--	--
4.37-4.65	--	1	--	--	1	--	--	1	--	--	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--
>4.96	1	--	--	2	--	--	--	--	--	--	--	--
Number responding	65	104	94	99	54	102	91	77	20	80	50	31
Number not responding	8	0	2	14	19	2	5	36	53	24	46	82
Total shrimp	73	104	96	113	73	104	96	113	73	104	96	113
Percent responding within 1.66 seconds	60	93	89	61	42	89	82	50	8	69	45	9
Percent responding within 1.90 seconds	71	98	94	65	51	93	86	55	10	69	46	9

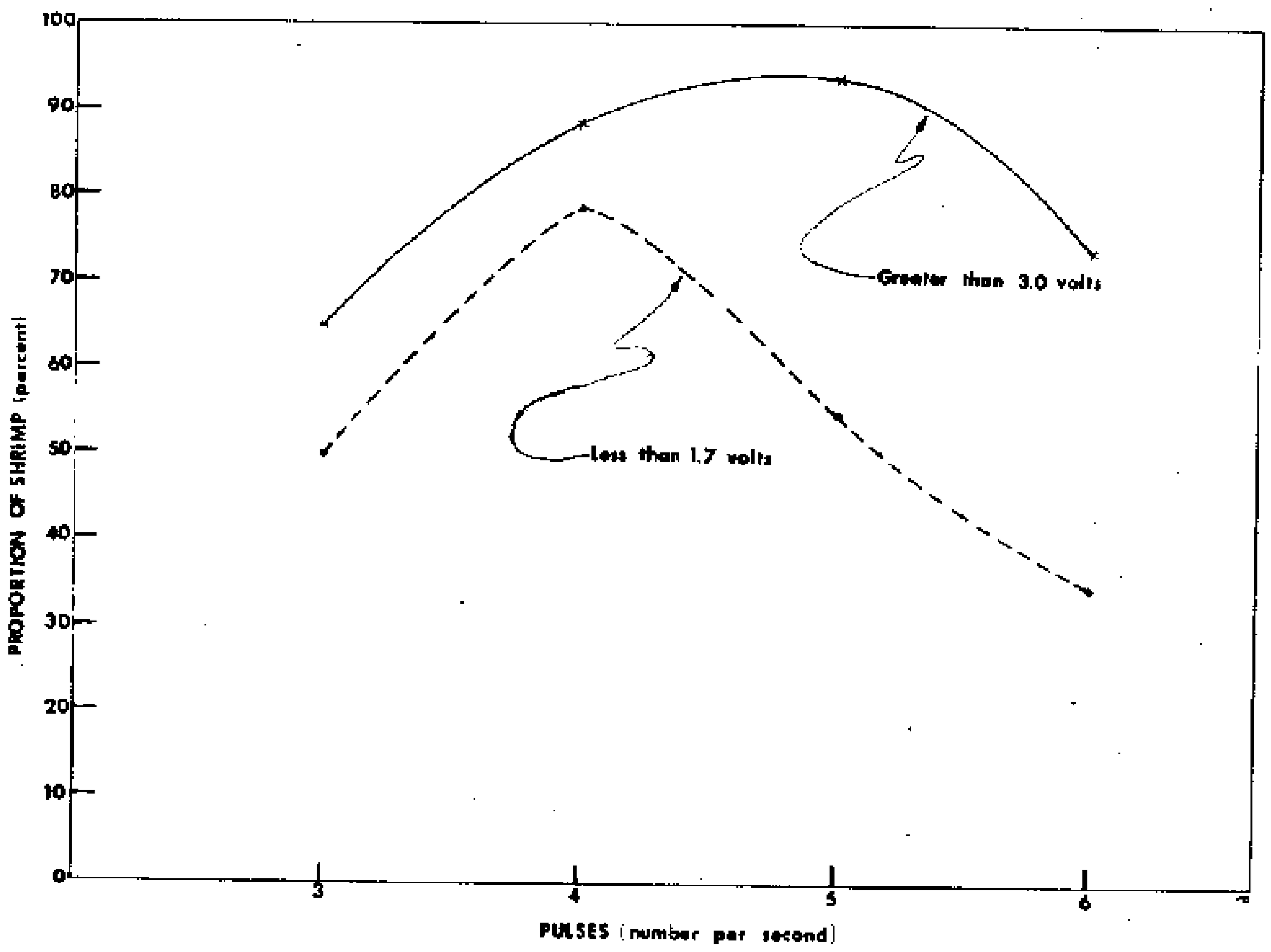

Figure 5.—Relation between pulse rate and percentage of shrimp jumping 75 millimeters high within 1.90 seconds.

highest activity is again at a high voltage combined with repetition rates between 4 and 6 pulses per second. The activity level was reduced at low-voltage stimulation.

The relation between percentage activity and the three escape criteria for various pulse characteristics is shown in Figures 7, 8, 9, and 10. Percentage activity and the three escape criteria show a curvilinear relation between the percent deburrowing and the percent jumping 75 and 150 millimeters high within 1.90 seconds. As would be expected, the proportion of shrimp that deburrow within 1.90 seconds is greater than the proportion that

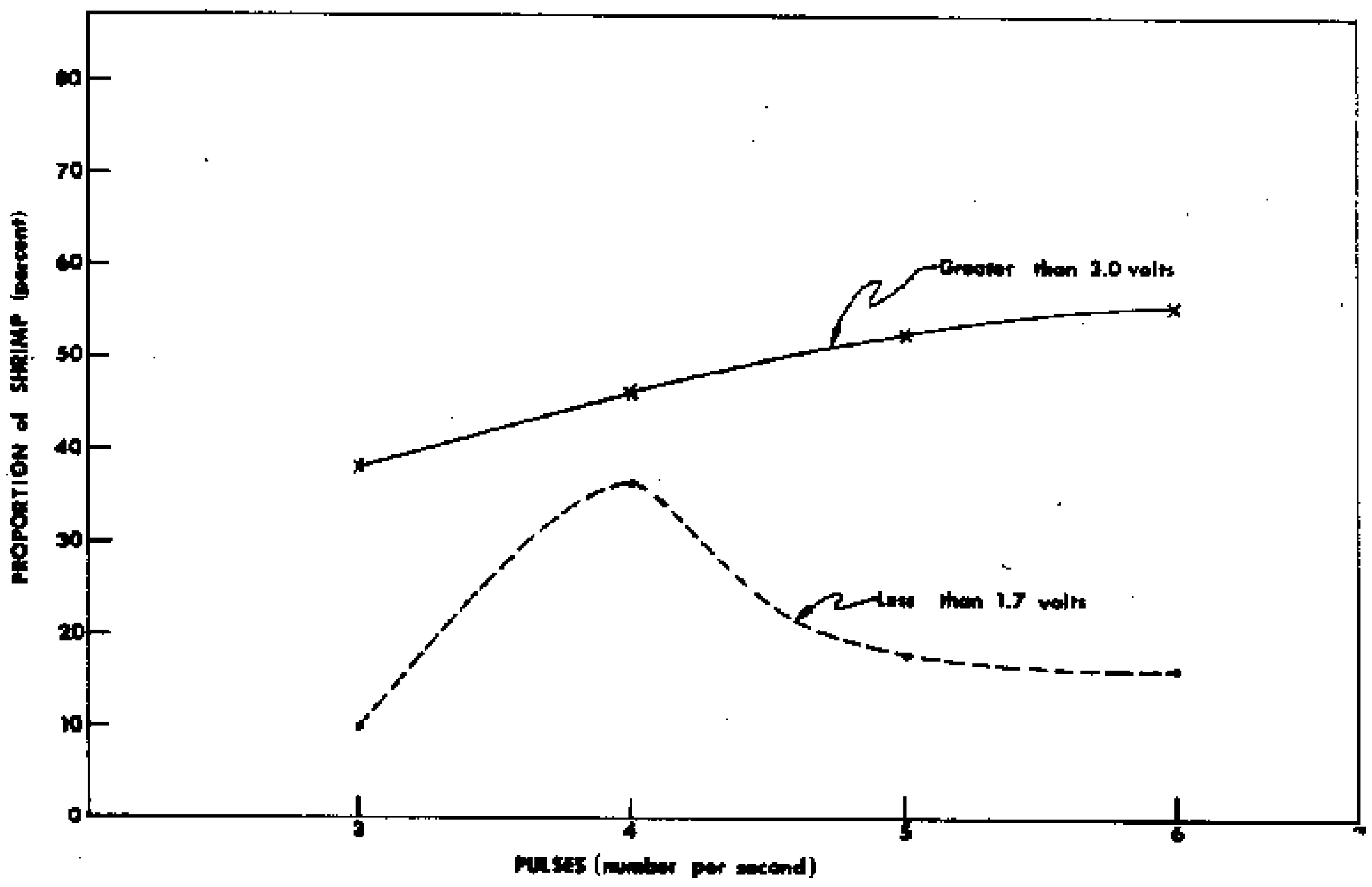

Figure 6.—Relation between pulse rate and percentage of shrimp jumping 150 millimeters high within 1.90 seconds.

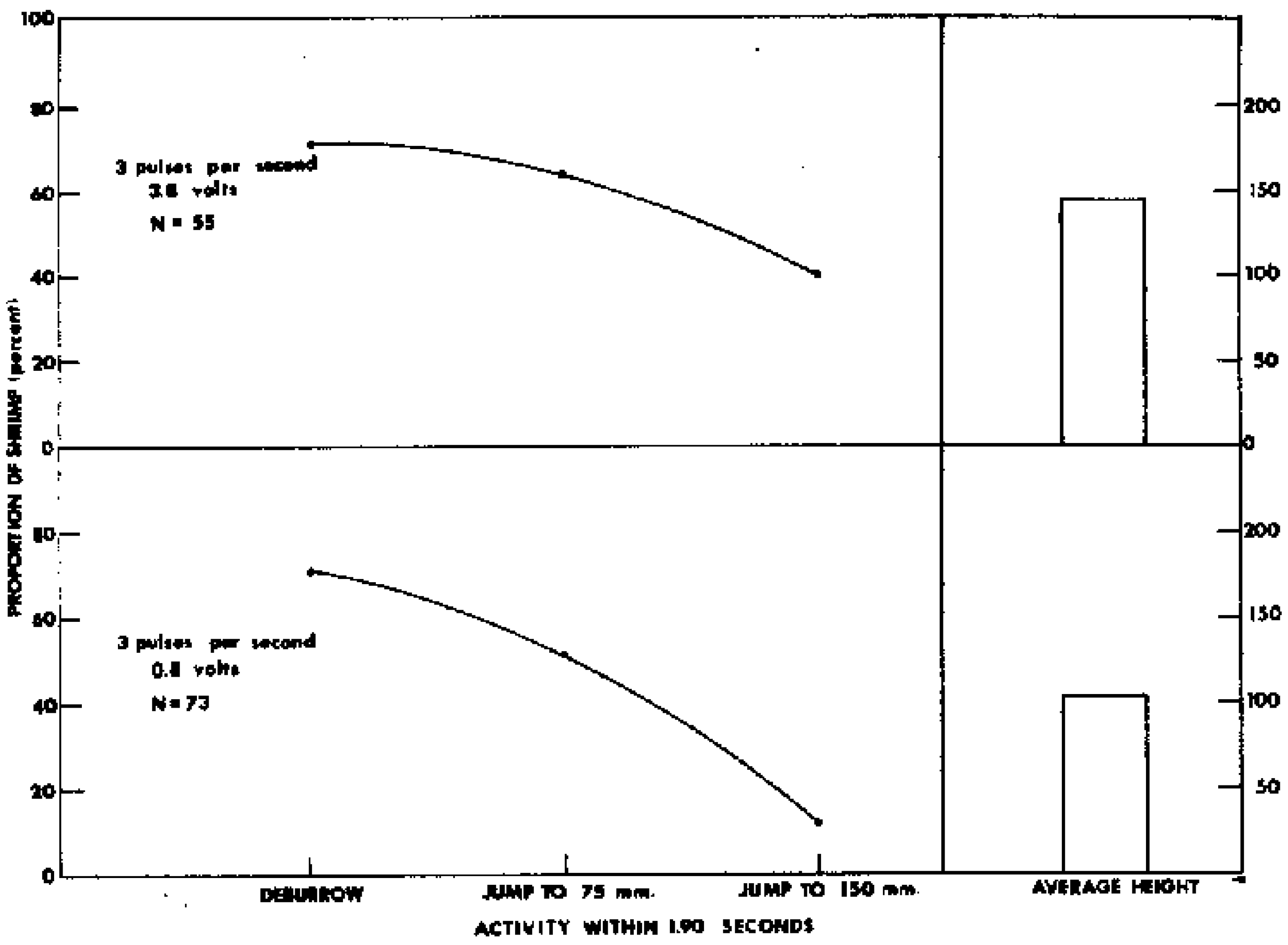

Figure 7.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 3 pulses per second at 0.8 and 3.8 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

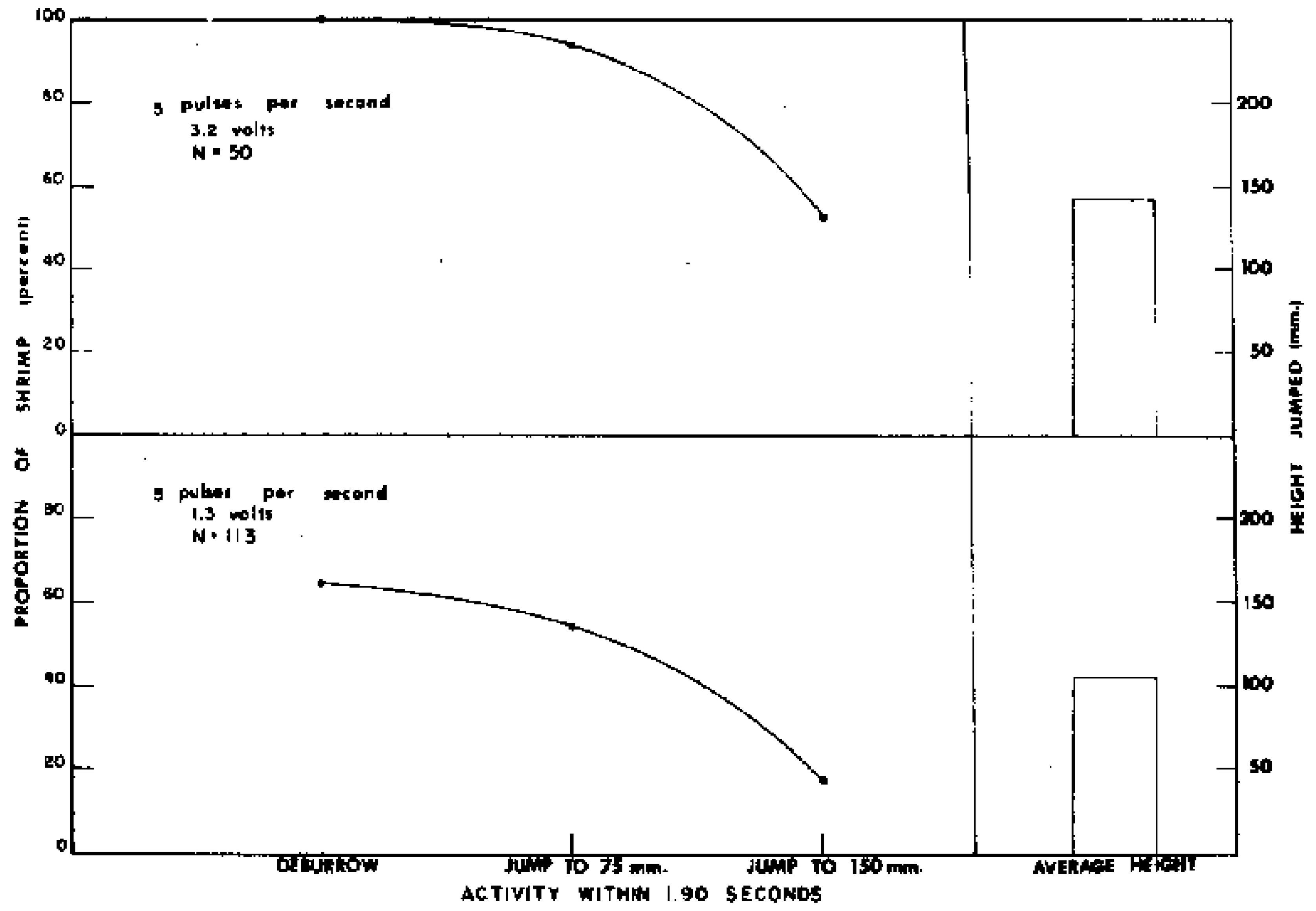

Figure 9.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 5 pulses per second at 1.3 and 3.2 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

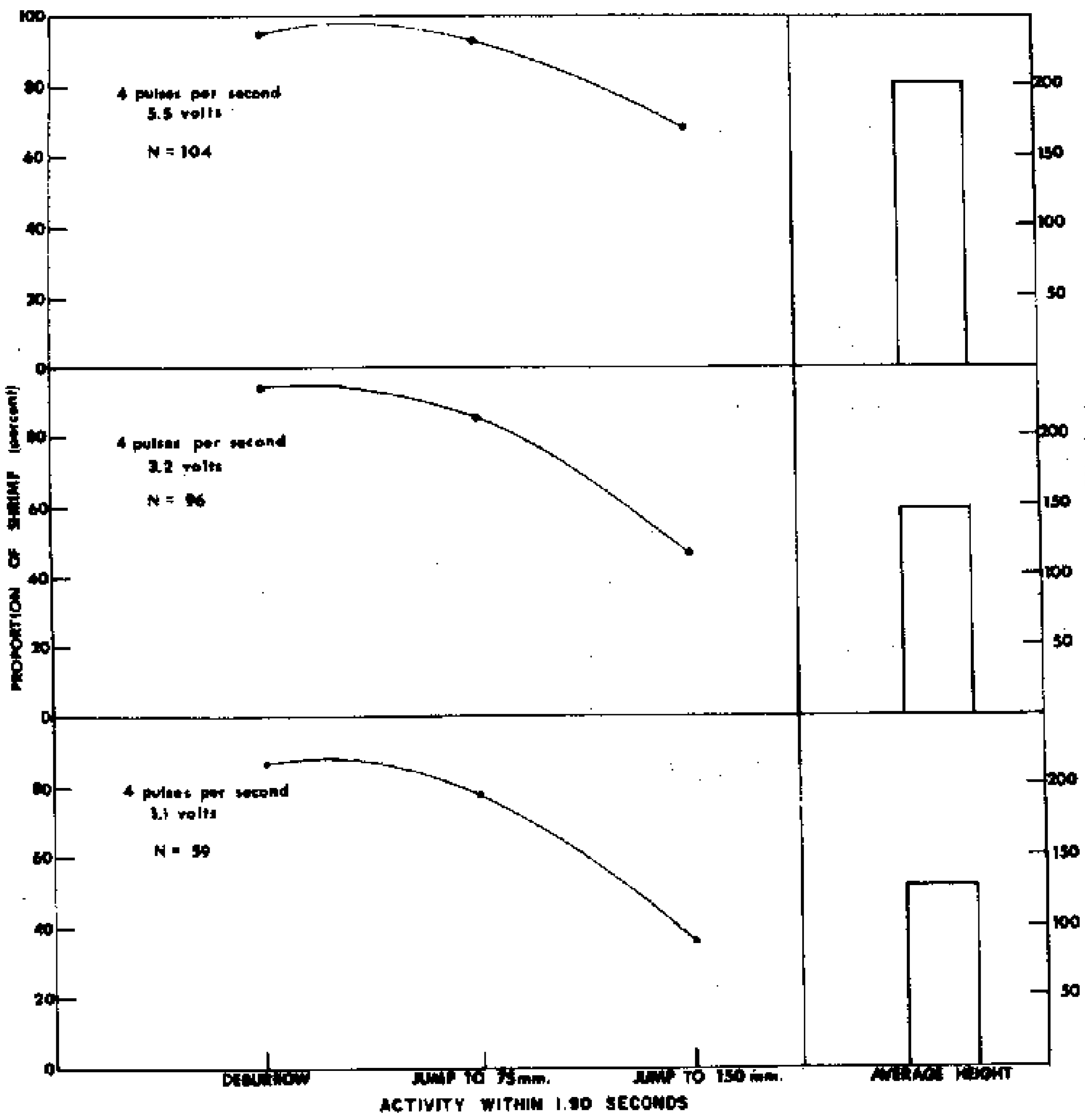

Figure 8.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 4 pulses per second at 1.1, 3.2, and 5.5 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

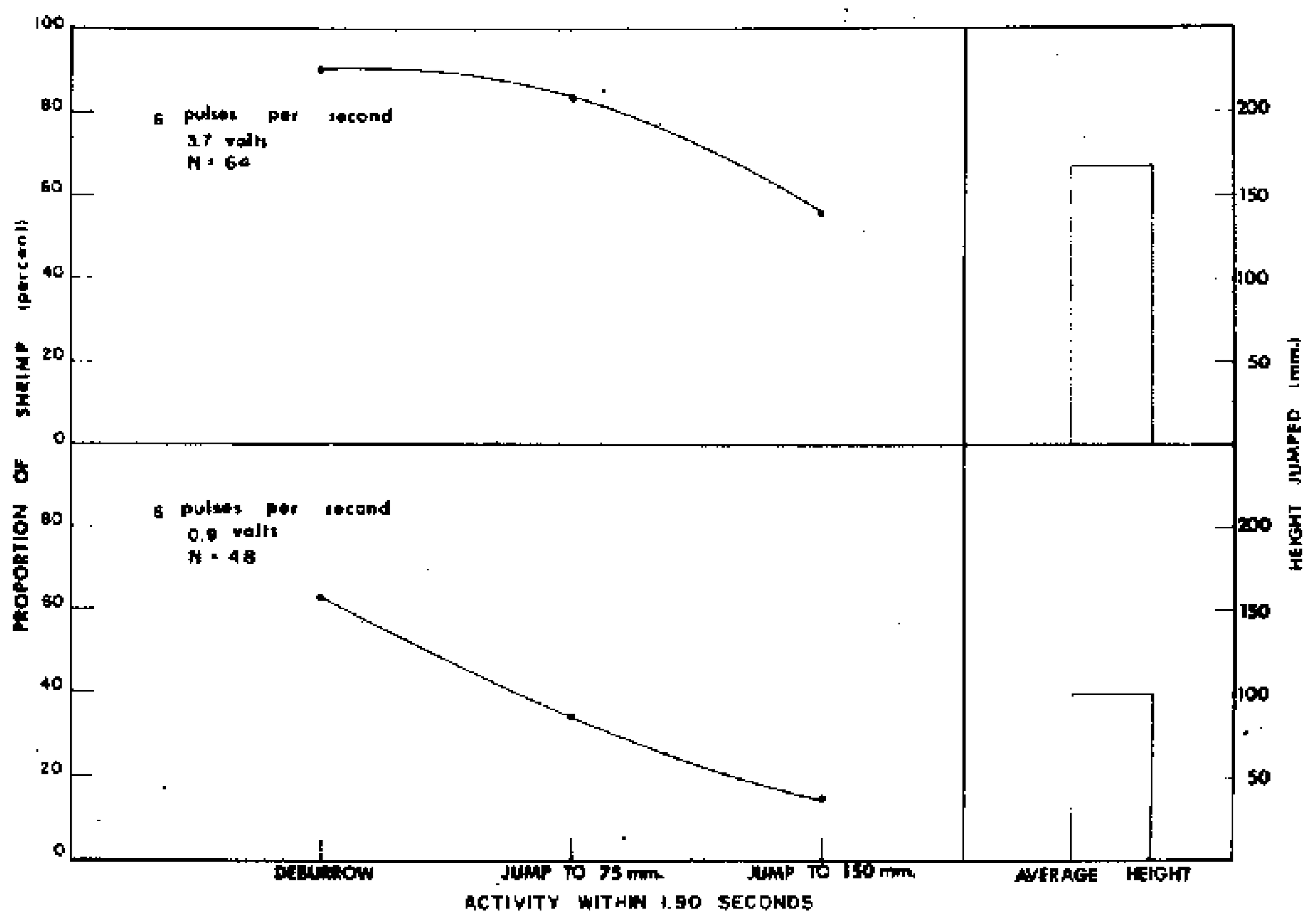

Figure 10.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 6 pulses per second at 0.9 and 3.7 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

jumped a height of 75 or 150 millimeters. Further, the proportion is higher for those that jumped 75 millimeters than for those that jumped 150 millimeters. Comparison of the curvilinear relation between groups shows that the overall activity increases with an increase in voltage. This trend in activity is evident generally for all the repetition rates tested.

As voltage increases, the average height of the jump also increases (Figures 7, 8, 9, and 10). At 4 pulses per second and 1.1 volts, the shrimp averaged a height of 132 millimeters, whereas when stimulated with 3.2 and 5.5 volts, they averaged heights of 152 and 206 millimeters, respectively.

Comparison of activity levels between pulse rates shows the highest levels of activity for the curvilinear graph at pulse rates between 4 and 6 (Figures 8, 9, and 10). Shrimp stimulated with more than 3.0 volts at 5 pulses per second have the highest activity level, whereas those stimulated with high voltage at 4 and 6 pulses per second have similar activity levels. At 5 and 6 pulses per second, at low voltage, however, the level of activity is considerably more depressed than is the level at 4 pulses per second at a similar voltage. This observation indicates that the optimal pulse rate for a given range of voltage would be 4 pulses per second.

The rate at which shrimp jump 75 millimeters high (Figure 11) is remarkably similar for animals stimulated with pulse rates of 4, 5, and 6 per second at high voltage. At these pulse rates, the rate of reaction increases exponentially from 0 to about 1.70 seconds; thereafter, no appreciable change is noticeable. At 4 pulses per second, shrimp stimulated at more than 5.0 volts appear to have a slightly faster rate than do those stimulated at 3.0 volts.

As voltage increases, the reaction time decreases. This relation is evident when the reactions of shrimp stimulated at low and high voltages are compared within a range of pulse rates. Figure 12 depicts the reaction rate at low voltage at pulse rates of 4, 5, and 6 per second. These reaction rates are slower than are those for similar groups exposed to high voltage (Figure 11). Because the reaction time is slower at less than 1.3 volts, the optimum voltage appears to be in excess of 3.0 volts.

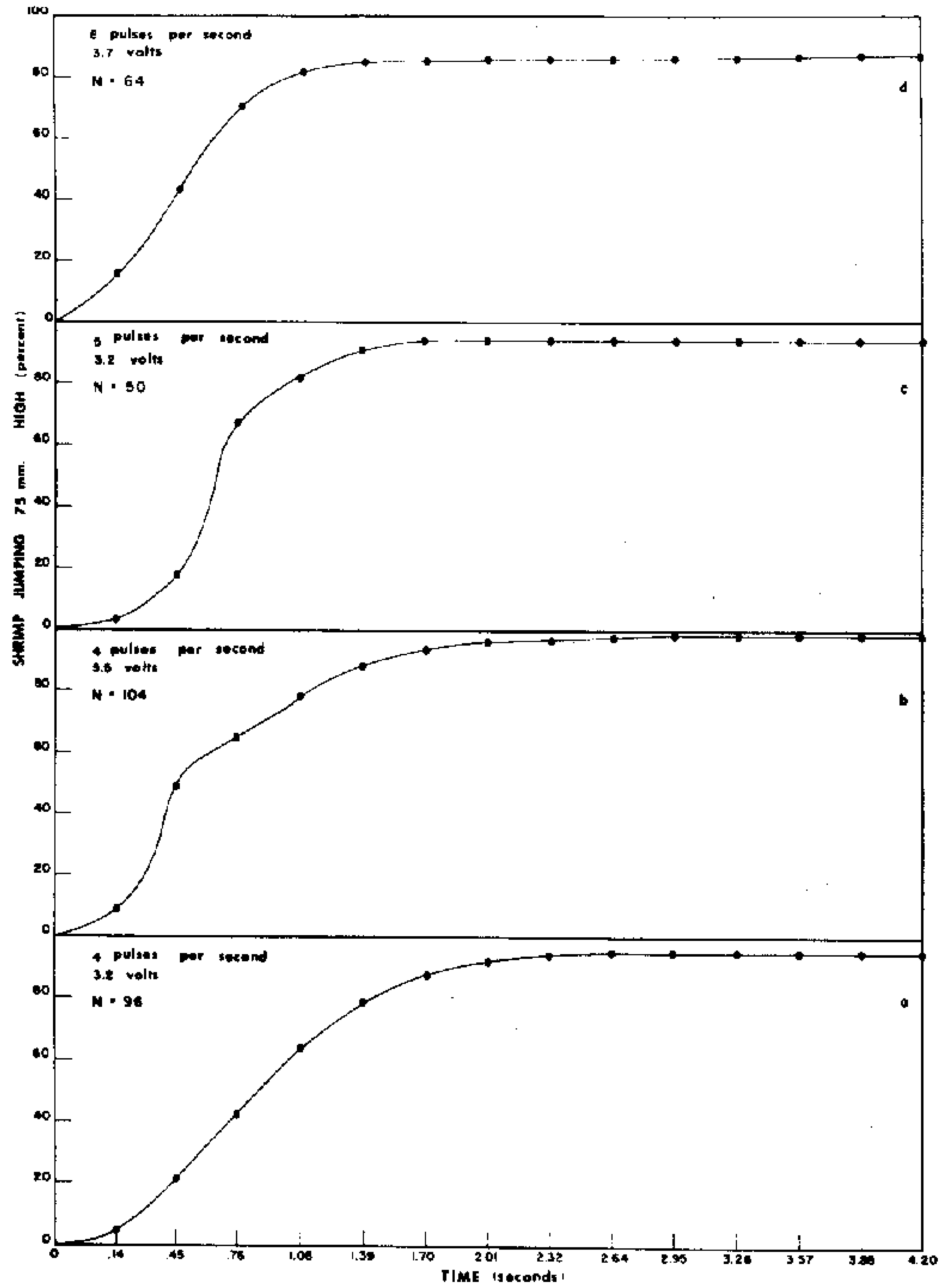

Figure 11.—Reaction rate of shrimp jumping 75 millimeters high when stimulated with (a) 4 pulses per second at 3.2 volts, (b) 4 pulses per second at 5.5 volts, (c) 5 pulses per second at 3.2 volts, and (d) 6 pulses per second at 3.7 volts.

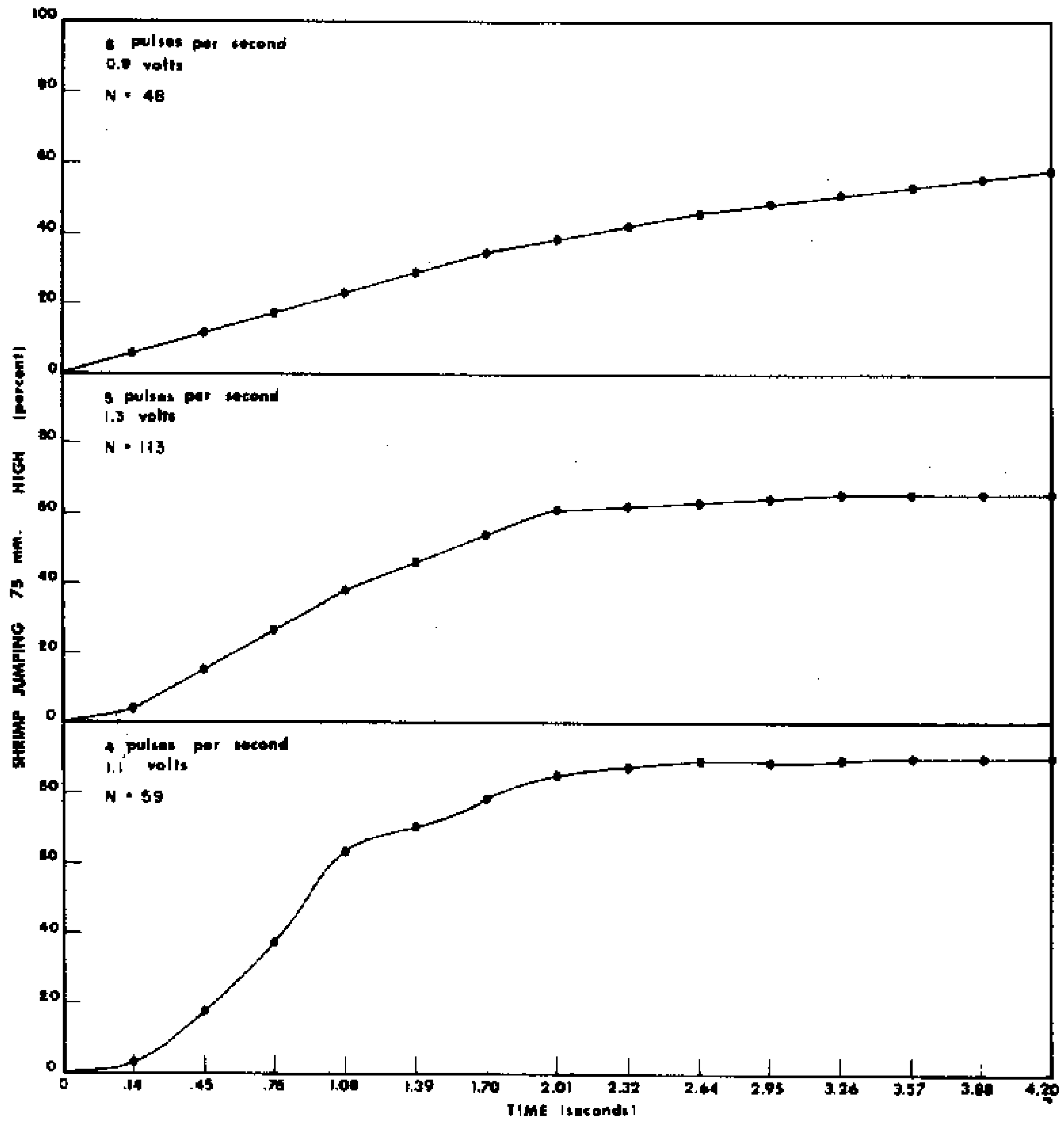

Figure 12.—Reaction rate of shrimp jumping 75 millimeters high when stimulated with 4, 5, and 6 pulses per second at 1.3 volts or less.

B. RESPONSES OF ELECTRICALLY STIMULATED SHRIMP BURROWED IN SUBSTRATA FOUND IN COMMERCIAL SHRIMP GROUNDS

Shrimp were tested in the substrata found on Cape San Blas, St. Andrews Bay, Dry Tortugas, and Mississippi shrimp grounds.

1. Cape San Blas Substrata

Two types of sediments were encountered on the Cape San Blas shrimp grounds (Table 3). The first was similar to the sand found off Panama City and contained about the same proportion of sand (99 percent). The other was also classified as sand, although it contained 83 percent sand, 11 percent silt, and 6 percent clay.

The rate of the escape reactions of Group 15 stimulated from the latter substratum was generally slower than was that of Group 16 stimulated from the pure sand substratum (Figure 13). In Group 15, about 80 percent of the shrimp jumped a height of 75 millimeters within 0.59 second; over 94 percent attained this height within 1.22 seconds. In Group 16, however, 80 percent of the shrimp took 2.15 seconds to jump a height of 75 millimeters, and 94 percent reached this height in 2.46 seconds.

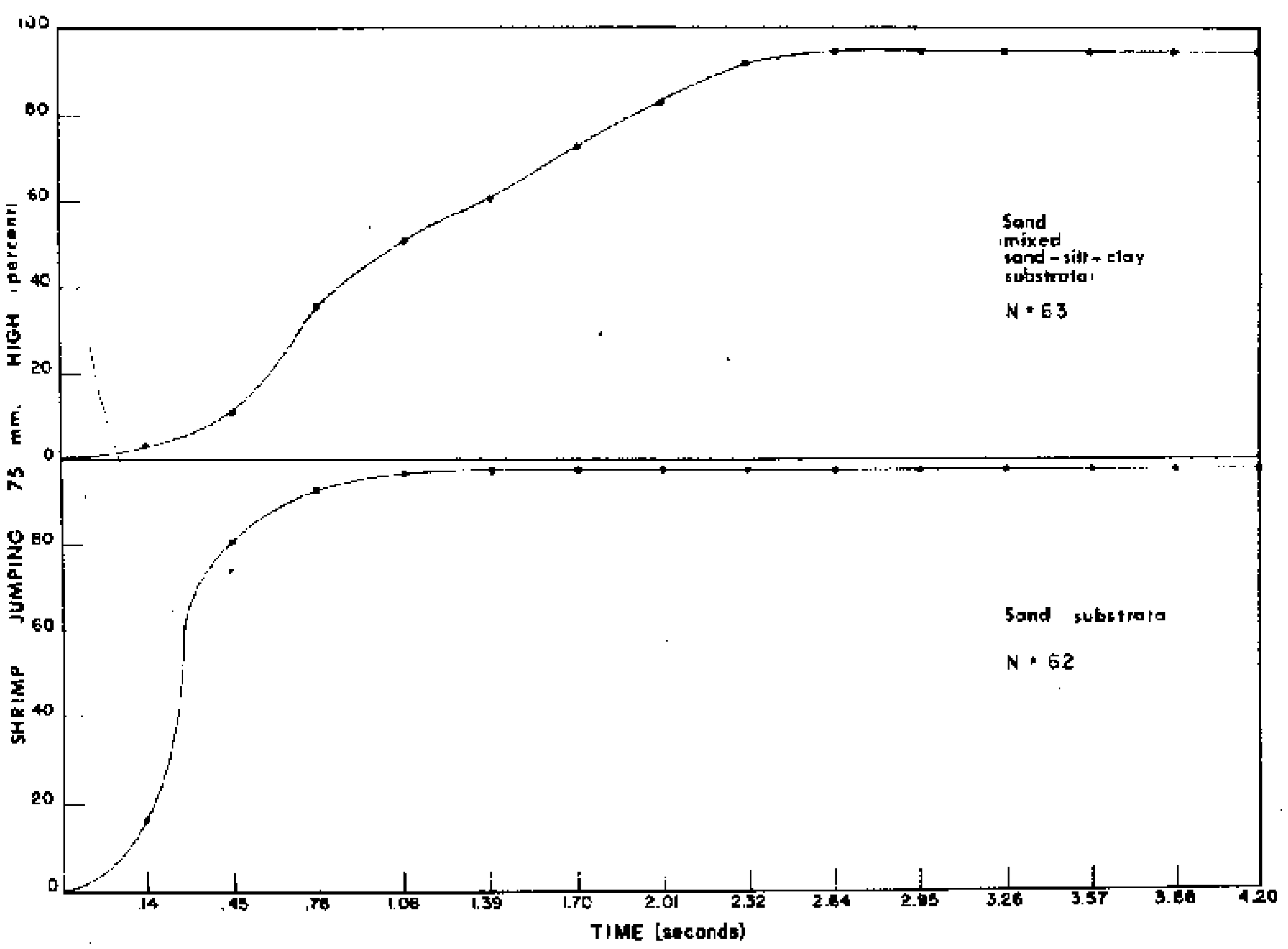

Figure 13.—Relation between reaction rate of shrimp jumping 75 millimeters high and the two bottom types found in the Cape San Blas area (stimulation was 3.6 volts at 4 pulses per second).

The proportion of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds was much lower for Group 16 than for Group 15 (Figure 14). Figure 14 also shows that shrimp burrowed in pure sand jumped slightly higher than those burrowed in mixed sand.

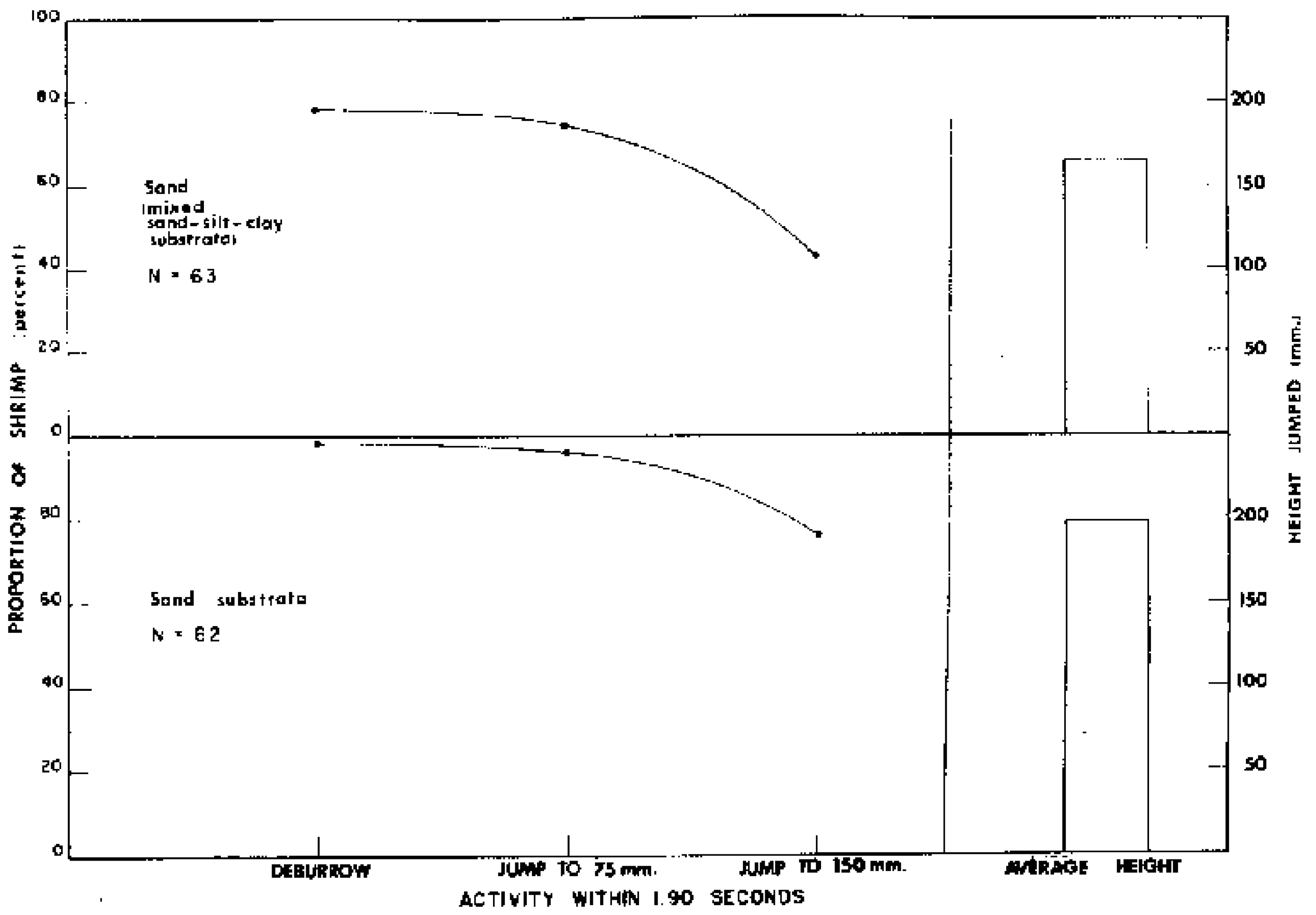

Figure 14.—Comparison of activity level of shrimp burrowed in the two bottom types found in the Cape San Blas area (stimulation was 3.6 volts at 4 pulses per second). The average height jumped within 1.90 seconds is shown on the right side of the figure.

These results indicated that the substratum does affect the escape reactions of electrically stimulated shrimp. Although some difference was noted in the escape reaction of shrimp from the two types of bottom, the pulse characteristics tested appeared adequate for use in an electric shrimp-trawl system.

2. Types of Substrata Other Than Cape San Blas

The escape reactions were remarkably alike for similarly stimulated shrimp burrowed in silty sand, sand silt, and sand-silt-clay found in St. Andrews Bay, offshore areas of the State of Mississippi, and the Dry Tortugas, respectively. Figures 15 and 16 shows the similarity in escape reactions among Groups 18, 21, and 22 burrowed in three different types of bottom. The curves showing the proportion of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds are very

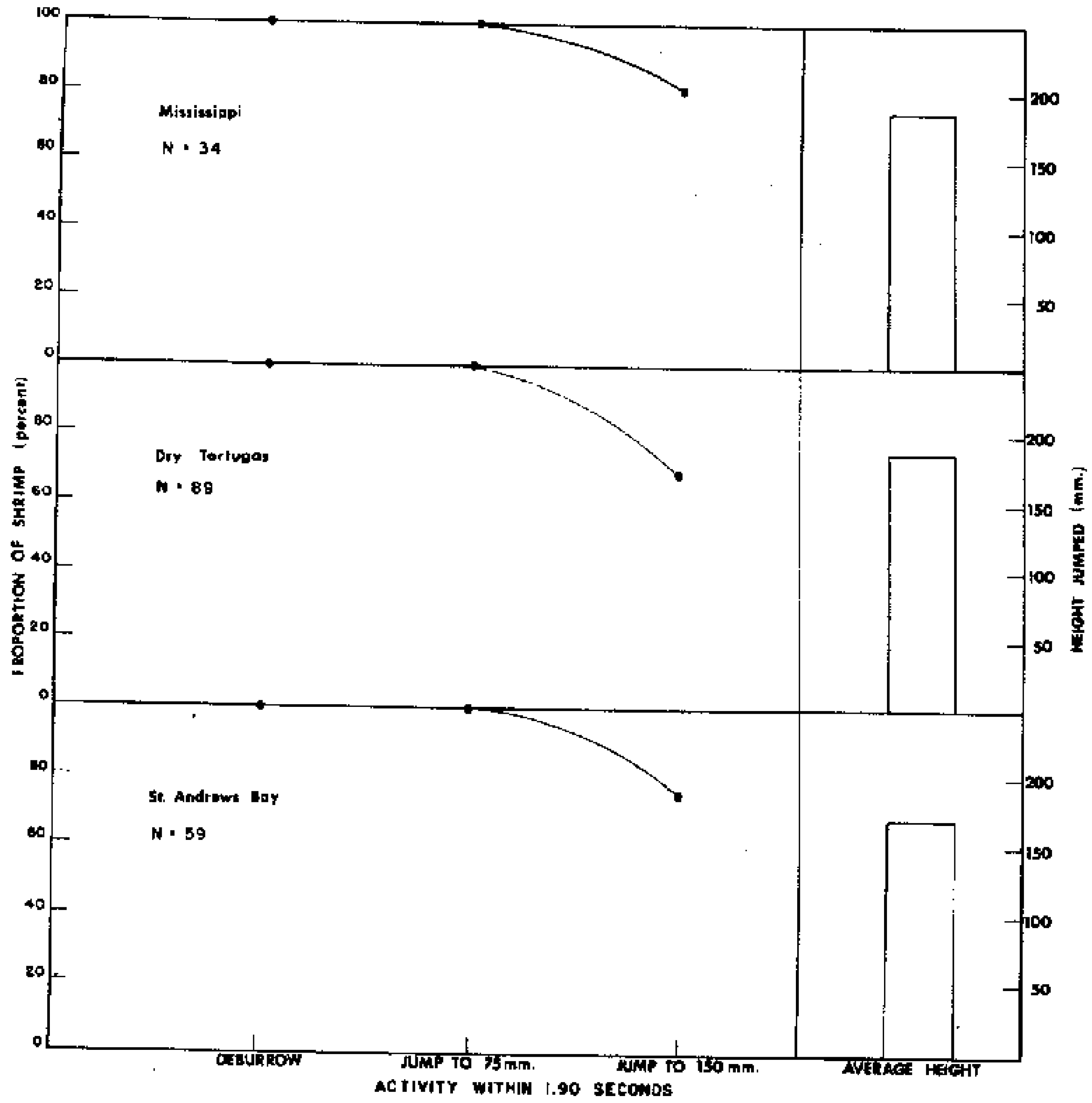

Figure 15.—Comparison of activity level of shrimp burrowed in substrata found in St. Andrews Bay, off Dry Tortugas, and off Mississippi (stimulation was 3.3 to 3.6 volts at 4 pulses per second). The average height jumped within 1.90 seconds is shown on the right side of the figure.

similar (Figure 15). In addition, the groups differ but little in the average height jumped.

Rates of jumping 75 millimeters high among the three groups indicate that the escape rate was slightly slower for shrimp stimulated from a sand-silt-clay bottom than for those stimulated from the two other types of sediments. More than 96 percent of the shrimp in each of the three groups jumped 75 millimeters high within 0.90 second.

The reaction rates of shrimp stimulated from substrata on the shrimp grounds were faster than those of shrimp stimulated from the substrata off Cape San Blas and Panama City. These high levels of activity and the rapid rates of reaction indicate that an electric stimulus with pulse characteristics of 4 pulses per second and more than 3.0 volts was optimum for the substrata tested.

The optimum pulse characteristics for stimulating shrimp from a sand substratum were also effective on commercial shrimp grounds in the Eastern Gulf of Mexico. Groups 15 to 22 provided information on the efficacy of these pulse characteristics for various substrata. The shrimp exhibited no great difference in the rate of escape from the different types of substratum found on the commercial shrimp grounds. The shrimp burrowed in the mud bottom substrata on the shrimp grounds generally had more rapid escape reactions than those burrowed in the sand substratum off Panama City.

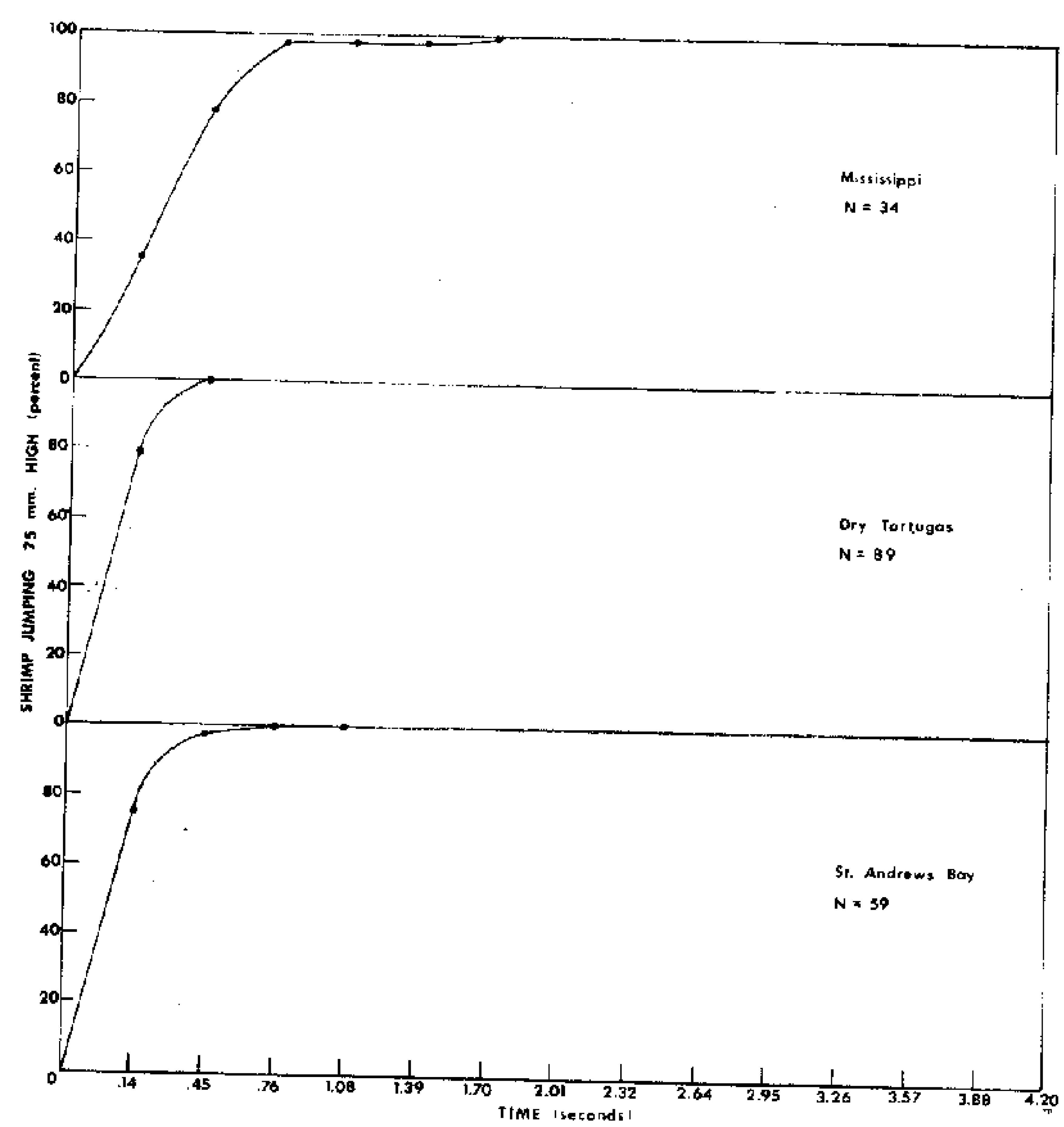

Figure 16.—Relation between reaction rate of jumping 75 millimeters high and substrata found in St. Andrews Bay, off Dry Tortugas, and off Mississippi.

SUMMARY AND CONCLUSIONS

Laboratory studies showed that the voltage to which a shrimp was subjected was a function of its orientation in relation to the electric field as well as the size of the shrimp. This relation was described as L cos $\Theta = \Delta$ V. The height the animal jumped was a function of the voltage applied. As the stimulation voltage increased, the height to which the shrimp jumped also increased.

Field studies indicated that shrimp burrowed in sand were most effectively forced from the substratum with a voltage greater than 3.0 volts at pulse rates of 4 or 5 per second. When these voltages and pulse rates were used, the reaction rates were faster, and a larger proportion of the shrimp jumped heights of 75 and 150 millimeters above the bottom within 1.90 seconds.

Bottom type affected the escape reactions of similarly stimulated shrimp. Generally, shrimp escaped from mixtures of sand, silt, and clay faster than they did from sand. Shrimp jumped higher from substrata found off Mississippi, Dry Tortugas, Cape San Blas, and in St. Andrews Bay than they did from the sand found off Panama City. At 3.0 volts and 4 pulses per second, 100 percent of the shrimp burrowed in mixtures of sand, silt, and clay jumped 75 millimeters high within 1.90 seconds, whereas between 78 and 98 percent of the shrimp burrowed in substrata classified as sand jumped 75 millimeters high within 1.90 seconds.

Pulse characteristics of either 4 or 5 pulses per second, at more than 3.0 volts across 100 millimeters parallel to the field, appear to be satisfactory for use in an electric shrimp-trawl system. These pulse chracteristics caused the greatest percentage of burrowed shrimp, in the substrata tested, to jump 75 millimeters high within the time a trawl would take to cover the distance from the front of a 2.4-meter wide electric field to the footrope.

However, the optimum stimulation voltage appears to be greater than 3.0 volts because a greater percentage of shrimp responded at voltages in excess of 3.0 as compared with those that responded at lower voltages. (Limitations in the pulse generator used in the field studies, however, prevented my testing higher stimulation voltages.)

Application of slightly more voltage could likely increase the average height jumped and decrease the reaction time for brown and pink shrimps. The minimum stimulation voltage should not be less than 3.0 volts, across 100 millimeters parallel to the electric field, for effective utilization of an electric shrimp trawl. Two to three times this minimum value would be preferable because the electric force felt by the shrimp is related to its size as well as to its position relative to the anode and cathode ($L \cos \theta = \Delta V$). Fuss and Ogren (1966) showed that orientation of burrowed shrimp appeared generally to be random. Consequently an electric trawl would encounter shrimp positioned at varying angles relative to the electric field. A minimum 3.0 volts across 100 millimeters in the electric field of a trawl would mean that a 100-millimeter shrimp positioned perpendicular to the electrodes would receive 3.0 volts, positioned at 45° would receive 2.1 volts, and at 75° would receive only 0.6 volt. If the minimum voltages were raised to 9.0 volts across 100 millimeters parallel to the field, a 100-millimeter shrimp positioned at 45° would receive 6.4 volts, and those at 75° would receive 2.3 volts. As the size of the shrimp increases, the voltage it received would also increase. I believe that an increase to 9.0 volts in the electric field would cause the shrimp to jump higher and to jump to a height of 75 millimeters faster.

LITERATURE CITED

Brophy, James J.
1966. Basic electronics for scientists. McGraw-Hill Book Company, New York, 471 pages.

Fuss, Charles M., Jr., and Larry H. Ogren, 1966. Factors affecting activity and burrowing habits of the pink shrimp, *Penaeus duorarum* Burkenroad. Biological Bulletin (Woods Hole) 130: 170-191.

Higman, James B.
1956. The behavior of pink grooved shrimp, *Penaeus duorarum* Burkenroad, in a direct current electrical field. Florida State Board of Conservation Technical Series No. 16, 23 pages.

Kessler, Doyne W.
1965. Electrical threshold responses of pink shrimp *Penaeus duorarum*, Burkenroad. Bulletin of Marine Science 15: 885-895.

Krumbein, W. C., and F. J. Pettijohn.
1938. Manual of sedimentary petrography. Appleton-Century-Crofts, Inc., New York, 549 pages.

Shepard, Francis P.
1954. Nomenclature based on sand-silt-clay ratios. Journal of Sedimentary Petrology 24: 151-158.

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