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THE EFFECT OF THE INTERSTIMULUS INTERVAL BETWEEN A TONE
AND INTRACRANIAL STIMULATION UPON THE SUBSEQUENT
REINFORCING POWER OF THE TONE

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
Bret Adolph Charipar, A. B., A. M.

*****

The Ohio State University
1962

Approved by

[Signature]
Adviser
Department of Psychology
ACKNOWLEDGMENTS

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INTRODUCTION

There is general agreement that a stimulus is a reinforcement when it produces new learning or increases the level of performance of a simple response which the animal already makes. A stimulus showing reinforcing properties is considered a secondary reinforcement when, without previous association with a primary reinforcement, its effect is neutral.

Until recently, the onset of auditory stimulation, unless negative, has been assumed to be neutral for animals. Barnes and Kish (1961), however, have demonstrated that the onset of certain frequency tones at certain intensities have a reinforcing effect without prior association with organic need reducing stimuli. Therefore in order to demonstrate a secondary reinforcing effect, it is not sufficient to show only that performance is better with a tone than without it. It is necessary to show that the performance level of a response for a tone, after association with primary reinforcement, is higher than the performance level for that tone prior to association. That is to say, the reinforcing power of a tone has been increased beyond its primary level. Accordingly, the strength or power of a stimulus as a secondary reinforcer may be considered the degree to which the stimulus, after association with primary reinforcement, increases the performance level of a response over its initial level for the same stimulus.
Previous research on the establishment of secondary reinforcers and the variables which affect their strength have been reviewed by Myers (1958) and by Kimble (1961). One important variable has been found to be the time interval between the exteroceptive stimulus and the reinforcing stimulus.

Bersh (1951) paired a light with the delivery of food pellets 160 times for each subject. The interval between the onset of light and food delivery was varied from one experimental group to another. After pairing, a bar was inserted into the test chamber, and each bar press delivered one second of light. Bersh used the number of bar presses in the first ten minutes as the dependent measure, and found that the group medians differed from one another except for the .5 and 1.0 sec. interval groups. However, the differences were not significant except for those with the 10-second group. The plot of these medians indicate a non-monotonic relationship between the dependent measure and the interstimulus interval. The median for the "zero" interval group was less than the median for the .5 and the 1.0 sec. groups, as was the median for the 2.0 sec. group.

Jenkins (1950) also investigated the effects of the interstimulus interval on the establishment of a secondary reinforcer. He used the interval between the offset of a buzzer and the activation of a food magazine as his independent variable. His dependent variable was the number of bar presses in 6 hours during
extinction where each bar response delivered 3 seconds of buzzer sound. Jenkins' data indicated that the number of responses decreased monotonically from the one second interval as the interval increased.

In actuality the interstimulus interval in these two studies was measured between two stimuli, of which the food delivery sound was not by itself a primary reinforcement. Therefore, these studies have a similarity to the one done by Ward (1961), who investigated the effects of delay of secondary reinforcement on the establishment of a bar pressing response. His results were similar to those of Bersh in that the plot of the mean number of responses in 50 trials vs. the delay interval was non-monotonic and that the means of the "zero" and 2.0 second groups were each less than the means of the intervening interval groups.

Such studies as those of Bersh and Jenkins, which attempt to study the effects of the interstimulus interval on the establishment of a secondary reinforcer, are handicapped by the use of food or water as the primary reinforcement. The time of presentation of these reinforcements can be controlled by the experimenter without difficulty, but he has no control over the time at which they are ingested. Also, since precise timing requires mechanical delivery, electronically controlled, it is almost impossible to present these reinforcements without the sound of a delivery mechanism. It was to avoid these difficulties that Ward used a
secondary reinforcing stimulus to study delay of reinforcement.

One means to avoid the difficulties involved in the use of food and water reinforcement is to use intracranial electrical stimulation (ICS) as the primary reinforcement. The onset of the ICS may be controlled precisely in terms of milliseconds and there need be no accompanying auditory stimulus.

The reinforcing effect of ICS was originally demonstrated by Olds and Milner (1954) in rats. Subsequent work with ICS has demonstrated its reinforcing effect for monkeys (Bursten and Delgado, 1958), for cats (Brady et al., 1957), for guinea pigs (Valenstein, 1958), and for the dolphin (Lilly and Miller, 1962). In 1960 Olds, Travis, and Schwing published data on the rate of response for brain stimulation as a function of the electrode placement and the amperage level. Very high response rates were obtained when the stimulation was in the posterior hypothalamus. Hodos and Valenstein (1962) found that the stimulation intensity preferred by rats does not always coincide with the intensity giving the higher rate. Specifically, they found that the animals always preferred the higher ICS intensity, even in those instances in which the rate of self-stimulation at the higher intensity was less than the rate of self-stimulation at the lower intensities. They point out that at higher stimulus intensities responses are disrupted by the motor effects of stimulation.
Comprehensive discussions and reviews of the experimental
and behavioral effects of intracranial stimulation have been pub-
lished in *Electrical Studies on the Unanesthetized Brain* (Ramey
and O'Doherty, 1960) and in *Electrical Stimulation of the Brain*
(Sheer, 1961).

Using ICS as the primary reinforcer, Stein (1958) estab-
lished a tone as a secondary reinforcer. He paired the tone
400 times with ICS and used .5 sec. between onset of the tone
and onset of the train of brain stimulation. A two-bar situation
was used, one bar delivering 1 second of tone when pressed, the
other bar having no effect when pressed. After pairing of the
tone and ICS, it was found that those animals for whom ICS had
a positive reinforcing effect (1) switched their pre-pairing
preference from the "no tone" bar to the "tone" bar and (2) in-
creased their rate of responding on the "tone" bar above the pre-
pairing level.

In conclusion, intracranial stimulation was used in the
present study to investigate the effect of the interstimulus
interval because it has been demonstrated as a primary rein-
forcement capable of establishing a secondary reinforcer; its
onset can be precisely controlled; and it avoids the difficulties
of delivery inherent with the use of food and water.
Statement of the Problem

This experiment is an attempt to investigate the effect of the interstimulus interval between an exteroceptive stimulus and a reinforcing stimulus upon the subsequent secondary reinforcing power of the exteroceptive stimulus. The study was intended to determine -

1. Whether one interstimulus interval is better than another in establishing a secondary reinforcer.

2. Whether there is an orderly relationship between inter-stimulus interval and the subsequent strength of a secondary reinforcer if the number of pairings is the same.

3. What the general form of the relationship is if it exists.
METHOD

Subjects

The subjects were 36 male hooded rats of the Long-Evans strain without previous experimental treatment. At the time of the electrode implant their weights ranged from 200 to 350 grams. Throughout the experiment, the animals were fed ad libitum.

Electrode Implants

Bipolar electrodes manufactured by Plastic Products Co. were chronically implanted in the vicinity of the medial forebrain bundle and lateral hypothalamus by means of a stereotaxic instrument manufactured by the Baltimore Instrument Co. Stainless steel screws were anchored in the skull and dental acrilic was molded around them and the electrode socket to form a permanent pedestal.

Apparatus

The apparatus consisted of pulse and waveform generators, two separate and different test chambers (a cylinder and a box), Foringer switching components, and an audio oscillator.

The pulse and waveform generators, Tektronix Models 163 and 162 respectively, were used to generate a 0.5-second train of bi-phasic pulses with a frequency of 100 cps and a pulse duration of 0.2 msec. Additional pulse and waveform generators were used to
provide, when necessary, a delay between the triggering of a tone via the audio oscillator, and the triggering of the ICS pulse train. A Hunter KlockKounter Model 120A was used before each animal's experimental session to calibrate in milliseconds the duration of the tone, the length of the ICS pulse train, and the interval between the onset of the tone and the onset of the ICS.

The apparatus used to evaluate the effect of ICS for each subject consisted of a cylinder chamber, a photoelectric switch and an associated light beam projector, and eight counters.

The upright cylinder was 9" in diameter and 12" tall with a clear plastic lid and wire mesh floor. The cylinder itself was made of sheet metal in which a 3/4" diameter hole was cut out. This hole was centered 1 and 1/2" above the floor of the cylinder. A beam of light from the projector was directed upward into the photoelectric cell, parallel to the outside of the cylinder and opposite the hole. Whenever a subject inserted its nose far enough into the hole, the light beam was broken and a single train of ICS was delivered to the subject. If the beam of light remained broken no additional stimulation was delivered. Each time the beam of light was broken, a remotely situated counter was stepped. Every 5 minutes a clock activated a stepping switch, moving the count of the nose responses to a new counter.

The apparatus in which tone and ICS were delivered to the
subject was a box, 10" x 10" x 9", painted black, with a slotted clear plastic lid. This box was located in a larger sound-resistant box also painted black and with a 6" speaker mounted on one wall. A 7 and 1/2 w. bulb powered by 10 VAC was located 23" above the floor of the box chamber.

Remotely located in another room from the box was the Tektronix equipment, power supplies, counters, an event programmer and other relays and switches.

The event programmer (Foringer) used a celluloid tape which moved at 1mm per second. A microswitch was activated when a hole in the tape passed the arm of the switch. Whenever the microswitch was activated, a 1200-cps. tone at -30 db, generated by the audio oscillator was delivered for .5 seconds via the speaker. Simultaneously with the onset of tone, the time delay circuits were activated. At the end of the prescribed inter-stimulus interval a single ICS train was triggered and delivered to the subject. When the experimental conditions specified that the tone and ICS be delivered simultaneously, the delay circuits were bypassed. When the experimental conditions specified that the tone and ICS be presented independently of each other, the intervals between tone onsets were controlled by tape via the event programmer and the ICS was controlled by hand with the aid of a stop watch.

In certain phases of the experimental procedure a pedal
bar (Fig. 1) 9 and 1/2" long, mounted on the end of a telegraph key, was installed at one end of the box chamber. A force of 15 grams was required to close the key. Each time the key was closed the 1200 cps. tone was presented for .5 seconds to the subject via the speaker. If the key remained closed no additional tone was presented. Each time the key was closed, a remotely situated counter was stepped. Every 5 minutes, a clock activated a stepping switch moving the count of bar responses to a new counter.

Procedure

Each animal underwent a procedural cycle of handling, electrode implant, post-operative rest, habituation to the test chambers, and test of the effect of ICS on a nose response. Those animals for whom the ICS had a positively reinforcing effect were used in the subsequent stages of the experiment and were subjected to the following general procedure: underwent extinction of the nose response; had measures taken of their performance level of bar pressing for the tone; were presented tone and ICS either in pairs or independently according to the treatment condition; and were then given the opportunity to bar press for the delivery of tone.

1. Pre-experimental treatment. The subjects were handled for three days prior to the implantation of the electrode. On two of these days the subjects spent ten minutes a day in the cylinder test
Figure 1. Cross Section of the Pedal Bar
chamber with the hole plugged. During these periods a relay near
the cylinder was activated at random intervals by means of the
tape programmer. The purpose of this was to adapt the animals to
handling and to the experimental environment.

In order to provide a group of subjects to fill each of the
six treatment conditions, the electrode operations were made in
blocks of at least twelve. Several operations were performed each
day, on consecutive days.

Following a post-operative rest period of two days, each
animal was further habituated to handling and to the experimental
apparatus over a period of five days. They spent 15 minutes a
day in each test chamber (cylinder and box) for three days. On
the fourth day they spent 15 minutes in the cylinder with the
hole unplugged. A record was kept of the number of unreinforced
nose responses made. On the fifth day they spent 15 minutes in
the box.

2. Evaluation of ICS effects. Following habituation, the
effects of ICS for each animal was evaluated by using it to rein-
force the nose response. Each nose response delivered .5 seconds
of intracranial stimulation. When the ICS produced little or no
change in behavior from the unreinforced level of the response,
the peak voltage for the animal was raised until threshold was
passed and the animal was responding at a high rate.

Those animals for whom the ICS had a positively reinforcing
effect were used as subjects in the subsequent stages of the experiment. An average of fourteen responses per minute over a period of at least fifteen minutes was considered as indicative of a positively reinforcing effect. This level of performance was well above the unreinforced level of nose response given by any of the animals. From one block of operations to another, the percentage of animals for whom ICS had a positively reinforcing effect was found to vary between 25% and 69%.

3. Preparations for experimental treatment. Those animals who met the performance criteria and who therefore were to be used as subjects, were given a 40 minute session in which the nose response did not deliver ICS. During this session a nose response still produced the click of the photoelectric switch.

On each of the following three days the subjects were placed in the box for 40 minutes with the bar mounted. Depression of the bar delivered .5 seconds of tone. The number of bar presses for blocks of five minutes were recorded as a measure of the strength of the bar response for tone prior to the pairing of the tone with ICS.

4. Establishment of secondary reinforcement. In the next stage of the experiment, tone and ICS were delivered to each subject 20 times each day, for six consecutive days, on a random interval basis (3 minute mean). The presentations were made under six
conditions while the animal was in the box chamber with the bar removed. Each subject was assigned on a chance basis to one of these conditions, with six subjects run in each condition. Five of the conditions were experimental and the sixth was a control condition. In the experimental conditions the tone and ICS were presented together in pairs. The interstimulus interval between onset of tone and onset of ICS was fixed within an experimental condition but varied from condition to condition. The interstimulus intervals used were "zero," 500, 1000, 1500, and 2000 milliseconds. However, in the control condition there was no fixed time interval between stimulus onsets. In this latter condition the tone and ICS were presented independently of each other on a non-systematic basis and never closer together than thirty seconds.

5. Test of secondary reinforcement. The next day the animal was placed in the box chamber with the bar mounted. As before, a depression of the bar delivered .5 seconds of tone to the animal. The number of responses in each 5 minute period was recorded over 40 minutes.
RESULTS

For those animals used as subjects for the main portion of the experiment, the number of nose responses per minute averaged over a stable 15-minute period ranged from 14.1 to 48.3 when ICS reinforced the response. Among these animals during post-operative habituation, the highest mean number of nose responses per minute, without ICS reinforcement, averaged over 15 minutes, was 5.5.

Table 1 gives for each animal the difference between the number of bar responses for tone made in the 40 minute period before pairing and the number of bar responses for tone made after pairing. A minus sign indicates that the number made after was less than the number made before. Table 1 also gives the median difference score for each group. These medians are plotted in Figure 1. As an overall test, the Kruskal-Wallis test (Siegel 1956) gave an H of 16.94, which with 5 degrees of freedom, had a chance probability of occurrence of less than .01. Therefore the null hypothesis was rejected.

The Mann-Whitney U-test was used to evaluate the differences in central tendency between groups. The two-tailed probability of occurrence of the differences between groups estimated for each comparison by this test are given in Table 2. Both the 500 and 1000 msec. interval groups were significantly (p<.01) higher than the "zero" and 2000 msec. interval groups.

The sign test (Siegel, 1956) was used to test the difference
Table 1

The Difference Score for Each Subject in the Bar Response Task

<table>
<thead>
<tr>
<th>Interstimulus Interval in Milliseconds</th>
<th>Zero</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-27</td>
<td>5</td>
<td>7</td>
<td>-62</td>
<td>-48</td>
<td>-49</td>
</tr>
<tr>
<td></td>
<td>-20</td>
<td>7</td>
<td>8</td>
<td>14</td>
<td>-14</td>
<td>-12</td>
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<td></td>
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<td>10</td>
<td>17</td>
<td>16</td>
<td>-8</td>
<td>-4</td>
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<td></td>
<td>-5</td>
<td>15</td>
<td>19</td>
<td>20</td>
<td>-1</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>-2</td>
<td>16</td>
<td>21</td>
<td>22</td>
<td>2</td>
<td>-2</td>
</tr>
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<td>6</td>
<td>19</td>
<td>27</td>
<td>44</td>
<td>5</td>
<td>40</td>
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<tr>
<td></td>
<td>-12</td>
<td>12.5</td>
<td>18</td>
<td>18</td>
<td>-4.5</td>
<td>-3.5 Median</td>
</tr>
</tbody>
</table>
Figure 2

Interstimulus interval in milliseconds
between the number of bar responses made before and the number of bar responses made after pairing for each group. Table 3 gives the two-tailed probability of occurrence of the differences. The probability of occurrence was less than .05 for the 500 and 1000 msec. interval groups, indicating that the change in performance level was significantly greater than zero.
Table 2

The Two-tailed Probability of Occurrence, Using the Mann-Whitney U Test, of the Differences Between Groups. The Test Was Applied to the Difference Scores on the Bar Response Task

<table>
<thead>
<tr>
<th>Interstimulus Interval in Milliseconds</th>
<th>Group</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>Control</th>
</tr>
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<tr>
<td>vs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td></td>
<td>.004</td>
<td>.002</td>
<td>.064</td>
<td>.700</td>
<td>.700</td>
</tr>
<tr>
<td>500</td>
<td></td>
<td>.180</td>
<td>.180</td>
<td>.002</td>
<td>.064</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td></td>
<td>1.000</td>
<td></td>
<td>.002</td>
<td>.064</td>
</tr>
<tr>
<td>1500</td>
<td></td>
<td></td>
<td></td>
<td>.064</td>
<td>.240</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.938</td>
<td></td>
</tr>
</tbody>
</table>
Table 3

The Two-tailed Probability of Occurrence, Using the Sign Test, of the Difference Between the Bar Response Level Before Pairing and After Pairing

<table>
<thead>
<tr>
<th>Interstimulus Interval in Milliseconds</th>
<th>Zero</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>.218</td>
<td>.032</td>
<td>.032</td>
<td>.218</td>
<td>.688</td>
<td>.218</td>
</tr>
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DISCUSSION

The results of the experiment suggest that some inter-stimulus intervals are more efficient for imparting secondary reinforcing power to an auditory stimulus than are others. The results also suggest that the relationship between the subsequent secondary reinforcing power of a stimulus and the inter-stimulus interval used to establish it is not monotonic.

A non-monotonic relationship between performance and inter-stimulus interval has also been found in previous studies. For example, it has been found with rats in the bar pressing task by Bersh and by Ward; in the classical conditioning situation with humans by Wolfle (1930), Spooner and Kellogg (1947), and White and Schlosberg (1952); and in the classical conditioning situation with rats by Kauppauf and Schlosberg (1937) and with fish by Noble, Cruender, and Meyer (1959). As in the present study, these studies found that simultaneous onset (zero inter-stimulus interval) was less efficient than the 500 msec. interval.

The relative efficiency or inefficiency of an interstimulus interval may be an empirical basis on which to explain the success or failure in establishing a secondary reinforcement. In the present study the results indicate that the use of 500 and 1000 millisecond interstimulus intervals established the tone as a secondary reinforcement while the use of "zero" and 2000 msec. did not. In previous experiments using the
pairing technique, a secondary reinforcement was demonstrated when the interstimulus interval was 500 msec. (Stein, 1958) or 1000 msec. (Hodge & Crowder, 1960), but was not demonstrated when the interstimulus interval was zero (Estes, 1949) nor when the reinforcement preceded the exteroceptive stimulus (Schoenfeld, Antonitis, & Bersh, 1950). Similarly, in previous experiments using the yoked control group method, a secondary reinforcement was demonstrated when the interstimulus interval between onsets was 1000 msec. (Crowder et al., 1959a, 1959b, and 1959c), but was not demonstrated when the interstimulus interval was zero (Wyckoff, Sidowski, & Chambliss, 1958, Experiment I) nor when the interstimulus interval was 2 seconds and greater (Wyckoff, Sidowski, & Chambliss, 1958, Experiment II).

Schoenfeld et al. (1950) at one time offered the hypothesis that the use of the neutral stimulus as a discriminative stimulus was a necessary condition for its establishment as a secondary reinforcement. However, both Stein's study and the present study established a tone as a secondary reinforcement by pairing it with ICS. It was established despite the fact that the procedure, as Stein states it, "did not provide, at the same time, the conditions favorable to its development as a discriminative stimulus." In the light
of these two studies, it is doubtful that the neutral stimulus must serve as a discriminative stimulus during training.

Wyckoff et al. (1958) have recently suggested that in the establishment of a neutral stimulus as a secondary reinforcer the primary effect is to increase its cue function for the response and that its reinforcing effect is increased very little if at all. However, both Stein's experiment and the present experiment have demonstrated that the performance level of the response delivering a tone increased after the tone had been paired with primary reinforcement. This occurred even though the response never was possible during pairing. It appears unlikely in such a procedure that the cue function of the tone for the response was increased.

Both the discriminative stimulus hypothesis (Schoenfeld et al.) and the cue function hypothesis (Wyckoff et al.) were made in response to negative findings. However, as this paper has already suggested, an alternative explanation of these negative findings (i.e., the failure to establish and demonstrate a secondary reinforcer) could be the inefficiency of the interstimulus interval that was used.

The use of intracranial stimulation as primary reinforcer is a technique which not only offers the advantage of precise control of onset, but also the advantage of delivery without associated exteroceptive stimuli. These advantages
make it ideally suited for the study of the effects of delay of reinforcement on the acquisition of a response. It would be interesting to compare the results of such a study with those of Ward who used secondary reinforcement and found that a short delay was superior in results to no delay.
SUMMARY

Thirty-six male rats for whom intracranial stimulation had a positively reinforcing effect on a nose response were presented a tone and a train of ICS 120 times each. In the five experimental conditions the tone and ICS were presented in pairs. The interstimulus interval between the onsets, while fixed within a condition, varied from condition to condition, using "zero," 500, 1000, 1500, and 2000 msec. In the control condition there was no fixed time interval between stimulus onsets; rather the tone and the ICS were presented independently of each other. After pairing, a bar was mounted in the test chamber. Depression of the bar delivered .5 seconds of tone. The number of bar responses in a 40-minute period was recorded for each animal. The number of bar responses made in a 40-minute period before pairing was subtracted from the number of bar responses made after pairing in the same period of time. The median difference for each group (six subjects each) was calculated. These were found to be higher for some conditions than for others. The 500 and 1000 msec. groups were significantly higher than the "zero," 2000 msec. and control groups but were not significantly different from one another. Neither were the "zero," 2000 msec. and the control groups significantly different from one another. The results were interpreted as suggesting that the relationship
between the subsequent secondary reinforcing power of a stimulus and the interstimulus interval used to establish it is not monotonic. The results were discussed in relation to the discriminative stimulus hypothesis and the cue function hypothesis.
BIBLIOGRAPHY


AUTOBIOGRAPHY

I, Bret Adolph Charipper, was born in New York, New York, May 25, 1932. I received my secondary-school education at Brooklyn Technical High School, New York, New York, and my undergraduate training at Columbia College, which granted me the Bachelor of Arts degree in 1954. In 1955 I received the Master of Arts degree in Psychology from the Faculty of Pure Science of Columbia University.

From June 1955 to June 1957, I was on active duty as a line officer in the United States Navy.

I was employed as a psychologist by the General Dynamics Corporation, Electric Boat Division, from July 1957 to September 1959. During this period I did psychological research on controls and information displays for submarine systems.

I was a teaching assistant in the Department of Psychology at Ohio State University during the 1959-1960 academic year. During the 1960-1961 academic year I was a research assistant for the Ohio State University Research Foundation, and in July 1961 I was appointed as a research associate.