STIMULUS PRODUCED AROUSAL PATTERNS AND LEARNING

Final Report

HD 00904 (1-8)
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PREFACE

This document is a report of eight years of research. It consists of an attempt to formulate a functional concept of Arousal, to develop a variety of measures of arousal, to relate the measures and experimental manipulations of arousal to standard phenomena of motivation, learning and performance.

The work is based on a theory of the relation of arousal to behavior. The theory has undergone extensive revision during the course of this research. Section I is a highly condensed, and largely undocumented, statement of the theory as it stands at this time.

The primary effort was to develop and use a measure of arousal that did not require confinement of the organism and would therefore permit continuous monitoring of the arousal level. The largest number of studies in this category concerned the measurement and manipulation of skin resistance in the rat. These studies are reported in Section II.

A smaller program of research on the output frequency of a weak electric fish, Gymnotus carapo is reported in Section III. The question was whether the frequency reflected the state of arousal of the fish.

Section IV reports an effort to develop a set of visual stimulus materials for use in studies of stimulus complexity and preference in human subjects. Also in this section are a number of studies of stimulus complexity and preference in rats.

Early in the period covered in this report, there were a number of studies of verbal learning and memory as they related to skin resistance in human subjects. These studies were reported in the major report written at the end of the first five years. No verbal learning studies have been done since that time, and therefore, this research is reported only in the form of lists of published and unpublished papers.
Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>List of tables</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>List of figures</td>
<td></td>
<td>ix</td>
</tr>
<tr>
<td>Section I</td>
<td>A theory of arousal and behavior</td>
<td>1</td>
</tr>
<tr>
<td>1.</td>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>Arousal as a concept</td>
<td>5</td>
</tr>
<tr>
<td>3.</td>
<td>Optimal arousal level</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>The diurnal cycle</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Optimal arousal during sleep</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Optimal waking arousal</td>
<td>12</td>
</tr>
<tr>
<td>4.</td>
<td>Choice behavior</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Mechanisms of arousal reduction</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Mechanisms of arousal induction</td>
<td>17</td>
</tr>
<tr>
<td>5.</td>
<td>Long-term characteristics of arousal</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Individual differences</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Genetic differences</td>
<td>22</td>
</tr>
<tr>
<td>6.</td>
<td>Arousal and concepts of motivation and performance</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Drive</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Incentive</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Approach-avoidance</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Pleasure-pain</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Performance</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Emotion</td>
<td>25</td>
</tr>
<tr>
<td>7.</td>
<td>Arousal and learning</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Kinds of learning</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Reinforcement</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Arousal learning</td>
<td>27</td>
</tr>
<tr>
<td>Section II</td>
<td>Skin resistance as an index of arousal in the rat</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Measurement techniques</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Basic studies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Typical values of BRL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effect of weight on skin resistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boredom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Handling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stimulus change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sex differences</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Individual differences</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Early experience and BRL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selective breeding for high and low BRL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Summary conclusions from basic studies of BRL</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>BRL and biological drives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estrus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hunger and thirst</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fear (Shock)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Summary of relations of BRL to biological drives</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>BRL and incentives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fear reduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water consumption (Thirst reduction)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consumption of water compared to consumption of liquids</td>
<td></td>
</tr>
<tr>
<td></td>
<td>containing nutritive and tasty substances</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BRL and food reward in the monkey</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Summary of BRL and incentives</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Conditioning of BRL</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Linear maze performance and the goal gradient</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arousal and the goal gradient</td>
<td></td>
</tr>
</tbody>
</table>

iv
The disassociation of BRL and running speed through stimulus change 133
BRL in learning, extinction, and relearning 137
The manipulation of the goal gradient through shock placement 143
Summary of goal gradient studies 147
8. Approach-approach and avoidance-avoidance conflict 149
9. Operant performance and arousal 154
  Skin resistance in a discriminated operant situation 155
  Fixed ratio reward and BRL 158
  Summary of operant performance and arousal 164
10. Discrimination learning under manipulated arousal 166
    Summary of learning and performance under manipulated arousal 170
11. BRL and heart rate as indices of arousal in conditioned suppression 171
12. Skin resistance, arousal, and behavior in the rat 181

Section III  Arousal in electric fish 185
1. Introduction 185
  Function of the electric discharge 186
2. General methodology and procedure 189
3. Light-dark cycle studies 192
4. Response to auditory stimuli 198
5. Response to solid objects 204
6. Discharge frequency and food deprivation 209
7. Discharge rate changes at feeding 212
8. Response to shock 218
9. Discharge frequency and arousal 220

Section IV  Stimulus complexity and preference 222
1. Introduction 222
2. Stimulus complexity and preference in human subjects 223
   Introduction 223
   Tartan patterns 225
   Stage set designs 236
Complexity, preference, and experience with graphics
Modern art
Summary of results of human studies of complexity and preference
3. Stimulus complexity and preference in animals
Two-dimensional versus three-dimensional complexity in the rat
Analysis of sequence of choices
Generalized complexity satiation
Effect of stimulus range on complexity and preference
Bias against repetition
Day-night cycle in rats
Frequency versus duration of response as a function of stimulus complexity
Summary of animal studies of complexity and preference
Section V Major results of the research program
Appendices Lists of published and unpublished papers supported by HD 00904 and K6-MH-21, 868
A. List of published papers discussed in this report
B. List of unpublished studies discussed in this report
C. List of published studies discussed only in the previous report
D. List of unpublished studies discussed in previous report
E. List of supported publications not discussed in either report
F. List of completed doctoral dissertations
G. List of honors dissertations
H. Current doctoral students with estimated time of completion
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table number</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Variations on being asleep and awake</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>Typical distribution of BRL values</td>
<td>41</td>
</tr>
<tr>
<td>3</td>
<td>Individual differences in skin resistance</td>
<td>57</td>
</tr>
<tr>
<td>4</td>
<td>BRL-BRL and BRL-weight correlations</td>
<td>59</td>
</tr>
<tr>
<td>5</td>
<td>Correlations of BRL with weight by sex and age</td>
<td>65</td>
</tr>
<tr>
<td>6</td>
<td>Data on early experience manipulations</td>
<td>70</td>
</tr>
<tr>
<td>7</td>
<td>Speed scores by kind and level of deprivation</td>
<td>83</td>
</tr>
<tr>
<td>8</td>
<td>Analysis of variance of minutes to recovery in the various sections of the maze across days</td>
<td>102</td>
</tr>
<tr>
<td>9</td>
<td>Response speeds in conflict situations</td>
<td>152</td>
</tr>
<tr>
<td>10</td>
<td>BRL in conflict situations</td>
<td>152</td>
</tr>
<tr>
<td>11</td>
<td>Response units to extinction</td>
<td>165</td>
</tr>
<tr>
<td>12</td>
<td>Effect of arousal manipulation during training</td>
<td>170</td>
</tr>
<tr>
<td>13</td>
<td>Percentage of time active in darkness and in light</td>
<td>196</td>
</tr>
<tr>
<td>14</td>
<td>Mean rate of discharge and moment-to-moment variation (lambda)</td>
<td>197</td>
</tr>
<tr>
<td>15</td>
<td>Correlation between initial discharge rate and magnitude of increase in response to tone for active and inactive states</td>
<td>200</td>
</tr>
<tr>
<td>16</td>
<td>Tartan patterns by name and physical characteristics</td>
<td>226</td>
</tr>
<tr>
<td>17</td>
<td>List of graphic prints</td>
<td>242</td>
</tr>
<tr>
<td>18</td>
<td>Complexity and preference scores</td>
<td>243</td>
</tr>
<tr>
<td>19</td>
<td>Modern paintings</td>
<td>246</td>
</tr>
<tr>
<td>20</td>
<td>Preferred compartments by days</td>
<td>261</td>
</tr>
<tr>
<td>21</td>
<td>Preferred stimuli by days</td>
<td>266</td>
</tr>
<tr>
<td>22</td>
<td>Preferred stimuli by successive 10-minute periods</td>
<td>267</td>
</tr>
<tr>
<td>23</td>
<td>Transitional probabilities of stimulus preference by animal</td>
<td>269</td>
</tr>
</tbody>
</table>
24 Changing preferences for stimulus complexities over time
   in terms of transitional probabilities  270
25 First order transitional probabilities  277
26 Day-night cycle effects on numbers of choices  282
<table>
<thead>
<tr>
<th>Figure number</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hypothetical arousal levels during diurnal cycles</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Sleep state transitional probability diagram</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Sample BRL records</td>
<td>38</td>
</tr>
<tr>
<td>4</td>
<td>BRL and weight</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>BRL and weight - unweighted trials</td>
<td>47</td>
</tr>
<tr>
<td>6</td>
<td>BRL and boredom</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>Effect of handling by experimenter on BRL</td>
<td>51</td>
</tr>
<tr>
<td>8</td>
<td>BRL response to stimulus change</td>
<td>54</td>
</tr>
<tr>
<td>9</td>
<td>Development of BRL - I</td>
<td>62</td>
</tr>
<tr>
<td>10</td>
<td>Development of BRL - II</td>
<td>63</td>
</tr>
<tr>
<td>11</td>
<td>BRL as a function of age, sex, and repeated experience</td>
<td>64</td>
</tr>
<tr>
<td>12</td>
<td>Prediction of BRL from weight</td>
<td>66</td>
</tr>
<tr>
<td>13</td>
<td>Selective breeding for BRL</td>
<td>71</td>
</tr>
<tr>
<td>14</td>
<td>Interaction of selective breeding and age variables</td>
<td>72</td>
</tr>
<tr>
<td>15</td>
<td>Interaction of age, breeding, and repeated experience</td>
<td>73</td>
</tr>
<tr>
<td>16</td>
<td>BRL, GSR, and estrus-related activity</td>
<td>78</td>
</tr>
<tr>
<td>17</td>
<td>BRL and water deprivation</td>
<td>81</td>
</tr>
<tr>
<td>18</td>
<td>BRL as a function of food and water deprivation</td>
<td>84</td>
</tr>
<tr>
<td>19</td>
<td>BRL as a function of food and water deprivation</td>
<td>85</td>
</tr>
<tr>
<td>20</td>
<td>GSR as a function of food and water deprivation</td>
<td>86</td>
</tr>
<tr>
<td>21</td>
<td>GSR as a function of food and water deprivation</td>
<td>87</td>
</tr>
<tr>
<td>22</td>
<td>BRL as a function of food and water deprivation</td>
<td>89</td>
</tr>
<tr>
<td>23</td>
<td>BRL as a function of food and water deprivation</td>
<td>90</td>
</tr>
<tr>
<td>24</td>
<td>GSR as a function of food and water deprivation</td>
<td>90</td>
</tr>
<tr>
<td>25</td>
<td>GSR as a function of food and water deprivation</td>
<td>91</td>
</tr>
<tr>
<td>26</td>
<td>Effect of shock on BRL</td>
<td>93</td>
</tr>
<tr>
<td>27</td>
<td>BRL recovery after shock</td>
<td>96</td>
</tr>
<tr>
<td>28</td>
<td>BRL response to shock</td>
<td>97</td>
</tr>
<tr>
<td>Page</td>
<td>Topic</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>BRL recovery time</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>BRL as a function of distance</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>BRL as a function of time</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Record of running and drinking while water deprived</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>BRL response while drinking</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>BRL response while drinking milk or water</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>BRL response while drinking sucrose or water</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>BRL response while drinking sucrose, saccharine or water</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Monkey response to grape reward</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>BRL conditioning</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Changes in BRL from pre-CS to CS period</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Conditioned BRL in conditioned suppression setting</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>The goal gradient in terms of speed and BRL</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>The development of speed and BRL</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Development of the goal gradient</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>BRL and latency changes in response to change in maze stimuli</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Learning, extinction and relearning</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>The goal gradient</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>The goal gradient</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>Learning with the effects of handling exaggerated by shock</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>The goal gradient under shock manipulation</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Light-sound discriminated operant</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>Light-sound discriminated operant</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>Light-sound discriminated operant</td>
<td></td>
</tr>
<tr>
<td>53</td>
<td>Skin resistance during fixed ratio reward</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>Extinction performance after fixed ratio reward</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>Skin resistance during fixed ratio reward</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>Extinction performance after fixed ratio reward</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>Discrimination and manipulated arousal</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>Relative general change in lever pressing, heart rate, and BRL from</td>
<td></td>
</tr>
<tr>
<td></td>
<td>adaptation to discrimination training and extinction</td>
<td></td>
</tr>
</tbody>
</table>
Relative courses of learning in three measures 179
Single electric organ discharge pulse of Gymnotus carapo 190
Light-dark cycle 193
Discharge frequency chart 194
Response to auditory stimuli 199
Discharge frequency changes in response to tones 201
Effect of intertrial interval on response to tones 203
Response to metallic object 205
Discharge frequency and time of food deprivation 210
Chart record of response to food 213
Discharge frequency changes at feeding 215
Discharge frequency before and after feeding 216
Response to shock 219
Physical versus psychological scales of complexity in tartan patterns 227
Complexity and liking 228
Shepard-Kruskal liking dimensions and complexity 230
Comparison of two scaling procedures 232
Complexity ratings as a function of range of stimuli 234
Complexity and 'interestingness' 235
Complexity and preference in stage set designs 238
Complexity and preference in stage set designs 239
Optimal complexity and experience 244
Comparison of 7-point and Shepard-Kruskal scales of complexity 249
Complexity versus preference in modern paintings 250
Complexity versus preference in modern paintings — Shepard-Kruskal scale data 251
Complexity versus preference for modern paintings 252
Complexity and preference for modern paintings 253
Complexity and preference and order of ratings 254
Summary of complexity and preference ratings 256
<table>
<thead>
<tr>
<th>Page</th>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>Complexity interaction index within days</td>
<td>260</td>
</tr>
<tr>
<td>89</td>
<td>Complexity interaction index between days</td>
<td>263</td>
</tr>
<tr>
<td>90</td>
<td>Stimulus complexity scales</td>
<td>264</td>
</tr>
<tr>
<td>91</td>
<td>Amount of prior experience and generalized stimulus preference</td>
<td>274</td>
</tr>
<tr>
<td>92</td>
<td>Change in stimulus preference with time</td>
<td>275</td>
</tr>
<tr>
<td>93</td>
<td>Generalized effects of stimulus exposure</td>
<td>276</td>
</tr>
<tr>
<td>94</td>
<td>The effect of stimulus range on preference</td>
<td>280</td>
</tr>
<tr>
<td>95</td>
<td>Action decrement to the fifth order</td>
<td>281</td>
</tr>
<tr>
<td>96</td>
<td>Frequency of response as a function of stimulus complexity</td>
<td>284</td>
</tr>
<tr>
<td>97</td>
<td>Duration of response as a function of stimulus complexity</td>
<td>285</td>
</tr>
</tbody>
</table>
SECTION I

A THEORY OF AROUSAL AND BEHAVIOR

1. Introduction

In the early part of the twentieth century, Psychology was characterized by the development of 'schools' which differed in approach, in problems, and in method. This phase was followed, beginning in the late 1920's and early 1930's by the development of what purported to be comprehensive theories of behavior, many of which concentrated on the phenomena of learning and motivation and others which emphasized personality development and structure. Very few such theories have appeared in the past twenty years.

In its most recent period of development, psychological theory has has tended to be less comprehensive, more oriented to narrow ranges of problems of behavior, and, above all, less pretentious. When attempts are made to formulate a theoretical structure concerning a set of problems, it has tended to be more like a tentative strategy than a grand design, to be a fluid, changing structure rather than an attempt to formulate a final answer.

The eight years of research discussed in this document have been guided by a general theory of behavior which has taken the concept of Arousal as its focus. The arousal construct may be regarded as an alternative to the Drive construct. Its appeal arises from the fact that since it is derived from neurophysiological considerations, it should be possible to develop one or more dependent variables which could be direct measurements of the arousal level. Direct and continuous measurement of arousal offers strategic advantages over manipulation, since manipulations usually apply only to what has been done to a group of organisms, while continuous measurement yields contemporaneous individual difference data.
Drive, in contrast to Arousal, can only be manipulated, but, except for activity measures which have a tenuous relation to the manipulation at best, there are no simple dependent variable measurements available. The relations between drive and performance are usually incorporated within the definition of the drive concept with the result that a direct empirical test of the relationship is logically impossible. Arousal, in contrast, offers the possibility of simultaneous measurement with performance measures being independent of the measure of arousal.

While the drive concept has been a fruitful one in behavior theory, there are certain inherent difficulties. One of the most important problems in learning is whether the amount of learning varies as a function of the drive level. Does a highly motivated organism learn more in a single trial than an organism which is less well motivated. The absence of a contemporaneous measure of drive has made the testing of this question difficult, if not impossible.

A major, but often ignored, difficulty with the drive concept is the contradiction involved when a hungry or thirsty animal (one that has been deprived of food or water) sleeps. The postulated relationship between time of deprivation and drive is a monotonically increasing function. By this postulate, the organism should be more active the longer the period of deprivation. Yet the animal continues to sleep periodically even in the continuous absence of food.

Arousal, in contrast, is usually defined in a manner to take into account the sleep-waking cycle. A sleeping organism represents a limiting arousal condition. A waking organism in obvious excitement characterizes the other end of the arousal dimension. This behavioral definition of the dimension is usually supplemented by the assumption that there are physiological indices which will bear a simple monotonically increasing functional relationship to the sleep-excitement dimension. In contrast to the drive concept, no definitional assumption is made concerning the relation of arousal to behavioral activity level. A classic conundrum of drive theory is how to explain the behavior of the cat waiting at a mouse hole. The cat appears
behaviorally inactive, yet is in a 'high drive' state in anticipation of pouncing. The arousal concept should handle this problem without difficulty and directly. It would be assumed that a physiological measure of arousal would show that the cat was in a highly aroused state although its overt behavior was statue-like.

A major difficulty with the arousal concept is associated with the assumption that there will be some simply physiological measure available. There are a number of physiological measures which can be and have been used to index arousal. Among them are skin resistance, heart rate, respiratory rate, muscle action potential, and various electroencephalographic recordings. The correlations between such measures tend to be low. Furthermore, some measures tend to show correlations with one behavioral phenomenon and not with another. There is also evidence of individual differences in autonomic mode of expression, some individuals seeming to reflect an aroused state with heart rate changes and another individual showing changes in skin resistance or respiration. There are additional difficulties arising from the lability of physiological indices in response to non-arousal variables. Skin resistance will respond to thermal variation, heart rate to physical effort, respiration to mild anoxia.

Despite these problems, the potential fruitfulness of the arousal concept, and the likelihood that physiological indices will yield meaningful measurements, even though they might be only partially and complexly correlated, argues for continued pursuit of the problem.

Progress in the laboratory often takes the form of the statement of tentative hypothesis followed by experimental test. If the area of research is fairly large, and the number of hypotheses fairly large, then the hypotheses tend to reflect a system of hypotheses that is dignified as a theory. What follows is a nearly cryptic statement of a skein of hypotheses concerning the relation of a concept of arousal and various aspects of learning, motivation, and performance. It is not offered as a theory in the sense in which learning theorists of the 30's and 40's presented systematic theories of behavior, but
It is offered as the current states of an interlocking set of hypotheses that serve to generate laboratory research.
2. Arousal as a concept

The term "Arousal" as used here is strictly an intervening variable. Basically, it is conceived as an intensity dimension of the functioning organism. Zero arousal can only refer to a dead organism. The maximum of arousal must be conceived as a state in which everything that could conceivably be happening within the organism is happening. If expressed in muscular activity, it would be tetanus. If expressed in cognitive terms, it would undoubtedly be a state of mental chaos.

Arousal is construed as being conceptually independent of stimuli. That is, it is assumed to be a characteristic of the living organism that is influenced by a great many factors, both internal and external. At the outset, it is not to be identified with any particular behavioral or physiological variable. Rather than to postulate such a relationship as an element of the theory, the strategy is to state tentative relationships that can then be explored empirically. If relationships of sufficient stability can be found, then they can be made a part of the basic theory.

Given this tentative status, the initial form of the arousal concept can be formalized as follows:

Arousal is a theoretical concept or intervening variable that is conceived to be a characteristic of an organism at any given point in time that can range in value from low to high as a linear dimension.
3. Optimal arousal level

It is a fundamental characteristic of arousal theory that there is a value of arousal that the organism appears to work to sustain. If the arousal level is very high, then the organism will perform various acts or undergo a variety of adjustments to reduce the level of arousal to or as close as possible to the optimal value. If the arousal level is too low, then the organism will perform acts or undergo various kinds of adjustment to bring the arousal level nearer to or up to optimum.

The diurnal cycle. It seems clear that arousal level is lower when a person is asleep than it is when he is awake. In fact, the word 'arousal' was probably chosen because of its meaning in the phrase 'arousing a person from sleep.' However, it is doubtful if the organism really occupies a wide range of values on the arousal dimension with any consistency. Rather, one can think of two states - asleep and awake - which are generally two narrow ranges of the arousal dimension, and the organism is typically in one state or the other.

The range of fluctuations in the schematic drawing of Figure 1 represent typical fluctuations during sleep and waking. It should be obvious that there are times when an organism might be in an intermediate state, for example, a state of drowsiness. Under abnormal conditions, states of excitement above the normal waking state can undoubtedly be achieved as well as states below the normal sleeping state. Hibernation is probably a lower arousal level than normal sleep, and abnormal states above and below normal or typical can probably be achieved through the use of drugs.

Despite the exceptions, the normal or typical pattern is for an organism to oscillate around one optimum during most of the waking state and around another during the sleep state.

If there is a typical sleep state and a typical awake state, then there must be mechanisms which control the states of arousal to keep them within
FIGURE 1

HYPOTHETICAL AROUSAL LEVELS DURING DIURNAL CYCLES

Schematic representation of the diurnal cycle in arousal, indicating minor variation around two relatively stable arousal level states — waking and sleeping.

Schematic representation of the diurnal cycle in arousal, indicating minor variation around two relatively stable arousal level states -- waking and sleeping.

narrow ranges. Furthermore, there must be controlling mechanisms which produce transitions from one to another. A complete account of the three sets of mechanisms, within the sleep period, within the awake period, and the transition between the two, is beyond the scope of this paper, but some speculative elaboration seems warranted.

Optimal arousal during sleep. Normal sleep requires that the arousal
level be kept within a relatively narrow range and at a sufficiently low level that the organism does not awaken. The basic data would be a temporal tracing of some index of depth of sleep. The most generally accepted index of arousal relevant to the sleep state is the EEG. The awake or aroused state is characterized by a desynchronized EEG pattern of highly variable fluctuations of low voltage. The sleep state is characterized by a high voltage, synchronous, slow wave pattern.

This simple EEG distinction was complicated by the discovery of rapid eye movement sleep (REM). Periodically, during the course of a normal night of sleep, subjects were observed to undergo periods of very rapid eye movement. During these periods, the musculature (except for the eye muscles) tended to go into an extremely relaxed condition, the sensory thresholds in all modalities tended to rise to very high values, frequency of dream reports tended to be very high, and the EEG pattern tended to be desynchronized and thus resemble the waking pattern. Thus during the periods of REM sleep, the brain gave evidence of being awake, while the body gave evidence of being in the most relaxed state of all.

Dement\(^1\), using EEG as the index of depth of sleep, placed REM sleep just below the waking state, and designated several EEG patterns of progressively slower wave form as deeper states of sleep, indicating four such levels. In this system, then, there are six distinguishable levels of arousal -- Awake, REM sleep, and Levels 1, 2, 3, and 4 of non-REM sleep.

Another index of depth of sleep is the probability that a person will awaken in response to a controlled stimulus. Williams\(^2\) reports a study in


which subjects were instructed to awaken whenever a fixed tone came on and to ignore a neutral stimulus. He found that using probability of awakening as an index made REM the deepest of the sleep states. However, if he punished a failure to respond with shock, his results showed the REM state to be intermediate between EEG stages 1 and 2. Thus the placement of REM on the depth of sleep scale appears open to question. The data indicate three different positions:

Dement
EEG Scale       A → REM → 1 → 2 → 3 → 4
Williams
No punishment   A → 1 → 2 → 3 → 4 → REM
Williams
Punishment      A → 1 → REM → 2 → 3 → 4

Williams\(^1\) has reported another test of the ordering of EEG indices of depth of sleep. This study is based on the logic that if any particular order of EEG states represents a scale of depth of sleep, then a subject during normal sleep should change from any particular state (other than the lowest and highest) only to the next higher or next lower level. Following this logic, he analysed the complete records of a number of night's sleep for several subjects and reduced the records to a sequence of states. Williams found it useful to use only four of the six states. He combined states 3 and 4, and the frequency of state 1 sleep was too small to deal with. Using these four categories of depth of sleep, he generated a transitional probability table. The basic data from the first order transitional probability table for one subject for three nights of normal sleep is arranged in the diagram of Figure 2. The two most obvious characteristics of the diagram are that even these four states do not order themselves in a line from awake to a deep level of sleep, and the probability of going into a state and out of it tend to

\(^1\) Williams, H.L., & Williams, Cindy L. Nocturnal EEG profiles and performance. *Psychophysiology*, 1966, 3, 164-175.
FIGURE 2
SLEEP STATE TRANSITIONAL PROBABILITY DIAGRAM

Diagram of transitional probabilities of shifting from the awake state into three distinguishable sleep states and the probabilities of shifting from one to the other. Data represent the sleep pattern for one subject for three nights and is taken from Williams and Williams.

Diagram of transitional probabilities of shifting from the awake state into three distinguishable sleep states and the probabilities of shifting from one to the other. Data represents the sleep pattern for one subject for three nights and is taken from Williams and Williams.

be different. The most probable sequence is from the awake state to Level 2 sleep and then back to the awake state. Both REM and Slow Wave sleep are entered only from Level 2. The most likely state to follow either is to reenter the awake state. It is most notable that there never appears to be
a transition from REM to Slow Wave sleep or the reverse. While other subjects show slightly different patterns, with some individuals showing some probability of going directly from the awake state to REM, the total lack of interchange between REM and Slow Wave sleep appears to be universal.

It is apparent from the two sets of data from Williams, that the relation of arousal to depth of sleep is not simple. Optimum arousal during sleep should be the lowest level, but there is no state that can be called the lowest level unambiguously. REM appears to be the lowest level in terms of overt musculature and sensory threshold, and the Slow Wave sleep state seems lowest in the EEG scale. The desired definition of optimum would be the state of the organism that mechanisms operated to maintain, but which state does the organism operate to maintain?

No simple answer is available, but an hypothesis could be offered for later test. Suppose that the classic trilogy of afferent, central and efferent represented functional divisions that could be in an awake or high arousal state or a sleep-like or low arousal state independently.

When the afferent system is 'inactive,' it would be in a state in which afferent input would be effectively gated out. This would be a relative matter, but the transmission rate in all afferent systems would be low in this state. When the afferent system is in an 'active' state, sensory information would be subject to processing in all channels. Selective attention to one channel would amount to making it active and the others relatively inactive.

When the efferent system is inactive, especially if we think of the motor system as representing the efferent system, then the organism would be motorically quiescent. When it is in an active state, then tonus would be high and movement would generally occur. On this side, the equivalent of selective attention would be selective responding.

The central system would be generally active during waking and during REM sleep. Thus the desynchronized pattern would the sign of central activity. When the central system was inactive, then slow synchronous waves would appear in the EEG.
The simple combinations of the two states in the three systems could define eight states. If we let A, C, and E stand for afferent, central and efferent, and if we let '+' stand for an active state and a '-' stand for a quiescent state, then the states of Table 1 are possible.

This speculation must, of course, be highly tentative. It has the virtue of providing one simple general principle that applies to each system independently. That principle would be that optimal arousal for the sleep-like state would be the level that the organism undertook to maintain. The mechanism for maintaining each at the low arousal level are yet to be worked out and will probably be the product of sleep research. It also has the virtue of providing at least one possible account for the complex transitional matrix in the depth of sleep research.

Optimal waking arousal. The fundamental assumption is that the organism seeks to maintain an optimal waking arousal level and it does so by whatever means is available. If for any reason, the arousal level is above optimum, the organism will do whatever is necessary to reduce it. If the arousal level is below optimum, the organism will do whatever is necessary to increase it.

Suppose a rat is placed in a simple environment with a few novel objects. The most likely sequence might be that the handling of the animal had produced an arousal level higher than optimal. The animal is therefore likely to remain where placed until he 'calms down' or reaches an arousal level that is less than optimum. That he will reach such a level is almost certain. When he will reach it will be a function of his own optimal level and the level of arousal produced by the handling. When his arousal level falls below optimum, he will begin to explore. He may then choose that object which has the potential of producing arousal nearest to his optimum. It may be that in the process of approaching it, it will produce an above-optimum level and he will then retreat. Eventually, however, he will approach again. During the course of his interaction with the novel stimulus, its capacity to produce arousal will be undergoing a progressive decrease. At some point
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Possible Interpretations

State 1  Normal sleep
State 2  Alert sleep while highly sensitive to stimuli
State 3  REM sleep
State 4  Sleep walking
State 5  Audience behavior at play
State 6  Any functionally decorticate state
State 7  Intense and concentrated physical activity
State 8  Normal, active waking
it will reach a level that is farther below optimum through this process of adaptation, than one of the other stimulus objects is above optimum. At that point, the animal will begin to explore the second stimulus. The sequence will continue in these terms, with the animal choosing at any moment in time that stimulus situation that offers the arousal level nearest to optimum.

A sequence of psychological events may represent a sequence of overt acts or movement, or it may represent a sequence of thought processes. The termination of one thought to be supplanted by the next would also be described in terms of the decline in arousal value of the current thought and its inevitable supplantation by the next thought, the choice of which was determined by its likelihood of coming closer to optimal arousal than other alternatives.
4. Choice behavior

Choice behavior involves two fundamental questions: (1) why does the organism stop doing whatever it is doing at any given moment in time? and (2) what are the factors which determine its choice of the next event in the sequence? This problem has been analysed in detail elsewhere. In that treatment, it was postulated that the organism sought optimal psychological complexity. The following is a summary of the position taken in that article.

"A normal alert organism can be described as one which selects successive events in terms of the psychological complexity of the alternatives. It chooses as a next event that one of the available next events which is nearest its optimal psychological complexity. The activation of the event promptly and automatically produces a sharp rise in complexity followed by a slow fall over an arbitrarily selected 500σ period. The automatic drop brings the complexity level of that event below optimum, forcing selection of a next event nearer optimum, to occur in the following 500σ. The psychological complexity of an event will depend on (1) the complexity of the stimulus, if there is one, that initiates the event; (2) the arousal properties of the event; (3) the frequency and recency of past occurrences of the event; and (4) selective readiness for that class of events.

"The ambient or operant level of complexity is usually slightly below optimum, and the organism is propelled onward by the automatic termination of the current event. The theory stated here is a push-pull, tedium-titillation theory. The mechanism, with respect to the termination of a single event, is a miniscule tedium or boredom. The organism then chooses the most titillating of the next alternatives -- that one which is arousing enough but not too arousing. The key or essential characteristic of the event is its neural

net and thus psychological complexity. Arousal is a potent but ancillary factor.

"The theory has two sources or origins. The debt to Dember and Earl\(^1\) has already been acknowledged. A similar debt is owed to Daniel Berlyne\(^2\). Berlyne postulates an optimal arousal level which the organism will strive to maintain. If the arousal level is too high, the organism will strive to reduce it. If the arousal level is too low, the organism will strive to raise it to an optimum level. The optimum in Berlyne’s theory, however, is not a resting place. If the arousal level is at optimum the organism will seek to increase the level by a small amount, if, among other things, immediate reduction is certain to be forthcoming. The mechanism for getting the organism off dead center arousal he calls an "arousal jag." The parallel between Berlyne’s theory and the one offered here should be quite apparent. However, by choosing complexity with its automatic reduction and optimal complexity as the value sought, as key variables, the mechanism becomes at once simpler, more parsimonious, and probably wider in its applicability. The need for that rather untidy deus ex machina, "arousal jag," is thereby eliminated. On the other hand, repetitive striving for optimal complexity can be fit as well into Berlyne’s theory of esthetic and epistemic behavior, and hopefully with improvement to both."

The arousal concept is intimately associated with the concept of stimulus complexity. Optimal stimulus complexity should be associated with optimal arousal level. A stimulus that is too complex should produce too high an arousal level. A stimulus that is too simple should produce an arousal level below optimum. Thus the mechanisms for reducing or inducing psychological complexity should be the same as the mechanisms for reducing or inducing arousal.

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Mechanisms of arousal reduction. The arousal produced by most stimuli is a very temporary effect. The conditions that insure that it is temporary may be several and various.

Most stimuli are of brief duration. The arousal produced by such stimuli tends to dissipate simply as a function of the disappearance of the stimulus. If a stimulus is external, then the organism can frequently choose to terminate the stimulus through a change in orientation. Thus stimuli may be initiated or terminated by the environment, or through orientation, an organism may initiate or terminate a stimulus. The cognitive counterpart might be shifts in attention.

Stimuli which persist are more arousal-producing at the onset than they are some moments later. Typically, the onset produces a relatively high arousal state which is immediately followed by a decline which will continue at an ever diminishing rate as long as the stimulus remains effective. This temporary reduction in arousal value continues for a considerable period after the termination of the stimulus and is correlated with the reduced evocative power of the stimulus which has been discussed elsewhere as action decrement. 1

Stimuli which are repeated undergo a semipermanent reduction in their arousal properties. This is the process generally referred to as adaptation. Theoretically, action decrement refers to the temporary decrement in arousal property, while adaptation refers to the permanent effect. Under most circumstances, the decrement to be observed is a combination of the two.

Thus the major voluntary mechanism for the termination of a psychological event and reduction in arousal associated with it is orientation away from the stimulus or a shift in attention, and the major involuntary mechanisms for the reduction in arousal are action decrement and adaptation.

Mechanisms of arousal induction. The major mechanism of arousal induction is stimulus seeking and its cognitive counterpart, the procession of one psychological event after another. We know more about the arousal

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properties of events that are initiated by stimuli than we do about the arousal properties of internally controlled events. Our discussion will therefore be in terms of the properties of stimuli. In many instances the same discussion can be applied to cognitive events.

All afferent input has a specific component and a non-specific arousal component. It would take several chapters to spell out everything that is relevant to the questions of the parameters of stimuli which affect the arousal value of their application. A few will be discussed here.

The various sensory modalities differ quite profoundly in their arousal properties. There is a study of the capacity of various stimuli to produce EEG activation depending on the depth of anesthesia that is relevant. Under the lightest anesthesia, all modalities were effective in producing arousal. With deeper anesthesia, visual stimuli lost their capacity. With still deeper anesthesia, auditory stimuli lost their capacity. Tactile stimuli were next and kinesthetic stimuli were the last to go. These differences seemed quite large. They indicate that the arousal value of a movement of the organism itself is probably very high, a characteristic worth keeping in mind.

Within a sensory modality, the intensity of the stimulus is an obvious variable, although I am not at all sure that intensity, with onset and offset rate controlled is very important. The rate of onset and offset is important. Sudden onset and sudden offset have large arousal value while gradual onset and offset have minimal value. This is very difficult to investigate in a manner to dissociate it from other factors. For example, a stimulus that produces an orienting movement undoubtedly has arousal value on its own, but the movement involved in orientation clearly confounds the situation by producing massive arousal of its own. If the act of attending is an adapted surrogate of orientation, then it is probable that the act of attending to a stimulus has its own arousal producing properties to add to those produced by the stimulus.

All of Berlyne's collative variables are directly related to the arousal properties of stimuli. I would interpret 'surprisingness' as being a function
of onset and offset rate. Novelty is related to variation in arousal with repeated interaction. Complexity of a stimulus is assumed to be related to the arousal value - the more complex, the more arousing.

The arousal value of a stimulus is usually, but not always, an immediate effect. The effect of a mildly novel stimulus is one of producing immediate arousal. A drink of water to a thirsty organism produces an immediate effect. Strong stimulation on the other hand may not have full effects immediately on application.

The effect of strong stimulation is worth elaborating. What is meant by immediate effect is that the arousal value of the stimulus in question is a direct neural effect. The informational component of a visual stimulus is transmitted over known primary visual pathways. The effects of the same stimulus on arousal involve links with the brain stem structures with effects that arrive at the visual cortex with a delay of 30-70\(\sigma\). This is the most immediate effect. Stronger stimuli may have the additional property of producing faster breathing and a variation in heart rate which make a further addition to the arousal state of the organism, and this effect is delayed by a matter of several seconds. Such a stimulus has an immediate effect of increasing arousal by a small amount followed by a further increase within a second or two. If the stimulus has even greater arousal properties, it may induce autonomic secretions, such as adrenaline, which produces a further increase in arousal that is delayed even longer in time. Thus the peak of arousal initiated by a strong or traumatic stimulus may be delayed for a considerable period of time.

In summary, a number of factors determine the arousal properties of a stimulus. Arousal value varies with modality, with intensity, with rate of onset and offset, with associated sources, such as movement, and with the frequency and character of previous experience.

To recapitulate the dynamics of choice behavior we have the following. The organism stops doing whatever he is doing at any moment in time when that event produces arousal that is farther from the optimum than some other
available event. An event loses arousal potential during its occurrence through stimulus removal or action decrement. The major variable that seems to affect the prolongation of an event is the relative complexity of the event.

The choice of the next event to occur is thus a joint property of the arousal value of the ongoing event and the arousal potential of one of the immediately available events. The organism will stop doing one when its arousal value falls farther below optimum than one of the immediately available alternatives. He will choose that alternative that promises likely restoration of something close to optimum. Dynamically, the push is supplied by the falling arousal value of the ongoing activity, and the pull is supplied by the prospects, or arousal potential, of the next alternative. This push-pull mechanism automatically produces a restless organism.
5. Long-term characteristics of arousal

It is assumed that the characteristic arousal level of an organism can vary with a number of very general characteristics. A few of these characteristics are the following:

Age. Arousal level is assumed to be virtually zero at conception and to rise on a positively accelerated curve during the first nine months and to continue to rise throughout the normal developmental period to a maximum and then decline with age. The shape of the curve would in part be an empirical matter depending on the particular index one chose. Since it is so difficult without further specification of the measurement of arousal to separate arousal from response capacity, it is difficult to determine where the maximum really is.

It is tempting to guess that the curve would generally follow the development and decline of general intelligence. This would mean that the curve would reach a maximum at age 17 or 18, perhaps, and would remain high through ages 30-35 and then decline slowly. On the other hand, it seems possible or even likely, that the maximum arousal level might be reached at a much earlier age, possibly as low as the fifth or sixth year. Since arousal refers to vigor as distinct from strength as well as direction of response, it would be reasonable if maximum capacity for arousal developed much prior to any behavioral expression of the maximum. Arousal would therefore be at an appropriate level to produce the development of both physical and intellectual capacities.

Individual differences. It seems very probable that there are characteristic and significant differences in arousal level between individuals, both when awake and asleep. That is, there are light sleepers and heavy sleepers as well as individuals who are characteristically hyperactive and relatively torporous. Nearly all behavior theorists have such a variable in their theories. Tolman has individual differences associated with all variables (the so-called
H. A. T. E. variables), but he also uses the word 'libido' to distinguish high output people from low output individuals. In Hull it is a little more difficult to find because he does not incorporate an individual difference variable in his concept of drive. The closest approximation to differences in characteristic arousal level in Hull is the constant $a$ associated with the formula for $K$.

$$K = 1 - 10^{-a/w}$$

In this formula, individual differences in intensity of reaction to an incentive, in this case the weight of food reward, is expressed by $a$.

It also seems likely that in the literature on the effects of sensory deprivation and handling during infancy on individual differences is a matter of characteristic arousal level, although it would be very difficult to sift it out of the profound disturbances so produced. However, the Scottie dogs in the social deprivation studies are clearly suffering from a defect in the arousal system.

**Genetic differences.** If there are palatable individual differences, then there is a distinct possibility that there are genetic differences. Differences in characteristic arousal level that would be attributable to genetic factors as opposed to environmental factors would be very difficult to determine unambiguously, as are differences in intelligence. However, the possibility is a real one that should be kept in mind.
3. Arousal and concepts of motivation and performance

The arousal concept is related in various ways to traditional concepts of motivation and performance. The following is an exploration of some of the possible relations it might have to some of the major traditional variables in this area.

**Drive.** The cyclical drives such as hunger and thirst may be nothing more than mechanisms which control the arousal properties of certain classes of stimuli. When an organism is hungry, edible food has arousal value. Satiation produces a reduction of arousal value. The development of hunger does not seem to be a matter of an increase in arousal, but a special mechanism for endowing food stimuli with arousal properties. The special property of the hunger drive could be the special capacity to re-endow food stimuli with arousal value. The arousal value of stimuli not functional in one of the appetitive drives would be exhausted and would not be so fully restored after a period of time.

There is no reason to expect all biological drives to be alike. Hunger and thirst may be, but they undoubtedly differ from breathing and sex. There is obviously something about the sex drive that involves more readiness to participate at some times than at others. Therefore, something akin to the variation in arousal value of a set of stimuli involved in hunger is also involved in sex. Yet, the fact that a little sexual activity produces a change in the arousal properties of other sexual activities, and the suddenness of satiation appear to be special mechanisms controlling the arousal value of this set of activities.

**Incentive.** An incentive is anything that represents a difference in arousal value. A positive incentive is anything that produces an arousal level that is nearer optimum. A negative incentive is anything that changes arousal level away from the optimum.

**Approach-avoidance.** This concept is relevant only to external sources
of arousal. An organism will approach something that moves it nearer to optimal arousal than it is at the time and avoids anything that will tend to move it farther away. Thus, with respect to external stimuli, approach and avoidance are a perfect index of incentive value. When the sources of stimulation are internal, this concept is useless.

Note that the same activity can be a positive incentive at one time and negative incentive at another, depending on the arousal state and its relation to optimum. The result will be that the same activity will be approached at one time and avoided at another. In fact, a positive incentive will produce approach behavior, and in the process of interaction, the incentive value can become negative with resultant avoidance, even in the absence of a more attractive alternative.

**Pleasure-pain.** Pleasure and pain are primitive, conscious properties of certain stimuli and they do not correspond very closely to either positive and negative incentives or to approach and avoidance. It is a patent fact that organisms, or at least human organisms, do not operate on the basis of hedonism. They do painful and unpleasant things and they frequently eschew actions that would give them obvious pleasure.

It seems likely to me that pleasure and pain are very primitive adaptive devices that are generally vestigial, like an appendix. As an appendix performs some digestive function, but is wholly unnecessary, pleasure and pain can be used to account for human behavior, but it will turn out to control only a small portion of the variance and will frequently make predictions which are systematically wrong.

**Performance.** Optimal arousal level is likely to produce maximum performance efficiency. Too high a level of arousal is likely to produce a decrement in performance, and too low a level will also produce inefficient performance. This is the classic inverted U-shaped function, and it does not have an absolute relationship to a particular arousal level, since it is dependent on the characteristics of the structure — the unconditioned response, the channel capacity, the habit strength, the simplicity-complexity of the stimulus, etc.
Emotions. Arousal level may be the intensity dimension of emotions. If so, then sleep would be the lowest emotional state, normal activity would represent a moderately emotional state, and states such as fear and anger would represent the extreme end of the dimension. The major difference between regarding arousal as a motivational variable and an emotional one is probably relevant to the question of cause and effect. Conceived as motivational, arousal is presumed to produce behavior. Considered as emotional, arousal is more likely to be the product of the behavior.
7. Arousal and learning

Kinds of learning. There are obviously at least two kinds of learning. One is a transfer of or semi-permanent change in arousal properties of stimuli or psychological events, and the other is a change in structure having to do with the residual of information processing. They can probably be distinguished in terms of their differential effects on certain dependent variables, but it is not at all easy. For example, in a choice learning situation, the structural change is probably indexed by choice probability. Before learning, the organism doesn't know where the food is - that is, the relevant information is not stored in his nervous system. After learning, the information is stored there, a structural change has occurred and he can be induced to choose correctly.

One would think that speed of response would index the arousal value of the event of entering the correct alternative and consuming the food. Unfortunately, this value is dependent, in part, on structure. Before the relevant information is stored, the organism is uncertain, oscillates, and expresses the lack of structural learning in slow performance. After the structural change has occurred (after learning), then performance speed probably relates to arousal value. That is why many learning curves tend to rise and fall. As the food in the situation begins to lose its arousal value, the reduction in speed of performance is accompanied by a lack of inclination on the part of the organism to tell you he still knows where the food is by going there.

Reinforcement. I do not regard this word as particularly valuable because it implies more than is true. I think that such statements as "those events which are accompanied by reinforcement are learned, while those events not accompanied by reinforcement are not learned" are nonsense. I think rather, that the occurrence of the event is a necessary and sufficient condition for learning. Thus, everything that occurs is learned. The question
is not really one of whether learning occurred, but a question of what was learned, how long it will be remembered, and what will its effect be on subsequent behavior.

**Arousal learning.** Much of the experimental work that occurs in the literature of animal learning is what I would call arousal learning. That is, it consists, primarily, in the manipulation of the arousal values of an event or a sequence of events.

A single event, such as the event elicited by a fixed stimulus, is characterized by a rise and fall in arousal on a single occasion of its presentation, the rate of rise and rate of fall, and the amount of the rise are controlled by mechanisms previously discussed. If the same event is elicited repeatedly, the normal result is a gradual decrease in the arousal produced by that stimulus. While we tend to call this semi-permanent adaptation, it appears to me to be almost indistinguishable from experimental extinction. If it is an event that generally tended to produce optimal arousal on first presentation, then it will gradually become a boring stimulus and will become a low item on the choice list. If it is originally very arousing, it will generally tend to be avoided. However, if it cannot be avoided, the process of adaptation will gradually bring it within the tolerable range (close to optimum). Thus the élan of Indian high steel workers.

If a high arousal stimulus is presented with a low arousal stimulus, the net immediate effect is probably an arousal level near the average of the two. With repeated pairing, the low arousal stimulus acquires some of the arousal producing properties of the high arousal stimulus. This is the learned drive and learned reward value acquired by the CS in classical conditioning.

When there is a structured sequence of events which is immediately apparent to the organism (when there is no need to store information about the situation) the organism will approach or avoid in terms of an evaluation of the entire sequence. Thus an organism will do a little work to obtain a small reward, and a lot of word to obtain a big one. It will endure an event (shock) with too high arousal properties, to achieve one with just the right
amount, especially when the alternative is something involving very low arousal. When the whole sequence is apparent, then this is a problem of a sequence of expected subjective probability (structure) and expected subjective utility (arousal value) functions.

In consideration of the relation of amount of learning to amount of arousal value, it is clear that the amount learned is a monotonically increasing function of the arousal level present at the time of pairing of two stimuli. This is a trivial conclusion, for it stems from a consideration of what is learned rather than the amount learned.

In consideration of the learning of arousal values in a sequence of events, it is probably worthy of note that both forward and backward conditioning of arousal value occurs. The evidence that backward conditioning does not occur has to do with temporal sequences of stimuli and overt responses. In that case it is understandable that an organism doesn't learn CS-US when its experience is US-CS. I once did an experiment in which a tone was paired with shock in one piece of apparatus. I varied the temporal relations and order of tone and shock. I then put the animals in another situation in which they had to jump a hurdle to turn off the tone. Response latency was an inverted U function of the time between CS and US with little difference between the forward and backward conditions.

**Description of "Reward" learning in arousal terms.** Within this system, the way in which ordinary reward learning would be described is the following. If you put an animal in the starting box of a T-maze, he will not leave it for a while because the novelty of the new place brings him close to optimum arousal level. When the stimuli of the start box begin to lose their arousal value, as they automatically do, the stimuli of the alley offer a closer approach to optimum. The animal will then leave the start box and proceed down the alley, exploring. He will go slowly, and may even retrace, but will finally reach the goal box. Assume he is hungry and that there is food in the box. Because he is hungry, the food represents a significant increase in arousal over the events that have gone before. You then remove him from the maze.
The arousal pattern is a sequence of little arousal peaks followed by declines until the animal attends to a new stimulus which produces another peak and decline, etc. The reward produces a relatively high peak.

When the animal goes to the wrong arm, there is no such peak because there is no food. Over a number of trials, the stimuli of the start box and the maze itself tend to lose their arousal value through adaptation (experimental extinction). The reward, however, will retain its arousal value much longer than the 'neutral' stimuli. Furthermore, through backward conditioning the arousal value of the reward spreads back to the choice point and lends to the correct choice some arousal value that is not applicable to the incorrect choice. The increased speed of running is a function of the adaptation process, and the selection of the correct alternative is a function of the differential arousal value acquired by the correct choice. If the animal is run many times, and assuming that he is fed daily, the food in the goal box will lose its arousal value, and the animal will begin to run more slowly and will begin to make errors.

A simple kind of avoidance learning is one in which the animal receives food on one arm of the T-maze and shock on the other. Now the arm leading to shock acquires more arousal value than the arm leading to food. This result probably occurs because the choice leading to shock simply acquires much greater than optimal arousal value.

The more complicated kind of avoidance, such as the standard avoidance paradigm in dog conditioning which combines classical, escape, and avoidance learning in the same paradigm is more difficult.

**Structural learning.** As I suggested before, every event that occurs is learned. All information that is processed is retained to some degree. I would guess that the efficiency of structural learning (amount learned) is a function of two variables that have to do with the organism, as opposed to variables having to do with the material to be learned. One variable is the degree of attention, and the other is the arousal level at the time of learning. I would assume that it was generally true that the structural change that occurs
when an event occurs is directly proportional to the degree of attention devoted to it. When attention is diverted from the relevant material by other external stimuli, then the organism is 'distracted' from the task, and information is received but inadequately processed.

The quality of structural learning is also probably a function of the arousal level at the time of information processing (or immediately adjacent to it in time). The principle is probably, the amount (efficiency) of learning of structure is a monotonically increasing function of the arousal level during the information processing. Quality, amount, and efficiency refer to the accuracy of reproduction and the duration of memory or the capacity to retrieve.

The mechanism of learning. A fundamental controversy in learning theory is the mechanism of learning. One position is that simple contiguity of the elements to be learned is the necessary and sufficient condition of learning. So-called 'reinforcement' theories specify that in addition to contiguity, there must be close proximity of either the reduction of a need or an increase in drive stimulation. In arousal theory, the amount learned should be directly proportional to the level of arousal at the time. For an item of a sequence to be selected out and become more probable, it follows that it would be necessary for it to be accompanied by a higher level of arousal than its temporal neighbors. Thus response selection could occur as a function of arousal increase, or arousal decrease, but most effective selection should occur if there is both an increase and a decrease associated with the event in question. Thus the best condition for response selection would be for it to be accompanied by a peak of arousal. Both arousal increases and arousal decreases would serve to isolate the element to be learned.
SECTION II

SKIN RESISTANCE AS AN INDEX OF AROUSAL IN THE RAT

1. Introduction

The series of experiments that are reported in this section represent an effort to determine the extent to which skin resistance in the rat can be measured in the freely moving animal and the extent to which measures of skin resistance could serve as an index of the momentary arousal level of the rat.

There were a number of arguments which could be offered in favor of embarking upon this line of research. A continuous measure of arousal offers the possibility of relating arousal to performance in a much more direct fashion than is possible with a manipulation such as food privation. Privation of food creates a strong presumption that the organism is motivated, but the fact of privation does not guarantee that every animal is appropriately motivated or that any particular animal is so motivated at a given moment in time. A continuous measure of arousal should yield data that is much more dependable.

The rat is an excellent animal upon which to acquire basic data concerning arousal because of the vast quantity of data concerning its behavior in a large variety of situations. Theoretically it should be possible to relate a program of research on arousal to all of the available data on motivation, learning and performance in the rat.

Skin resistance appears to be a likely measure of choice since a variety of possible means of measuring it from a platform on which the animal can be induced to stand or to walk seemed available. Thus, skin resistance might possibly be measured continuously without attaching anything to the animal - effectively without noticeable modification of the usual ex-
perimental environment of the animal.

There is some reason to believe that changes in skin resistance in the rat might be a direct reflection of the state of the midbrain reticular activating system. For example, Bloch has used skin resistance changes in the cat as a means of mapping the excitatory and inhibitory portions of the midbrain reticular. His procedure is to implant a fixed electrode in the excitatory area. When stimulation is provided through this electrode, there is an immediate and marked drop in skin resistance in the cat's paw. A second, traveling electrode is then introduced and lowered step by step through the reticular. At each step, stimulation is applied through both electrodes. When the result of stimulating both was a drop in skin resistance, Bloch assumed that both were in an excitatory portion. When stimulating both resulted in no skin resistance change, he assumed that the traveling electrode was in an inhibitory portion.\(^1\) Such strong evidence of a direct connection between the excitatory portion of the reticular activating system and skin resistance changes in the cat creates a strong presumption of such a connection in the rat.

There are a number of arguments which could be and were offered against embarking on this line of research. It seems likely that no single physiological measure will prove to be relatable to the concept of arousal in a simple monotonic fashion. For example, Lacey\(^2\) has summarized much research on physiological measures of activation or arousal. He has shown that no single measure is a perfect index, and that different measures

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do not show consistent correlations. Thus, the pursuit of a single measure as an index of a very general concept of 'arousal' appears doomed to failure.

It is generally assumed that skin resistance changes in human subjects reflects, at least in part, activity in sweat glands in the skin. Rats are not believed to have thermoregulatory sweat glands, and there appears to be no histological evidence of their existence. However, there is some equivocal evidence of some related activity.

Marzulli and Callahan\(^1\) report positive results in tests of capacity to sweat. In rats, they employed a starch-iodine test. The skin of the footpad is painted with a 2% solution of iodine in alcohol and then brushed with a 1:1 mixture of soluble starch and castor oil. When these animals were placed in a compartment heated to 100\(^\circ\) F. with 70% humidity, small brown spots developed in the starch, the usual evidence of perspiration. They report 35-52 active glands per squ. cm. under these conditions. The positive results obtained by these authors are encouraging even in the absence of histological evidence of sweat glands in the rat. It should be noted, however that placing a rat in an oven is likely to be a frightening experience. It is therefore not clear whether the observed glandular activity was thermoregulatory in nature or the product of an emotional response.

Finally, there is the set of technical problems involved in the measurement process. Assuming that the electrical circuitry can be built, the measurement of skin resistance involves using at least two footpads as electrical contacts. If the rat is to move freely, then these electrical contacts - an absolutely necessary part of the system - will obviously be faulty.

In summing up the advantages and disadvantages at the outset, the balance appeared to be against a profitable conclusion. Nevertheless, Stephen and Rachel Kaplan had the courage and faith to begin. Their efforts and the efforts of subsequent students was sufficient to motivate continuation.

2. Measurement techniques

The techniques of measuring skin resistance in the rat were developed by Stephen Kaplan, Rachel Kaplan, and James L. Hobart. They were based in part on the work of Lykken.\(^1\) The technical essentials have been published in detail elsewhere by Kaplan and Hobart\(^2\) and Kaplan and Kaplan\(^3\) and will therefore be described here in general terms.

The basic procedure is to induce the animal to stand on two pieces of metal in such a manner that his body closes a circuit. The circuit involves a constant current of 10-50 microamperes with the value in any one arrangement fixed at one level, usually 10 microamperes. Variations in the amount of resistance the animal offers to the passage of current produces variations in voltage.

Two platforms or floor arrangements have been used in most of the studies that are reported here. The first is the standard "shock grid floor" that is found in most commercial apparatus that provides for shocking the animal through the feet. This platform is a part of the standard Grayson-Stadler picnic ice chest type Skinner Box and a standard maze manufactured by the Hunter Manufacturing Company. In addition, some of the studies involve the use of tailor made apparatus with a similar grid floor.

The second platform is one that can be used only in a narrow alley or compartment. It consists of two pieces of stainless steel sheet metal


cut into two narrow strips and fastened to the bottom of a maze alley in such a manner that about 1/2 inch separates the two pieces and thus forms separated parallel strips the length of the alley with a narrow opening between, also the length of the alley. In this arrangement, the animal must stand on two electrodes and provide firm contact when standing still.

Skin resistance in these studies was usually recorded by means of a recording volt meter. Basically, the instrument was a Varian G-11 A (Varian Associates, Palo Alto, California). This instrument was chosen because it provided a 5" rectilinear writeout, provided an event marker, had its own amplifier, and was portable. Kaplan and Hobart designed an additional device which extended the range of the Varian, provided a calibration circuit, and limited the voltage at the upper end to prevent damage to the instrument when the animal broke contact and provided a momentary value of infinity resistance.

There are a number of sources of possible artifact in a skin resistance record, where any variable that is not related to arousal would be considered an artifact. Various means were adopted to deal with them.

An obvious artifact could be produced by the accumulation of dirt on the grid floor or on the parallel strips. This problem was generally handled by frequent cleaning, a procedure that is effective in dealing with the slow accumulation of dirt. In other instances, for example, when shock was employed, there was the possibility of the instant appearance of urine or feces, and thus the rapid accumulation of foreign matter on the electrode surfaces. This problem was dealt with by cleaning the surfaces in some instances, but by a matter of logic in others. Thus, urine and feces generally tend to reduce the area of contact and produce a higher resistance reading. If shock is employed, the fear induced produces a sharp drop in resistance. Thus the effects of the artifact and the effects of the variable are of opposite sign. The effects of shock cannot be accounted for by the artifact of foreign matter on the grid floor.

Polarization of the grid or the strips is a persistent possible artifact.
In the case of the parallel strips, the record would show a drop in resistance which tended to reach an asymptote in 3 to 5 seconds after the animal was placed in the apparatus. This was generally handled by retaining the animal in a starting box for a period, and then ignoring the first thirty seconds or so of the record. When the problem was carried out on the grid floor, the animal was rarely still long enough to permit polarization, tending to shift back and forth from one pair of grids to another. Polarization obviously did occur and was uncontrolled. However, it is very doubtful if any of the results reported in these studies can be accounted for in this manner. In general, the recording period for a single measurement was two or more minutes long, and the magnitude of the changes involved were several order of magnitude larger than that produced by polarization.

The two classes of apparatus have very different properties as situations for measurement of skin resistance. The advantage of the grid floor is that the animal can be permitted to roam at will through any sized space the problem calls for. The disadvantage is a very noisy record. As the animal walks on the grid there are brief periods in which he is not simultaneously in contact with bars of unlike sign. The resistance reading during those periods is, of course, infinity. The lowest reading is obtained when the animal has all four feet in firm contact with at least two bars of unlike sign. All of the various other possible forms of contact yield recorded values of skin resistance in between the minimum and infinity. Thus for any given period of time, the record is likely to appear like a series of excursions of the pen ranging from the infinity position to a variety of low points. To make such a record useful in research, the assumption was made that the low points were likely to represent some aspect of the arousal level of the animal since none of the likely artifacts (except polarization) would tend to lower a reading from its true value. In the earliest studies, a variety of measurement rules were tested in which the major difference was the period of time to be sampled. In these studies, it was found that if the record was marked off in two minute intervals, and the lowest point on the record taken as representing the whole
interval, a population of values was obtained that was essentially normally distributed. If a shorter interval was used, for example 15 sec., a number of the intervals would yield values several standard deviations from the mean of the sample. Thus, it seemed likely that with two minute samples, the probability that the animal would make firm contact with the grid at least once during the period was very nearly 1.0. If the sample interval was appreciably shorter than two minutes the probability tended to drop. As a consequence, the measure most frequently reported throughout this series of studies is based on the lowest resistance reading recorded during a two minute sample period. While this procedure appears to yield useful data, there is an obvious disadvantage. No change in resistance that occurs in less than two minutes can be handled with this technique.

The parallel strips yield a much cleaner record. There is 'noise' while the animal is moving, but there is an unambiguous record present whenever the animal pauses. The disadvantage of this procedure lies in the fact that it can be used only in problems in which the animal can be confined in a narrow (2 to 2 1/2 in.) space. The parallel strips have been used in straight alley problems, in one simple T-maze, and in a problem in which the animal could be confined in a small box or compartment. Sample BRL records from the two platforms can be seen in Figure 3.

Thus the difficulties seemed to be formidable. The record of skin resistance in the rat appears subject to a wide variety of artifact, not all of which can be convincingly eliminated in a given problem. The range of situations in which the measurements could be taken seemed limited. Rats might not have thermoregulatory glands that are presumed to be a source of at least some of the resistance changes observed in human skin resistance work. Should all of these problems be overcome, it is by no means certain that variations in skin resistance would bear any simple relation to the concept of arousal.

Nevertheless, the sequence of studies was begun by Stephen and Rachel Kaplan in spite of my discouraging advice. It was continued as results appeared to warrant further effort.
FIGURE 3
SAMPLE BRL RECORDS

A. Record from animal on shock grid floor.
B. Record of animal on parallel stainless steel strips.
3. Basic studies

While the primary interest in skin resistance and arousal lies in the question of the relation of arousal to drive and to various aspects of learning and performance, a number of studies were done in an effort to establish the basic properties of skin resistance. While many of them are of little intrinsic interest, they represent information that is necessary to make interpretation of the more interesting studies possible.

I have labeled this section 'basic studies' for this reason. In it will be considered the relation of skin resistance to such enduring characteristics as the weight of the animal, its age, sex, individual differences within sex, and whether animals can be bred for high or low skin resistance. We shall also consider some relevant short range variables as the effects of boredom, handling and stimulus change. Some of these variables were studied in experiments designed for the purpose, while in other cases, information was obtained during the course of experiments to be reported in later sections.

Typical values of BRL. Skin resistance is measured in ohms. In standard usage, the most common value reported in the literature is the GSR (Galvanic Skin Response). This value is typically the per cent deflection or per cent change in resistance produced by some stimulus or other relevant manipulation. The values of skin resistance (usually in ohms) that are needed to calculate a GSR value will be referred to as BRL (Basal Resistance Level). In the studies reported here, the long time sample needed to obtain a useful value precludes (except in rare instances) the demonstration of a momentary effect of a stimulus. As a consequence, nearly all of these studies involve comparisons of the resistance level over one relatively long period with the resistance level over another long period. Therefore, throughout this document, the basic measure of skin resistance to be reported is the BRL.

The recording instrument was generally calibrated to record from 0 to 4,000,000 ohms in its 5 inch excursion subject to the limitation imposed by the current limiter installed to prevent the marker pen from banging
against the stop at the end of the 5 inch excursion. Thus the record could be read typically as a linear scale from 0 to about 3,800,000 ohms. However, readings above 3,000,000 ohms were so rarely obtained under conditions in which the reading could be meaningful, that the effective range was 75% of the scale from 0 to 3,000,000 ohms.

To give the reader a feel for the kind of data yielded by this method, two sets of values for BRL have been tabulated and are presented in Table 2. The first set is essentially the first set of data obtained in this series. Rachel Kaplan\(^1\) acquired data on individual differences in BRL, the effect of boredom, and the effect of shock. The data tabulated in Table 2 are from 56 black hooded male rats that were nearly a year old at the time. She placed the animals in the picnic type Skinner Box with a grid floor and took measurements for the first 10 minutes. In reading the records, she took the mean of the three lowest values during the 10 minute period and thus recorded a single value for each animal. In four cases, usable records were not obtained. The 52 usable records appear to be normally distributed and range in value from 80,000 ohms to 8000,000 ohms.

The second set of data is from an unpublished study designed and carried out by Bruce E. Walker. It was the final study of the long series and was the first successful attempt to obtain data on the effect of the weight of the animal on BRL. This study will be described in detail shortly.

The values distributed in Table 2 were obtained from 18 male agouti hooded rats.\(^2\) They were also about a year old at the time and had previously


\(^2\)The agouti hooded rat is a strain of hooded rats developed from successive crossbreeding of the original Lashley albino strain, a strain of brown laboratory rat imported from Germany by Professor N. R. F. Maier, and the Long-Evans black hooded rat. The agouti hooded rat is white with a beige colored hood and with partially pigmented eyes. It is generally less emotional than other strains, makes an excellent pet, and tends to achieve better scores on most learning and performance problems.
### TABLE 2

**TYPICAL DISTRIBUTION OF BRL VALUES**

Distributions of skin resistance values in ohms obtained in the first and the last studies in the series. The values in the first study were obtained from 52 different male black hooded rats. Value is for the mean of the three lowest values obtained in a 10 minute period immediately after first introduction to a Skinnerbox. The values in the last study are four measurements each for 18 male agouti (Beige colored) hooded rats taken in a straight runway with a parallel strip floor. The animals were approximately 300 days of age at the time of the measurements. See text for explanation of second set of values in the Last Study.

<table>
<thead>
<tr>
<th>Range</th>
<th>Frequency</th>
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</thead>
<tbody>
<tr>
<td>1,910,000 - 2,000,000</td>
<td>1</td>
</tr>
<tr>
<td>1,810,000 - 1,900,000</td>
<td></td>
</tr>
<tr>
<td>1,710,000 - 1,800,000</td>
<td></td>
</tr>
<tr>
<td>1,610,000 - 1,700,000</td>
<td></td>
</tr>
<tr>
<td>1,510,000 - 1,600,000</td>
<td>1</td>
</tr>
<tr>
<td>1,410,000 - 1,500,000</td>
<td>2</td>
</tr>
<tr>
<td>1,310,000 - 1,400,000</td>
<td>1</td>
</tr>
<tr>
<td>1,210,000 - 1,300,000</td>
<td></td>
</tr>
<tr>
<td>1,110,000 - 1,200,000</td>
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<td>1,010,000 - 1,100,000</td>
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<tr>
<td>910,000 - 1,000,000</td>
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<tr>
<td>810,000 - 900,000</td>
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<tr>
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</tr>
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<td>3</td>
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</tr>
</tbody>
</table>

\[N = 52 \quad \text{Total} \times 4 \times 18 = 72 \quad \text{Total} = 72\]
been used in a learning problem. They were placed in a straight alley with a grid floor and permitted to run to the end for water under about four hours of water deprivation. The BRL measurement recorded in the table was from a one minute period in the starting box on each of the first four days for the 18 animals.

All of the measures taken are reported in the table. It seems clear that most of the measurements are normally distributed around the 200,000 to 300,000 ohm modal point. Several of the measures, however, clearly fall outside of this range. Eight of the nine highest values were from two animals. The ninth value was obtained from a third animal on the fourth day.

Since this was a study of the effect of weight on BRL, these animals ran for the next four days with small weights attached. The second set of values are four measures each for the 18 animals on days 5 through 9 with the weights attached. It can be seen that not only did the weight reduce the BRL value, but the frequency of 'out of scale' values of BRL was reduced to one. The pattern of readings suggested that in this study, we had encountered a rare situation that was found only with the agouti hood, of an animal succeeding in walking on the strips primarily on toenails instead of footpads. In previous instances, such values had been eliminated by the expedient of trimming the nails. In this study, the added weight had effectively accomplished the same purpose. As a consequence, the nails were not trimmed, in order to avoid the emotional upset of the animal that would be involved. Instead, BRL values above 5000,000 ohms were simply discarded. In 432 measurements, 18 were discarded using this criterion, slightly over 4%. This percentage of unacceptable readings was unusually high.

**Effect of weight on skin resistance.** It is obvious that the amount of resistance which will be recorded will vary as a function of the weight of the animal. The human observer can make contact on the grids or on the parallel strip bars and induce the resistance reading to fluctuate by varying the amount of pressure exerted at the points of contact. There are two general ways of determining the magnitude of this effect. One is to weight a group of animals and take skin resistance measures under a set of standard conditions.
The two values can then be correlated and a regression equation can be used to evaluate the quantitative relationship between weight and BRL. The other class of procedure is to somehow induce weight differences, such as attaching standard weights to the animal. The effect of weight on skin resistance can then be seen in differences in value between readings with and without the weights attached to the same animal. Both of these techniques can be employed in a single study.

The weighting of animals was accomplished in the same way in which horses are handicapped in handicap races. Small 'saddles' were made for the animal to wear on all trials. On some trials, fish weights were inserted in small pockets in the 'saddles' to increase the weight of the animal and thus the pressure exerted against the grid floor.¹ The detailed statement of methods and procedures is as follows.

Subjects. The subjects were 18 male agouti rats which were approximately one year of age at the time of the study. They had previously been used in an operant conditioning study involving food reward.

Apparatus. The apparatus was a 50 in. runway, 5 in. high and 3 in. wide. It was constructed of unpainted wood sides with a wire mesh roof. The floor consisted of two parallel stainless steel strips separated by .5 in. in the middle of the alley. The starting alley was 10 in., the goal box was 10 in., and the runway 30 in. The starting alley and goal alley were separated from the runway by guillotine-type gates, and photoelectric cells were placed at the gate positions arranged in a vertical orientation. A water bottle was attached to the end of the alley so that the spout projected through the end of the goal box. BRL was measured by passing a current through the stainless steel strips and recording variation in the resistance imposed by the animal on the standard Varian recorder.

Procedure. The animals were caged individually and allowed ad lib access to food and water except for the four hour deprivation period before

¹This study was designed and executed by B. E. Walker, and most of the data analysis was carried out by J. L. Williams. Since this study has not been published, the routine statement of methods will be included in the text.
each trial. There were two trials per day for 12 days. Access to food and water was allowed for 15 minutes immediately before the second period of deprivation for the day.

On each trial, the animal was removed from the home cage, wrapped in a 'belly band' made of a piece of ACE bandage to which standard hood and eye fasteners had been sewn. The bandage had been made with small pockets on either side into which small lead fish weights could be inserted to increase the total weight of the animal and to manipulate the amount of pressure exerted on the stainless steel strips by the footpads of the animal. The animal was then weighed and placed in the starting box. The starting gate was then raised and the animal allowed to proceed to the second gate. It was then raised and the animal allowed to enter the goal box to drink. After 30 sec. in the goal box, the animal was removed, the belly band removed, and the animal returned to the home cage.

On each trial, three values were recorded: the weight of the animal, total time from start box to entry into the goal box, and the mean BRL in the maze. Mean BRL was the average of the lowest value obtained in the start box, the first half of the runway, the second half of the runway, and the goal box.

On the first four trials, the animals were run without weight added but with the bands in place. On the next four trials (5-8) weights were inserted in the pockets. These days served largely to accustom the animals to wearing the band with or without weights present. On the next 16 trials (9-24) half of the animals had weights inserted during the trial and half did not. Individual animals ran with weights inserted on alternate trials during this period. The average difference in weight between the weighted and unweighted animals was approximately 35 grams.

Results. The primary effects of the animpululation of the weights is shown in Figure 4. The data in the figure are based on the last sixteen trials. In the figure on the left it can be seen that the skin resistance was significantly lower when the animals carried small lead weights in the pockets.
of the saddles in comparison to the BRL during the trials without the weights. In the figure on the right, it can be seen that the mean weight difference was approximately 35 grams.

![Graphs showing BRL and weight changes](image)

**FIGURE 4**

**BRL AND WEIGHT**

The figure on the left shows the skin resistance of animals while carrying weights compared to the skin resistance of the same animals on trials when they were not carrying weights. The figure on the right shows the mean weight of the groups throughout the experiment, again divided on the basis of being with or without weights added to the saddles.

There is one obvious anomaly in the BRL curves on the left. Both curves (the weighted and the unweighted) rise. This result is expected as will be shown later, during the acquisition phase of a simple learning problem. The anomaly is in the curve for the weighted animals when it turns sharply
downward during the last four trials of the experiment. This was a totally unexpected result and can only be explained post hoc. The animals in this experiment were approximately one year of age at the time of the study. They were chosen at that age in the expectation that there would be little growth or weight change during the course of the experiment. However, as is clear in the figure tracing the actual weight of the animals at the end of the experiment was approximately 40 grams greater than at the beginning. It is possible that animals that are involved in a benign experiment in the hands of a gentle experimenter are healthier and happier than the same animals under unvarying maintenance conditions. Whatever the explanation, these animals appear to have gained more weight in a short span of time than comparable animals would have gained under standard maintenance. Since this result was completely unexpected, no control animals were weighed twice daily to determine what the normal weight gain might have been.

Since the weight gain was unexpected, no provision was made for adjusting the saddles for size during the experimental period. The experimenter who ran the animals observed that near the end of the experiment, it was more difficult to insert the weights in the saddle pockets than it had been earlier. The animals objected to the insertion for the first time. Thus it is likely that the preparation process, which was routine earlier in the study, became distressing to the animals late in the experiment. If so, one would expect a drop in skin resistance as a function of the stress. Thus the meaning of the last point on the weighted curve must be reserved.

When the study was designed, it was hoped that the results would permit a simple translation of grams into ohms. The mean difference in BRL in the first four trials is approximately 40,000 ohms, and the weight difference is approximately 35 grams. Therefore, each gram of weight appears to reduce skin resistance by a little over 1100 ohms. In the next four trials, the difference is approximately 46,000 ohms yielding an estimate of slightly over 1300 ohms per gram. In the next four trials the difference is about 24,000 ohms yielding an estimate of just under 700 ohms per gram. The final four trials give an estimate of slightly more than 4000 ohms per gram, but it is obvious that this estimate is not to be taken seriously.
The second approach to the problem of the relationship between weight and skin resistance is to examine the relationship between individual differences in weight and individual differences in skin resistance. It is apparent in Figure 4, that we just examined, that major changes in both weight and skin resistance were occurring during the course of the experiment. Therefore, correlations were run on data samples at selected points in the course of the study that did not involve great changes in either BRL or weight. Three correlations were run on three sets of data, all involving trials when weights were not employed. The results may be seen in Figure 5.

![Figure 5: BRL AND WEIGHT](image)

**FIGURE 5**

**BRL AND WEIGHT**

**Unweighted Trials**

Correlations between individual differences in weight and individual differences in skin resistance (BRL) on selected trials.
On the first two trials (both run on the same day) the correlation was -.67. The slope of the regression line yields an estimate of approximately 720 ohms per gram. Measures taken on trials 11-14 (trials 3-6 in Figure 4) yield a correlation of -.47 and an estimate of about 650 ohms per gram. The correlation on trials 23-24 (trials 15-16 in Figure 4) is only -.18 and the slope of the regression line yields an estimate of approximately 500 ohms per gram.

Thus the manipulation of weights by inserting lead weights in the saddles yield estimates of 700, 1100, 1300, and 4000 ohms per gram, and the individual difference analysis yields estimates of 500, 650, and 720 ohms per gram. Since the one estimate from the manipulation of weights is probably in part a function of the inadvertent stress of the animal, it can probably be rejected. Since the other three estimates were also obtained immediately after the insertion of weights, any mild stress this operation might have caused would have tended to lower the resistance level compared to trials on which there were no weights. Therefore, all of the estimates taken from the weight manipulation are probably high. The variation in the estimates makes it clear that no simple translation of ohms into grams is reasonable.

One can conclude, however, that skin resistance does vary significantly as a function of the weight of the animal. It will therefore be necessary to take possible variation of weight into account in all studies in which this could be a factor. If one had to make an estimate of the quantitative relationship between weight and BRL, about the best guess that one could achieve from this study would be that 1 gram in weight was equal to from 500 to 1000 ohms.

Boredom. Most standard psychological experiments with rats require that an animal be in a standardized environment for some period of time and they frequently require the animal to have a number of trials and thus to be reintroduced to that environment a number of times. Thus, in relating skin resistance to most psychological variables of interest, it is important to know whether skin resistance changes as a simple function of the passage of time in an unvarying environment or if it changes systematically when an animal is repeatedly placed in the same environment. The term 'boredom' is a
handy label for the conditions under consideration, and the use of that label here does not imply a real anthropomorphism.

Rachel Kaplan investigated this problem in one of the very early studies that has already been cited.\(^1\) She placed 56 animals one at a time in a picnic type Skinner Box. Such boxes contain an inner plastic box that is about one cubic foot in size, has a variety of visible lights and levers, is lighted, and is provided with a ventilation fan that is relatively noisy but unvarying. Thus random noises from outside are generally masked. Such an environment induces a certain amount of exploration on the part of the animal which will subside within a few minutes. With repeated experience, the period of exploration is likely to grow shorter each day.

The animals in this study were left in the boxes for 30 minutes per day for three days with no other manipulation of the animal or the environment during this period. The mean resistance levels are shown in Figure 6. A single measurement was taken during the first ten minutes and another during the last 10 minutes of each of the three days by the method previously described (averaging the three lowest points in the 10 minute record). As can be seen in the figure, there is a significant rise in skin resistance over days and the difference between the two plotted curves reveals the rise within days. Kaplan reports significant \(t\) tests between Days 1 and 3 in both curves, and between each of the three pairs of points within days.

Again, estimates of the relation between time units and BRL are quite variable. Within Days, the differences between the points are approximately 55,000, 64,000, and 83,000 ohms. Since the two measures average 20 minutes in separation, a best guess of 60,000 per 20 minutes would indicate


a conservative estimate of a rise in BRL of 3000 ohms per minute in this environment. The changes between days are also variable, being approximately 47,000 and 26,000 ohms in the first measurement period, and 56,000 and 45,000 ohms in the second measurement period. Thus a crude and conservative estimate might be an expected rise of about 45,000 ohms per 30 minute day.

![Graph of BRL and Boredom](image)

**FIGURE 6**

**BRL AND BOREDOM**

Mean resistance (BRL) in 10,000 ohm units. Animals were confined in a Skinner Box for 30 minutes per day for 3 days. Plotted values are for the first 10 minutes and the last 10 minutes for each day.

animal before it is picked up and the manner in which the animal is handled
by the experimenter. Since animals are handled routinely in nearly every experiment, it is important to know whether this routine handling produces a change in the skin resistance or BRL.

In the course of a study designed to measure BRL during the course of learning, extinction and relearning of a straight alley maze, handling was made an independent variable in the following manner.\(^1\) Twenty-four black

---

\(\text{FIGURE 7}
\)

\textbf{EFFECT OF HANDLING BY EXPERIMENTER ON BRL}

Mean BRL values (in 20,000 ohm units) of two groups of rats which were handled either during the second minute or the fourth minute of a five-minute delay period in the starting box.

---

hooded rats which were 130-140 days of age were given a total of 22 trials each in the straight alley. On each trial, a 5 minute waiting period was instituted in the starting compartment before the run. Half of the animals were removed by the experimenter during the second minute and the other half were removed during the fourth minute. It is then possible to measure the amount of drop in BRL between the first and third minutes in one group and between the third and fifth in the other. The effects of handling are apparent in Figure 7.

Translated into ohms, the drops in value are approximately 32,000 ohms in the one group and about 52,000 ohms in the other. The only meaning that these values can have is that they are relatively large. The particular experimenter in this instance has a very gentle hand with rats and probably produces a minimum of arousal. Other experimenters have been known to produce much greater effects even while attempting to be as gentle as possible.

Very little can be said concerning the recover rate. Under normal circumstances one could expect BRL to increase over the 5 minute period because the environment of the starting box is unvarying and probably boring. Thus the decreases in BRL seen in the figure probably replace increases which would have occurred otherwise. Therefore, an estimate of 50,000 ohms decrease in BRL as a function of handling (and an unknown recovery rate) is about the best estimate that is available.

**Stimulus change.** It is of interest whether simple stimulus change also produces a drop in skin resistance. In studying handling, the amount of change is gross, and it could possibly involve threat not involved in a simpler environmental change. Furthermore, in studying handling, the measurement is, of necessity taken some time after the manipulation.

Our efforts to determine the effects of stimulus change have met with mixed results. The first study yielded effects of stimulus change that were profound and reliable. A substantial second effort produced results that were entirely negative.

Positive results were obtained in a study of stimulus change and estrus in rats.¹ In this study, which will be reported in detail in the section on

biological drives, 6 male and 14 female rats were tested. They were placed in Skinner Boxes for 25 minutes a day for two days before testing began. On the next five days they were also placed individually in the boxes for 25 minutes. To produce stimulus change, the outer doors of the picnic-like boxes were opened during the 11th and 12th minutes. They were then closed for 11 minutes and opened again for the final 2 minutes of the 25 minute period.

The results of the stimulus change operation is clear in the upper portion of Figure 8. The upper curve for the female animals showed decreases of 180,000 ohms and 45,000 ohms for the two openings of the door. The lower curve for the male animals showed decreases in BRL of 190,000 and 125,000 ohms for the two manipulations. Furthermore, in data not shown in the figure, the amount of change in the female animals varied with the stage of estrus with little or no change occurring during metestru and the largest stimulus change effect occurring during diestru.

Negative results were obtained by Donald Dewbury in a series of unpublished studies of the effects of time of food and water deprivation to be discussed later. A sample of Dewbury's results are in the lower portion of Figure 8. In these studies, Dewbury was following the general procedure of depriving animals of food or water and testing for differences in BRL by placing the animals in the Skinner Boxes for periods of 20 minutes. In some studies he introduced white noise during the 11th and the 16th minutes and observed no effect of the stimulus change. In one instance, he also used the same stimulus change procedure employed in the earlier study - opening the outer door of the box. Still no effect of stimulus change was observed.

No satisfactory resolution of the discrepancy between the two sets of results has been achieved. Dewbury's animals were generally in the boxes for suitable lengths of time and for a number of days. The number of animals and the number of observations were suitably large. The levels of BRL when the stimulus changes were introduced were high enough to suggest boredom, 700,000 to 800,000 ohms on the average in the figure. Experimenter differences seem an unlikely explanation, since the measurements were taken some minutes after last contact between the animal and the experimenter in both sets of studies.
FIGURE 8

BRL RESPONSE TO STIMULUS CHANGE

A. Walker, Cohen and Doyle.

B. Dewsbury.
This unresolved discrepancy was a major factor in the decision to suspend journal publication until a substantial number of studies were completed and subject to comparative analysis.

**Sex differences.** While most studies use only male or only female rats, it is of some interest to know whether skin resistance differs systematically between male and female animals. The upper portion of Figure 8 shows such differences. Rough approximations of the differences between the two curves at the five paired points are 145,000, 165,000, 170,000, 185,000 and 265,000 ohms.

Unfortunately, the weights of these animals were not recorded. There is usually a weight difference of 40–60 grams between the heavier male and the lighter adult female. Taking the minimum estimate of 40 grams and the minimum estimate of the effect of weight, 500 ohms per gram, the estimate of the difference in BRL to be accounted for on the basis of weight differences would be about 20,000 ohms. Taking the higher estimate of the weight difference and the higher estimate of the weight effect (1000 ohms per gram) gives a calculation of 60,000 ohms difference in BRL based on the weight difference. Even if the weight difference was as much as an unrealistic 100 grams, the observed differences in Figure 8 cannot be accounted for on the basis of differences in weight.

One would therefore conclude that male rats typically show significantly lower skin resistance readings, and that the difference is probably larger than can possibly be accounted for on the basis of the fact that they are heavier than the females.

**Individual differences.** It is a common observation that among a group of rats that have a common heritage, that are of the same sex and strain and have had similar experiences, there are observable differences in "emotionality". Some are calm and stoic when handled while others are likely to be skitterish. Some are quite safe to handle, while some are likely to bite the experimenter. It is therefore of interest to know whether there are individual differences in skin resistance that might reflect this differences in emotional disposition.
Data relevant to the problem of individual differences in skin resistance were collected and reported by Rachel Kaplan.\(^1\) The data described in the section on "Boredom" can be analysed for individual differences. She categorized her data into 'High,' 'Mid,' and 'Low' BRL values and made a comparison of the classifications of individual animals on different days. In the upper portion of Table 3 (the a. portion) are the frequencies and proportions of animals in these categories during the first 10 minutes of the first two days. There is obviously a significant association. It is apparent that there are individual differences in the sense that the skin resistance measure on one day is predictable from similar measures under comparable conditions on another day. However, considerable caution is to be exercised in interpreting these results.

In the same study, Rachel Kaplan subjected her animals to shock. It was therefore possible to compare the skin resistance levels of animals before and after a very effective fear inducing manipulation. A representative sample of her data are contained in Table II. 3a. In this table it can be seen that the two measures are essentially unrelated. This result would support an interpretation of individual differences in skin resistance as differences in 'emotionality.' The argument would be that a traumatic shock would induce intense fear in all animals, regardless of individual variation among them. Thus one would expect shock to wipe out individual variations.

An alternative interpretation of individual differences in skin resistance arises from a consideration of the weight of the animal. As we saw in a previous section, differences in weight produce differences in skin resistance. Table 3c. contains the results of a similar individual difference analysis applied to some of the data from the weight study. In this instance, there were 18 animals, and four contingency tables were generated for this group from four relatively

### TABLE 3
INDIVIDUAL DIFFERENCES IN SKIN RESISTANCE

a. Comparison of resistance levels during the first 10 minutes of 30 minute sessions in Skinner boxes on two successive days.

<table>
<thead>
<tr>
<th></th>
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<th>High</th>
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<td>High</td>
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<td>14</td>
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b. Comparison of resistance levels in 10 minute period just before shock with 10 minute period immediately after shock.

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</tr>
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<td>2</td>
</tr>
<tr>
<td>Mid</td>
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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>c. Comparison of skin resistance levels during trials in straight alley maze with weight of animal.</td>
<td></td>
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<td></td>
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<tr>
<td>Resistance</td>
<td></td>
<td></td>
<td></td>
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<tr>
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</tr>
<tr>
<td>High</td>
<td>1</td>
<td>4</td>
<td>19</td>
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</table>

57
stable periods during the training. Since the four tables were nearly identical in character, they were combined for inclusion in a single table. It is clear that there is a very strong association of individual differences in weight and individual differences in skin resistance. This result suggests that the individual differences in skin resistance observed by Kaplan might be attributable in large part to individual differences in the weight of the animals.

Because of the small differences in the two contingency tables that have just been compared, one further comparison was developed from the data of the weight study. In that study, a number of measures of BRL and weight were taken only a few seconds apart. That study also provided repeated measures of BRL taken on the same animal a few hours apart and without intervening experimental manipulations. Furthermore, the weight study was done using the parallel stainless steel bar apparatus which gives a more reliable record of BRL. These data were used to generate the two scatter plots in Table 4.

Inspection of the two plots makes it apparent that most, but not all, of the correlation between successive measures of BRL in the same animal can be accounted for by differences in weight.

There can be an argument that there are residual individual differences in BRL on several grounds. Inspection of the plots suggests a slightly greater correlation between the two BRL measures than between BRL and weight. The two BRL measures were separated by a larger time gap, several hours as opposed to a few seconds. BRL measures, even in the better measuring situation, are subject to a greater range of errors of measurement than are measures of the weight of the animal. All three factors would tend to reduce the association between the two BRL measures. Furthermore, as previously noted, the application of strong shock tends to eliminate the correlation between skin resistance measures.

Yet, the technical problems are of sufficient magnitude that an attempt to tease out the differences, either experimentally or statistically seems fruitless. Furthermore, even if it was possible to remove the effects of weight and still demonstrate a residual individual difference factor in BRL, it is not at all clear
<table>
<thead>
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<table>
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</thead>
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<td>340</td>
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<td>350</td>
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**TABLE 4**

BRL-BRL AND BRL-WEIGHT CORRELATIONS

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<th>Weight of Animal in grams</th>
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<td>340</td>
<td>1 1 1</td>
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<td>1 3 2 2</td>
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</table>

<table>
<thead>
<tr>
<th>BRL in 20,000 ohm Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 11 12 13 14 15 16 17 18 19 20 21 22 &gt; 22</td>
</tr>
</tbody>
</table>

59
that such differences could be interpreted as individual differences in arousal. There are many other possible factors which could affect the BRL measure that could lead to alternative interpretations. Animals might differ in skin characteristics, or might differ in manner of walking. These and other non-arousal related factors could possibly account for the differences.

Thus one can conclude that there probably are small individual differences in characteristic BRL between animals, but that individual differences in arousal have not been established.

**Age.** There are a number of reasons why one might expect to find differences in skin resistance with age differences. First, there are the data of Richter which indicate that activity varies with the age of the animal, increasing up to a point and decreasing later in life. The data of Candland and Campbell show a similar functional relationship for activity and defecation in the open field situation. These measures are generally taken to be among the measures of arousal in the rat. If skin resistance is a similar index of arousal, one might expect to see skin resistance fall and then rise with age in the rat. Further, there have been a number of studies, reviewed by Duffy which show that skin resistance does vary with age in humans. The presumption of variation of BRL with age is thus strong enough to justify efforts to measure the development of skin resistance in the rat. Two studies done by Donald A. Dewsbury will be described in some detail.

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4 The two studies of the development of BRL in the rat were wholly the work of Donald A. Dewsbury, and much of the analysis and text are taken directly from an unpublished paper by Dewsbury entitled, *Changes in the Basal Skin Resistance Level of Rats as a Function of Age.*
Subjects. The animals used were Long-Evans hooded rats bred in the University of Michigan laboratory. In Experiment 1, 25 Ss from two litters were used. In Experiment 2, 68 animals from 7 litters were used. In Experiment 1 there were 13 females and 12 males, and in Experiment 2 there were 41 males and 27 females.

Apparatus. All litters were reared in stainless steel cages that were 14 in. x 14 in. x 16 in. They had five solid sides and a wire mesh front door. The skin resistance recording was done using the Kaplan technique previously described in the standard Gerbrands Skinner Boxes with grid floors.

Procedure. In Experiment 1, the two litters were reared in the standard cages and weaned at 22 days of age. Nine rats were first tested at 25 days of age, 8 at 39 days of age, and 8 at 53 days of age. On all test days rats that had been tested at an earlier age were retested in order to examine the lasting effects of the testing procedure. An additional test day was given when the rats were 147 days of age.

All tests were performed on Sunday mornings in order to provide maximally similar laboratory environments before and during testing. For the test, the animals were placed individually in one of four Skinner Boxes with the inside light on, the noisy fan on and the operant lever disconnected. The rats were allowed to remain in the apparatus for a period of 20 minutes while skin resistance was continuously recorded. White noise was introduced into the boxes during the 11th and 16th minutes. After testing, the animals were weighed and returned to their home cages.

Experiment 2 was designed on the basis of the results of Experiment 1 and was similar to it except for a number of details. In Experiment 2, no white noise was introduced into the boxes. Twenty-five rats were tested at 27 days of age, 21 animals at 76 days of age, and 22 at 125 days of age. Rats in this study were weaned at 24 days of age. Other rearing and testing procedures were identical with those of Experiment 1.

Figure 9 shows the mean BRL in the first experiment for animals tested at each age, thus tested four times. Skin resistance appears to rise and then
FIGURE 9
DEVELOPMENT OF BRL - I
Mean changes with age when the same animals are tested at each age.

fall with age. Two major artifacts are contained in the data of Figure 9. Skin resistance tends to rise under repeated testing, and these growing animals were increasing in weight. The first factor would tend to produce a rise in BRL, while the second would tend to produce a drop, independent of the development of emotionality.

Figure 10 eliminates one of the artifacts. In this figure, the means at each point represent the readings obtained from animals being tested for the first time. Both curves suggest a decreasing BRL with age.
FIGURE 10
DEVELOPMENT OF BRL - II

Mean BRL changes with age in both experiments when only the results of the animals' first experiences in the box are recorded.

A more detailed analysis of the effects of sex and repeated experience in the apparatus is shown in Figure 11. The lighter females generally have higher skin resistances than do males, although there are several exceptions. There is no apparent effect in this figure of repeated testing at 76 days of age. The difference at 125 days of age is quite striking. Animals that had experienced the apparatus before showed virtually no drop in skin resistance, whereas those placed in the box for the first time showed resistances that were considerably lower.
BRL AS A FUNCTION OF AGE, SEX, AND REPEATED EXPERIENCE

The data for Experiment 2 plotted separately for first trials in the apparatus and second trials and by sex.

Both the differences between the sexes and the differences found with age are generally consistent with the hypothesis that weight can account for the difference. The correlations between weight and skin resistance in this study are given in Table 5. They generally can be seen to be small and negative. They are not as high as the correlations reported for adult animals in Figure 5. An analysis of covariance was run to try to partial out the effect of weight. None of the F values reached significance. ¹

¹No effect of the introduction of white noise in the first experiment was observed. (See Figure 8.) This operation was therefore omitted from the second experiment and ignored in measuring BRL.
### TABLE 5
CORRELATIONS OF WEIGHT WITH BRL BY SEX AND AGE

#### Experiment 1

<table>
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<th>Group by Age of First Test</th>
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<td>-.98</td>
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#### Experiment 2

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<th>27</th>
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<tr>
<td>27</td>
<td>M</td>
<td>-.14</td>
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<td>M</td>
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<tr>
<td>125</td>
<td>M</td>
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<td>+.02</td>
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<tr>
<td>76</td>
<td>F</td>
<td></td>
<td>-.27</td>
<td>-.07</td>
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<tr>
<td>125</td>
<td>F</td>
<td></td>
<td></td>
<td>-.11</td>
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In a final effort to determine whether there was any residual variance attributable to age that could not be accounted for by the increase in weight of the growing animal, regression equations were used to predict skin resistance from weight differences alone at the respective ages. As can be seen in Figure 12, the regression equations would predict a major drop in skin resistance at an earlier age than it actually occurred.

![Graphs showing predicted BRL vs days for two experiments](image)

**FIGURE 12**

**PREDICTION OF BRL FROM WEIGHT**

Results of effort to determine the extent to which BRL could be predicted from weight alone.

There is no doubt that skin resistance drops as a function of the increasing age of the animal. The problem is to determine whether this is due to an artifact of weight or to true developmental change. The fact that no significant difference independent of weight could be demonstrated would argue
that this change is an artifact. There are, however, several reasons for believing that there might be a real effect.

1. The data are consistent with data on other measures obtained on rats and previously cited.

2. The data are consistent with developmental changes in skin resistance in human beings.

3. The major drop in skin resistance comes earlier than one would predict solely on the basis of weight.

4. Animals tested for the first time at 125 days of age showed decreases resistance whereas those which had been tested earlier did not, thus indicating that experience and not just age alone is a factor in determining skin resistance.

Early experience and BRL. It is fairly well established that variation in the amount of early stimulation of rats can produce differences in emotionality in adulthood. In one of the most commonly used forms of experimental manipulation, rats are removed from the home cage once a day during the first few days after birth and placed for brief periods in individual containers. Although this class of manipulation has been shown to have many physiological effects (cf Levine), the major effect is generally taken to be a decrease in emotionality as indicated by amount of activity in an open field and the number of fecal boluses left in the field. For example, Denenberg, et al., found that rats handled during the first ten days of life defecated significantly less in the open field than did rats handled during the first 20 days of life or a group that was not handled at all.

---

1 This study was conceived, designed, executed, and the data analysed by Donald A. Dewsbury. This section of the report is a revised version of an unpublished document written by Dewsbury.


If skin resistance as measured by the Kaplan technique reflects relative emotionality and if the Denenberg, et al., early experience manipulation affects emotionality, then rats handled in this manner should show higher skin resistance later in their development than non-handled animals. The following study was an effort to test this proposition.

Subjects. The subjects were seven litters totaling 61 animals, 27 males and 34 females. They were Long-Evans hooded rats bred in the Psychological Laboratories of the University of Michigan.

Apparatus. The litters were raised in the laboratory's standard breeding cages. They are of stainless steel with inside dimensions of 15 in. x 9 1/4 in. x 11 in. The upper half of the front is open mesh wire. A curtain of cheesecloth was placed approximately 5 1/2 in from both the front and the back of the cages to minimize external stimulation.

Testing was done in the Standard Gerbrands Skinner Boxes with the lights on, the fan running, but with the lever disconnected.

Procedure. Ten pairs of adult rats were placed in the breeding cages to start the experiment. Males were removed after 14 days. Seven litters were produced in this manner, and they became the experimental subjects for the experiment.

One per day for the first 10 days after birth, the animals of four of the litters were removed from their home cages and placed individually in a one gallon glass jar half filled with sawdust. After three minutes in the jar, they were returned to the home cages. These four litters are designated as the Handled Group. The other three litters constituted the Non-handled Group. All litters were weaned at 25 days. Aside from the weaning and the experimental manipulations, the only other disturbance was the minimum occasioned by the necessity of feeding and watering the animals.

Testing was carried out on the 43rd day. Each animal was placed individually in a Skinner Box for a period of 20 minutes during which skin resistance was continuously recorded and the number of boluses at the end of the 20 minute period was recorded. The skin resistance record was read by taking the lowest reading in each 5 minute quarter of the 20 minute period, and the lowest reading for the whole period.
The results were generally negative as can be seen in Table 6 which contains all the recorded data. Handling, if effective should produce a higher BRL and a lower number of boluses. In each of the 5 minute quarters the Handled Group showed lower mean values, and they left the larger number of boluses. However, none of the differences are statistically significant.

**Selective breeding for high and low BRL.** Rats have been bred for a variety of behavioral characteristics. Hull once developed a strain of emotional rats, and Tryon’s maze-bright and maze-dull rats have been employed in a number of psychological experiments. It seemed possibly to be worth the effort to develop strains of rats showing high skin resistance or low skin resistance, presumably reflecting differences in emotionality.

The first two of the four generations involved in this study were the animals employed in the experiments designed to study the development of BRL discussed earlier in this report. The parental group consisted of two litters from parents that had been selected for high and low BRL. Matings from this generation, also selected on the basis of high or low BRL, produced seven litters, three from High BRL parents and four from Low BRL parents. Pairings from this generation produced five litters, two High BRL litters and three low BRL litters. Animals in this generation were the subjects of this study.

Throughout the period of the experiment, the four generations were reared under similar laboratory conditions, in identical cages, with the same caretaker, and they were weaned at approximately the same age.

All of the testing was done by the standard methods described earlier. Animals were placed in the Skinner Boxes with the shock grid floor with lights and fan turned on and the operant lever disconnected.

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1 This section is based on a study carried out by Donald A. Dewsbury. The report given here is a revision of an unpublished document written by Dewsbury entitled Selective breeding of rats for high and low skin resistance: A pilot study.
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<thead>
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<tr>
<td>Number of females</td>
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<tr>
<td>Mean weight, females</td>
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BRL measures (in 20,000 ohm units)

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<th>Group NH</th>
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<tr>
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<tr>
<td>Second 5 minutes</td>
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<td>Fourth 5 minutes</td>
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<tr>
<td>Males</td>
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</tr>
<tr>
<td>Females</td>
<td>27.5</td>
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Mean boluses

<p>| | |</p>
<table>
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<td>0.82</td>
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Correlations - weight and BRL

<p>| | |</p>
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The animals of the fourth generation were divided into six groups, and animals from High and Low BRL parents were tested for the first time at 27, 75, or 125 days of age. Animals tested at the younger ages were re-tested at the subsequent ages.

Figure 13 shows the mean values for a pair of groups when the lowest value in a one minute period is recorded as the representative BRL. Thus 20 values were recorded in a 20 minute period. In 17 of the 20 one-minute periods, the offspring of the High BRL parents showed the higher mean BRL values. The values reported in Figure 13 are those taken for animals tested for the first time at 125 days of age.

![Graph showing BRL values over 20 one-minute periods](image)

**FIGURE 13**

**SELECTIVE BREEDING FOR BRL**

Mean BRL values for successive one-minute recording periods over 20 minutes in the Skinner Box for the animals bred of high BRL parents and animals bred of low BRL parents in the fourth generation.
Figure 14 shows the mean BRL values obtained at each of the three testing periods for animals being tested for the first time at that point. There is a dramatic difference in the two emerging strains at 75 days. The animals bred from parents with low BRL show a large drop that is not seen in the offspring of High BRL parents until a later age. Since there was no difference in the weights of the two groups at any point, it is clear that the difference at age 75 days is a true BRL difference.

![Graph showing BRL values versus age for different BRL parent groups.](image)

**FIGURE 14**

**INTERACTION OF SELECTIVE BREEDING AND AGE VARIABLES**

Mean BRL values of two strains of animals bred through four generations for high and low BRL. Each point represents the mean values for animals being tested for the first time at that age.

Figure 15 is less encouraging. The animals that were first tested at 27 days of age show a reverse effect of 75 days. That is, the offspring of High BRL parents show a large drop, while the offspring of Low BRL parents do not.
FIGURE 15
INTERACTION OF AGE, BREEDING, AND REPEATED EXPERIENCE

The values of Figure 14 are plotted again, and the results of repeated testing are added.

On Day 125, the animals being tested for the first time show a slight difference with the animals from high BRL parents having the higher scores, animals being tested for the second time show a very large difference in the expected direction, while the animals being tested for the third time (which had shown the reversal at 75 days) now show a very small difference in the 'wrong' direction. Thus, the results in the predicted direction, with the test at 75 days being large and statistically significant. The second test for this pair of groups is also large and consistent with the hypothesis. Negative results, or results in the direction opposite from the predicted difference were obtained from the subsequent tests of the group first tested at 27 days.
The results of this attempt to carry out selective breeding for high and low BRL must be considered to be equivocal in nature. It seems probable that continued efforts might well have resulted in larger difference in BRL between the two strains, but inconsistent results in the fourth generation led to the decision to discontinue the effort.

Summary Conclusions from Basic Studies of BRL. Three variables stand out as producing highly predictable and significant changes in BRL in this set of studies. If animals are left in an unchanging environment and repeatedly introduced into the same unchanging environment, the skin resistance measures rise significantly within each day and between days. Even the normal gentle handling of an animal during the course of the carrying out of an experiment produces a sharp drop in skin resistance during the period of handling. Both of these results are consistent with the possibility that variation in skin resistance generally tends to reflect differences in the emotional state of the animal. Continued and repeated experience in an unchanging environment generally produces boredom in human subjects. Handling could be expected to produce arousal in the animal.

The third variable, weight, is also highly significant in its relation to BRL, but is a variable to be dealt with in experiments rather than being a variable of interest with respect to arousal.

Six other variables are reported in this section which may possibly reflect differences in BRL and thus arousal and emotionality, but yield data that cannot be interpreted unambiguously. Stimulus change in a context of a previously unvarying environment sometimes produces large differences in BRL and at other times appears to produce no change. The difference between conditions in which BRL changes do occur and those in which they do not were not resolved in this series of studies.

There are sex differences in BRL with male animals showing much lower skin resistance than females. While differences in the average weight of male and female rats accounts for some of the sex difference in BRL, it seems likely that there is a residual sex difference reflecting differences in arousal under
standard testing conditions between male and female animals. However, means
of factoring out the effect of weight are insufficiently precise to permit a strong
conclusion.

There are individual differences in BRL that are correlated with individual
differences in the weight of the animal. It seems likely that there is residual
variance which reflects individual differences in emotionality, but there is
insufficient evidence in these data to permit a firm conclusion on which further
studies could be based.

BRL decreases with age in the developing rat, but the animal's weight
is so overpowering, that the likely development of low resistance at a critical
stage of the development of emotionality in the rat could not be demonstrated
unambiguously. From the data, an increase in emotionality with increasing age
seems probable but by no means certain.

An effort to produce differences in skin resistance at a later age as a
product of handling during the first ten days after birth was entirely negative.
While positive results have previously been reported that show the rats subjected
to this handling procedure were less emotional than unhandled rats, neither
skin resistance nor number of boluses left during an open field test showed the
predicted results. Since the number of boluses is a measure that had previously
been shown to be significant, it is not clear from these results whether skin
resistance simply doesn't reflect the effects of handling, or whether the handling
procedure employed in this study simply doesn't produce differences in
emotionality.

The effort to produce a generation of 'emotional' rats by the criterion of
low skin resistance, and a generation of 'non-emotional' rats by the criterion
of high skin resistance was only modestly successful. It seems likely that it
could be done, but there was sufficient ambiguity in the results with the fourth
generation, that the effort was abandoned.
4. BRL and biological drives

The concept of drive is pervasive in psychology. The classic studies generally relate drive strength to vigor of performance. The classic manipulation is to deprive an animal of food for differing numbers of hours and then observe the speed with which he performs a task to obtain food. The general finding is that as time of deprivation increases, the vigor of performance increases up to a point. Beyond that point, further deprivation produces a decrease in the running speed. There is little agreement concerning the determinants of the point of nonmonotonicity.

The concept of arousal is an alternative to the drive concept, and the various advantages and disadvantages of the two are discussed in the theory section of this paper.

This section is devoted to a series of studies addressed to the question of the relationship between skin resistance and thus presumably between arousal and the various manipulations of drive.

The biological drives which have been studied most extensively are hunger, thirst, the sex drive, and fear. The four day estrus cycle in the female rat is rather easy to track. Hunger and thirst can be manipulated through food and water deprivation. Fear is usually induced through the application of shock. The following series of experiments are devoted to Estrus, Hunger, Thirst and Fear.

Estrus. ¹ The female rat typically has a four day estrus cycle. The various stages of the cycle can be determined rather simply by injecting a small amount of distilled water into the vagina, withdrawing the water, and observing the nature of the resulting vaginal material under a low power microscope. The four categories and the verbal description of the differences in vaginal material to be seen at each stage are the following:

Proestrus. Numerous cells, mostly round with large single nuclei.
Estrus. Numerous cells, mostly cornified and without nuclei.
Metestrus. Numerous cells, some cornified, some nucleated.
Diestrus. Few cells of any kind, some polynucleated.

In this experiment, 18 female Long-Evans hooded rats were about 120 days of age at the start of the experiment. Vaginal smears were taken daily for a week, and four animals with strange or irregular cycles were eliminated. Testing was begun with four animals in estrus, four in diestrus, four in proestrus and two in metestrus on the first day.

The procedure has been described previously in the section on the effects of stimulus change. Briefly, animals were placed in the Skinner Boxes with light and fan on and the operant lever inactivated and they were left there for 25 minute periods for five consecutive days. During the first 10 minutes of the period, the environment was unchanging. Stimulus change was produced by opening the outer door (the inner door is clear plastic) and thus exposing the animal to the sights and sounds outside the picnic-like apparatus box. The outer door was opened at the end of 10 minutes, closed at the end of the 12th minute, opened again at the end of the 23rd minute, and the animals were removed at the end of the 25th minute. Among the BRL measures taken were the lowest readings in the two minute periods just prior to the opening of the door and the lowest reading during the two minute periods while the door was open, thus two measures for each animal each of the five days.

Figure 16 indicates that there is some variation in skin resistance (BRL) with the stage of estrus with the highest reading obtained during diestrus and the lowest readings obtained in estrus and metestrus. However, these differences were not statistically significant. They represent mean values for the two minute periods just prior to stimulus change. The lines terminating in arrows indicate the amount of change in BRL (thus GRS) that occurred in response to stimulus change. The largest change, on the average, occurred in diestrus and the smallest during metestrus. This difference is statistically significant ($p = < .05$).
BRL, GSR, AND ESTRUS-RELATED ACTIVITY

The solid line shows the mean BRL of female rats at four points in the estrus cycle. The descending lines with arrows indicate the mean response to stimulus change at each of the four stages of estrus. The dashed curve that is superimposed is data on wheel turning as it is related to the four stages of estrus (see ordinate on the right) which was taken from Richter.

In the same figure, results taken from Richter\(^1\) have been plotted. Richter plotted the number of wheel revolutions made by an animal in an activity wheel per day. He also tracked the stage of estrus and plotted his results in the same manner as the BRL results were plotted. The mean number of wheel revolutions is scaled on the right hand ordinate in the figure.

Inspection of the three sets of values in the figure (BRL, GSR, and Wheel Turning) indicate little or no correspondence between them. The high

point and the low point in wheel turning both occur at the lowest values of BRL. The largest responses to stimulus change and the smallest both occur at the lowest values of wheel turning. Thus, one must conclude that neither BRL nor GSR could be used to predict the wheel turning data, and the latter has been taken as the classical index of variation in drive level with estrus in the female rat.

Hunger and thirst. ¹ It is generally assumed that increases in time of deprivation of food or water increase the level of drive. If skin resistance (either BRL or GSR) are indices of arousal, and if arousal and drive are correlated, there should be a relationship between time of derivation of food or water and skin resistance.

Since an increase in arousal should be indexed by a decrease in skin resistance, the expected relation between time of food or water deprivation and BRL should be one in which BRL decreases as time of deprivation increases.

Campbell and Sheffield² have suggested that animals in an unvarying environment will not necessarily show a relationship between time of deprivation and activity. However, they suggest that a hungry animal may show more activity in the presence of stimulus change than an animal that is satiated. If this idea is carried over to the relation between skin resistance and time of deprivation, it might be expected that BRL would not vary with time of deprivation, but that changes in skin resistance in response to stimulus change (GSR) might do so.

Four experiments were carried out to determine whether there was any systematic relationship between time of deprivation of food or water and either BRL or GSR.

¹The four experiments discussed in this section were largely the work of Donald A. Dewsbury. This section is a revision of an unpublished paper: Dewsbury, D. A., Zack, S., and Walker, E. L. Skin resistance in rats as a function of food and water deprivation.

In the first experiment, skin resistance was examined solely as a function of time of water deprivation. The measurements were taken in the starting box of a linear maze fitted with the parallel stainless steel strips. The details of this pilot experiment are the following:

Subjects. The subjects were six male hooded rats of the Long Evans strain bred in the Psychological Laboratories of the University of Michigan. They were 90 days of age at the beginning of the experiment and were experimentally naive.

Apparatus. Testing was done in a straight alley 2 3/4 in. wide and 3 in. high. It was made of plywood, had a hardware cloth top, and the floor was two parallel stainless steel strips separated by 5/8 in. down the middle of the alley. Skin resistance was recorded by the Kaplan technique as described earlier.

Procedure. After approximately one week of daily preliminary handling, each animal was placed in the maze with all doors open for a five minute period of free exploration on two successive days. Following this procedure, test trials were begun and run on alternate days. On each of four trials per day, the rat was placed in the starting box, confined for 10 sec., allowed to run to the goal box, and confined for a period of 20 sec. in the goal box which contained the spout of a water bottle. Trials were separated by 15 min. Each animal was given two days of trials at each of six levels of water deprivation, 0, 3, 6, 18, 24, and 30 hours, in an order dictated by a balanced design such that each animal received the treatments in a different order. The minimum BRL value during the 10 minute period in the starting box was taken as the measure of BRL.

The mean BRL for all animals over all trials at the six levels of water deprivation is shown in Figure 17. There is clearly an increase in skin resistance with increases in time of water deprivation. This finding is similar to that reported by Rasmussen¹ who interpreted his results as reflecting progressive dehydration with a consequent drying of the skin. It is also true that there is some weight loss with time of water deprivation, and the longer the time of

FIGURE 17
BRL AND WATER DEPRIVATION

Mean BRL values at six levels of water deprivation for six male animals in a balanced design.

depression, the greater the weight loss, and thus the higher the expected BRL values. The weight of the animal was not recorded in this experiment. It is to be noted also that these measurements were taken in the context of a learning experiment and one in which the animals were handled very many times. Both factors could be expected to produce major increases in skin resistance during the course of the experiment. While the balanced design should make such factors apply equally to all deprivation levels, a highly nonlinear change in BRL from these factors could produce artifactual increases in BRL.

In any case, the curve in Figure 17 rises with increased time of deprivation rather than falling as one might expect if BRL and arousal are correlated with drive.

Because of the small number of animals in this study and the ambiguity of the results, it was decided to try the same experiment again with a larger number of animals and with food deprivation as a variable as well as water deprivation.
Subjects. Twenty-four naive, male, hooded rats that were naive at the beginning of this experiment were chosen from the colony of the Psychological Laboratories.

The apparatus and the testing procedures were identical with those described in the previous experiment.

These animals were first given two weeks of preliminary training during which they were handled, trained to eat and drink under 24 hours of the appropriate deprivation, and were given preliminary experience in the straight alley.

The times of deprivation were 3, 12, or 24 hours of either food or water deprivation with the other material available ad lib. The order of deprivation was manipulated in such a manner that each animal was tested on two days of trials under each condition with the order different within each block of six animals, and each condition occurring for four animals on each experimental day. There were 15 minutes between the two trials each day, and animals were tested every second day.

Table 7 shows the mean speed scores in running the maze developed under the six conditions. The animals run faster under the longer periods of deprivation than they do under the shorter ones.

Figure 18 is a plot of the BRL values as a function of time of deprivation of food and water. In this figure, no significant change in BRL value is apparent. Instead, BRL appears to be unaffected by deprivation of food or water. If the data from the first experiment can be discounted as being a function of the small number of animals, the data from this one would suggest that skin resistance does not vary with variation in hunger and thirst, at least over a 24 hour period. A null conclusion, however, does not have the status of a positive one, and further effort seemed justified.

In a third experiment, a number of changes were introduced. The major changes were: (1) the design called for a single testing period for each animal rather than having each animal experience all conditions. (2) The range of deprivation durations was extended back to 0 and up to 48 hours. (3) An effort
<table>
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<td></td>
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<tr>
<td>Water</td>
<td>10.66</td>
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<tr>
<td>Food</td>
<td>11.00</td>
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</tbody>
</table>

¹ 1/running time in seconds x 100
FIGURE 18

BRL AS A FUNCTION OF FOOD AND WATER DEPRIVATION

The figure represents 24 animals tested on 4 trials each on each of 2 days at each level of deprivation (3, 12, and 24 hours).

was made to determine if GSR was influenced by time of deprivation, whatever the effect on BRL. This was done by introducing white noise in an otherwise unvarying environment. (4) In order to control for random noises, this study was performed in the Skinner Box apparatus. The details of this study are the following.

Subjects. Thirty black hooded, Long-Evans strain, naive rats were chosen from the Psychological Laboratories colony at 90-120 days of age.

Apparatus. Four standard Grayson-Stadler Skinner Boxes previously described were used. During tests, the house lights in the boxes were on, and the exhaust fan was running, but the lever connected to the food release
mechanism was inactivated. These boxes also contain a small speaker through which a white noise could be transmitted to the interior of the box. The loudness of the sound stimulus used in this experiment was not recorded, but it was of such intensity that even though it was inside the box and partly masked by the sound of the exhaust fan, it was clearly audible to an observer outside the box and across the room.

Procedure. After one week of daily preliminary handling, the rats were placed on a deprivation schedule. Five groups of six rats each were placed on one of the following deprivation schedules: 0 deprivation, 24 or 48 hours of food deprivation, or 24 or 48 hours of water deprivation.

Each animal was given a 20 minute test trial. During the 11th and 16th minutes, white noise was delivered through the speaker inside the box.

Figure 19 is a plot of the mean values obtained by taking the lowest measurement obtained during the first ten minutes in the Skinner Box. Both curves drop as deprivation is increased from zero to 24 hours and then rise as

![Graph of Skin Resistance vs Hours Deprivation]

**FIGURE 19**

**BRL AS A FUNCTION OF FOOD AND WATER DEPRIVATION**

The points plotted represent the means for six animals tested only once each during the experiment. The values are the minimum values obtained in the first 10 minutes in the Skinner Boxes.
deprivation is increased to 48 hours. The drop would be expected if time of deprivation increased arousal over the 24 hour period. The rise in the curves at 48 would not be expected. Thus BRL, by this measure, in this experiment, does not show a consistent pattern.

Figure 20 and 21 show the effects of the introduction of white noise. The first of these figures is a plot of BRL in the 10th minute in the Skinner Box, with the minimum value during the 11th minute, and thus during the white noise period, plotted as an arrow showing the amount and direction of change. The BRL values in the two figures are not unlike those in Figure 19 for the first ten minutes. The arrows in the two figures, taken together, are

![Graph showing skin resistance as a function of hours deprivation for water and food deprivation.]

FIGURE 20

GSR AS A FUNCTION OF FOOD AND WATER DEPRIVATION

The connected lines are between the minimum BRL values obtained in the tenth minute in the Skinner Box. The arrows represent the minimum values during the eleventh minute and thus during the period of stimulation with white noise.
FIGURE 21

GSR AS A FUNCTION OF FOOD AND WATER DEPRIVATION

The connected lines are between minimum BRL values obtained in the fifteenth minute in the Skinner Box. The arrows represent the minimum values in the sixteenth minute and thus during the second period of white noise.

inconsistent in direction and represent very small differences. Thus, this experiment offers no evidence that either BRL or GSR are influenced in a systematic way by time of deprivation.

The importance of the problem and the inconsistency of the results reported so far led to a fourth and final effort to determine whether there was a relationship between time of food or water deprivation and BRL or GSR. The final experiment was similar to the previous one except for some minor changes intended to increase the probability of finding differences if there were any. (1) The white noise was made intermittent rather than steady. (2) The second stimulus change was an opening of the outside door (an operation
that had worked successfully in an earlier study). There were other minor changes (from the previous experiment) which are detailed below.

Subjects. There were 40 naive, male, black hooded rats that were 90-120 days of age.

The apparatus was the set of Skinner Boxes previously described.

Procedure. The rats were divided into five groups of eight animals each, and each group was assigned to one of the five deprivation conditions: 0 deprivation, 12 or 24 hours of food deprivation or 12 or 24 hours of water deprivation.

Each animal was placed in one of the Skinner Boxes for 22 minute periods on each of five successive days. Throughout the 11th and 12th minutes intermittent white noise was presented through the speakers. This consisted of four 10-second periods of white noise spaced 30 seconds apart. The outer door was opened during the 17th and 18th minutes.

Figure 22 indicates that time of deprivation of neither food nor water had any effect on BRL. This figure looks very similar to Figure 18 which also involved means of a number of animals which had been measured repeatedly. Figure 23 is similar except that it represents only the first ten minutes of the test period. It shows a slight increase in BRL as a function of time of deprivation.

Figure 24 shows the effects of the introduction of white noise during the 11th and 12th minutes. Little effect of stimulus change is apparent. Figure 25 similarly shows the effect of opening the outer door of the Skinner Box during the 17th and 18th minutes. Again, the effects are small, and the largest difference is a rise in skin resistance rather than a drop.

Taking all four experiments together, one must conclude that no relationship between BRL and time of food or water deprivation has been demonstrated. It also seems likely that there is, in fact no relationship.

The last two experiments taken together would support a similar conclusion for GSR. No effect of time of deprivation on changes in skin resistance in response to either white noise or opening the outer door of the Skinner box could be demonstrated, and it seems likely that none will be found.
FIGURE 22

BRL AS A FUNCTION OF FOOD AND WATER DEPRIVATION

Each point represents a mean minimum value in a 22 minute period (excluding stimulation periods) for 8 animals tested 5 times each on 5 different days. BRL is scaled in 20,000 ohm units.
FIGURE 23

BRL AS A FUNCTION OF FOOD AND WATER DEPRIVATION

The plotted values are for the first 10 minutes of the 22 minute periods in the final food and water deprivation experiment.

FIGURE 24

GSR AS A FUNCTION OF FOOD AND WATER DEPRIVATION

The plotted values that are connected by lines are the mean minimum values for the two minutes before the introduction of the white noise. The arrows indicate the GSR, the amount and direction of change introduced by white noise in the eleventh and twelfth minutes.
GSR AS A FUNCTION OF FOOD AND WATER DEPRIVATION

The plotted values that are connected by lines are the mean minimum values during the fifteenth and sixteenth minutes. The arrows indicate the amount and direction of change induced by opening the outer doors during the seventeenth and eighteenth minutes.

Fear (Shock). The most effective manipulation of motivation employed by psychologists in rats is the application of shock. Animals will learn some tasks in a single trial to avoid or escape even mild shock. Strong shock can produce rapid learning that is very highly resistant to experimental extinction. If any biological drive or motive should be reflected in skin resistance changes, it should be the effects of shock.

The first study of the effects of shock on BRL was done by Rachel Kaplan. She used 56 male hooded rats from the Psychological Laboratories colony that were 250-300 days of age at the time of her experiment.

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These rats were divided into four groups (which were to experience different levels of shock intensity). After preliminary handling, they were placed in the Grayson Stadler Skinner Boxes for 90 minutes a day for four days. The first three of these days were analysed for the effects of boredom and the results reported in an earlier section of this report.

On the third day, the animals were subjected to shock by means of a constant current stimulator that delivered a dc square wave at 120 pulses per second for 5 seconds. Shock was introduced at the end of the 30th minute of the 90 minute session in the box. The same shock was introduced again at the same point during the fourth day in the boxes.

The four groups were subjected to 0, 4, 5, or 6 milliamps of shock, with the shock constant for a given animal on the two days. The animals were run in squads of four in the four boxes with one animal at each shock level in each box.

Kaplan reported her results by plotting the mean BRL value in the 10 minute period before shock and the mean BRL value in the 5 minute period after shock. The five minute period was chosen after shock because it appeared that rather rapid changes were occurring in BRL during the first ten minutes after shock.

Figure 26 shows the effects of shock as she reported them. Shock obviously produces a dramatic drop in skin resistance. The decreases shown for Day 3 are approximately 500,000 ohms, and those for Day 4 are almost as great.

Several other features of the data are of interest. The differences shown between the effects of the three intensities of shock are statistically not significant, and in the data for the first experience of shock, are not in the expected order. It seems highly likely, therefore, that the shock is producing fright rather than pain. One might expect pain to vary with intensity, but if the shock only frightens the animal, the intensity might not be expected to make much difference.
FIGURE 26
EFFECTS OF SHOCK ON BRL

The values plotted are the mean BRL values (in 20,000 ohm units) for four groups shocked at different intensities at the end of the first 30 minutes of the 90 minute periods in the Skinner Boxes on the third and fourth days. Pre-shock means are of the lowest values in the 10-minute period preceding the shock, and the post-shock means are for the lowest values recorded in the 5 minute period immediately after shock. (See Kaplan, op cit.)
The results for the 0 mil group are of some additional interest. On both days the curves rise during the 15 minute period involved in the two measurements. The rises could be the result to increasing boredom, or they could be in part an artifact of the measuring technique. Since the technique involved taking the lowest value in the two periods involved, the shorter period has a slightly smaller chance of containing a very low value than the longer period. While it is doubtful if this possibility had any real effect on the values in the figure, the extent to which it might have operated would tend to reduce the apparent effects of shock by producing an artifactually high mean value for the post-shock period.

The difference in BRL in the 0 mil group between the two days is also something of a curiosity. It will be recalled that in the study of boredom, BRL tended to increase by approximately 45,000 ohms between days when the measurements were taken at the same time on each day. In Figure 26, there is a rise in BRL within days but a very large drop of more than 250,000 ohms between days. This result was, of course, unexpected. However, it fits other casual observations. While the experimental boxes used in this study appear effective in isolating the four experimental animals from each other during the 90 minutes they are in the boxes, the animals were returned to the standard colony living conditions between daily sessions. Thus the unshocked and therefore unfearful animals were housed overnight with animals that had been shocked and which were fearful. Whatever the mode of communication, the unshocked animals appear much more fearful on the fourth day than they had on the third. Unfortunately, no experimental follow-up was made of this phenomenon, and it must therefore remain a speculation.

Following Kaplan's classic finding, a number of other experiments were carried out to replicate her findings and to explore other aspects of the effects of shock.1

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1These studies were run by Donald A. Dewsbury, Jon L. Williams and Bruce E. Walker.
In the first of these, an effort was made to determine whether the form of shock and the kind of apparatus made any difference. One group of 15 animals was run in the Skinner Boxes using a 4 mil shock to replicate one of Mrs. Kaplan's groups. It differed from the Kaplan procedure only in that the animals were not subjected to lengthy prior experience in the boxes, and the measurements were taken by dividing the record into 5 minute segments both before and after shock. This replication is referred to as Experiment 2.

Another 15 animals were shocked in the starting box of a linear maze with the parallel stainless steel strip floors. Since a prolonged shock would permit the animal to find a way to escape or avoid the shock in this apparatus, a condenser discharge type shock was applied. The current was approximately 1 milliamp and was delivered in something less than .01 sec. This study is referred to as Experiment 1. In it, with the more regular record of the parallel strips, the records were read in two-minute segments.

Figure 27 shows the results in the two pieces of apparatus, and it is apparent that they are highly comparable. The recovery from being handled is characteristically apparent in Experiment 1. The dramatic drop in BRL in response to the shock is present in both curves. Recovery appears to require at least 35-40 minutes, as was reported by Mrs. Kaplan. The rapid changes in BRL during the first few minutes after shock which led Mrs. Kaplan to use a 5 minute sample period as opposed to 10 minutes, is quite apparent in the curve for Experiment 1. The lowest value was recorded in the first two minute period after the shock. There is an immediate recovery. It is obvious that the results of shock are not dependent on a particular piece of apparatus or shock with very special form or intensity.

A second experiment was carried out with 30 animals in the starting box and with the same condenser discharge type shock employed in Experiment 1 of the previous figure. These animals were subjected to the same experience on two successive days. The results are plotted in Figure 28. The two days yield results that are essentially indistinguishable. They both show the same pattern of a large drop in BRL following shock. They both show incomplete recovery after 50 minutes.
FIGURE 27

BRL RECOVERY AFTER SHOCK

Experiment 1 shows the effect of a 1 milliamphere condenser discharge type shock applied to the rat in the starting box with parallel stainless steel strip floors. Experiment 2 shows the effects of a 5-second square wave dc shock at 120 per second applied through the shock grid of a Skinner Box.

All of the experiments on the effects of shock on skin resistance taken together yield a highly consistent picture. A wide range of shock intensities, from a 1 milliamp condenser discharge type shock lasting less than .01 second to a 5 second shock of dc square waves at 120 per second at 6 milliamps intensity and delivered in two quite different pieces of apparatus, all yield a very similar pattern of BRL changes. There is an abrupt drop in skin resistance of as much as 500,000 ohms, followed by a recovery of 15-25% of that value within the first few minutes, which is in turn followed by a slower recovery phase lasting 30 minutes or more.
FIGURE 28

BRL RESPONSE TO SHOCK

The curves show changes in BRL in response to shock on two successive days. There were 30 animals and they were shocked with a condenser discharge type shock in the starting alley of a linear maze equipped with two stainless steel strips in the floor. Measurement is the lowest value recorded in each successive 150-second period.
These results appear to be a convincing demonstration that BRL does reflect something about the emotional state of the animal in sharp contrast to the data previously reported on the appetitive drives for which the results were quite negative. However, the suspicion still had to be entertained that the results, while shock correlated, might not be a simple reflection of the arousal level of the animal.

One final study addressed to the effects of shock on BRL was designed based on an effort to manipulate the time of recovery from the shock. It was reasoned that if shock was inducing fear, and it was fear that was reflected in the pattern of BRL values, then a manipulation designed to manipulate the duration of the fear should produce a correlated manipulation in the BRL. To accomplish this, a long maze was employed that was divided off into sections by transparent doors, and with the sections distinctive in appearance. In this maze, rats could be shocked in one end and then allowed to run varying distances from the shock place. It was expected that the farther the rat was allowed to run, the quicker would be his recovery from the fear induced by the shock.

Subjects. Sixteen male hooded rats were chosen. They were 150 to 180 days of age at the beginning of the experiment and were experimentally naive. They were individually housed and food and water was available ad lib.

Apparatus. The apparatuses consisted of two straight alleys that were 7 feet long, 3 inches wide, and three inches deep. The walls were constructed of 1/2 inch plywood (leaving 2 inches in width for the interior of the alley). The floors consisted of two stainless steel strips separated by 1/2 inches in the middle of the alley. Six guillotine type doors of clear plastic divided the maze into seven sections, each 12 inches long. On the walls of the alleys were mounted plastic panels covering the whole wall on both sides of the sections. These panels were painted with black and white vertical stripes. The widest stripes were 4 inches, and each successive panel had narrower stripes until the opposite end of the maze had panels with stripes which were 1/2 inches in width. It was intended in this way to make each section clearly distinguishable from the others and to provide a progression from one end to the other. In one of the two mazes, the end section
with the wide stripes was used as the shock place, and in the other maze, the end with the narrow stripes was used as the shock place.

Shock was the 1 milliamp condenser discharge type shock employed previously in this type of apparatus and was discharged through the stainless steel strips. Otherwise, the current on the strips was the 10 microamp current used to measure BRL.

Procedure. The 16 animals were randomly assigned to four groups of four animals each. Half of each group was to be shocked in the end with wide stripes and half in the end with narrow stripes. The four groups differed in how far they were to be permitted to run after being shocked.

For two weeks before the beginning of training, all of the animals were placed individually in one of the alleys for a few minutes each day. In addition, each was handled and gentled for a 20 minute period each day. After this period of adaptation, each animal was placed in the appropriate first section of one of the mazes for a period of 15 minutes.

At the end of 15 minutes, two shocks were delivered as closely together as possible and at a time when the BRL record verified that the animal was in good contact with the two strips. Immediately after the delivery of the second shock, the animals were either retained in the shock compartment (for the 0 group) or permitted to run to the 1st, 3rd, or 6th section of the maze counting from the shock compartment. They were then retained in the appropriate compartment for 75 minutes. Each animal was run under the same conditions for four consecutive days.

The record was then sectioned into 18 five minute intervals, three before shock and 15 after shock, and the lowest value in each interval was recorded as representing that interval.

Because we wanted to determine how long it would take for BRL to recover to the pre-shock value, the values obtained just before the shock were examined in detail. There was a slight rise in BRL during the 15 minute periods with means of 33.2, 34.3 and 36.1 for the successive 5 minute periods. These differences however, did not approach significance. Nor were there differences
between days that were either ordered or statistically significant. It was therefore decided to average the 12 values for each animal, three periods on each of four days, to obtain a single pre-shock mean for each animal. It was then possible to determine how much time after shock it took for an animal to achieve recovery to his preshock BRL level and to determine whether the time consumed in recovery differed depending on how far the animal had been permitted to remove himself from the shock place.

The result is plotted in Figure 29. In general, the animals retained in the place where they were shocked took longest to recover, those permitted to run to

![Graph showing recovery time for different days.](image)

**FIGURE 29**

**BRL RECOVERY TIME**

Mean recovery times (number of minutes for each animal to recover his own pre-shock BRL) for each of the four days of the experiment and for each distance the animals were allowed to run after being shocked.
an immediately adjacent section took slightly less, while those permitted to run three feet away took the smallest amount of time, roughly half the time required by the animals retained in the place where they had been shocked. The animals permitted to run to the far end of the maze took slightly longer to recover, but the difference was very small.

A Treatment by Levels analysis of variance was performed and is shown in Table 8. It shows that there was a significant difference between sections of the maze (how far the animals were permitted to run, but not between days.

Two other ways of presenting the data are shown in Figures 30 and 31. In the first of these, the mean values for each time period are plotted across

![Graph showing BRL as a function of distance](image)

**FIGURE 30**

**BRL AS A FUNCTION OF DISTANCE**

Curves showing the mean BRL in successive 15-minute periods beginning with the pre-shock period and continuing through the 75 minutes of the post-shock period. The values are means across the four days of the experiment.
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<thead>
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<th>Source</th>
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<th>F</th>
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<td>359.1</td>
<td>.81</td>
</tr>
<tr>
<td>Sections</td>
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<td>1414.0</td>
<td>3.20</td>
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<tr>
<td>Days x Sections</td>
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<td>441.2</td>
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</tr>
<tr>
<td>Total</td>
<td>57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Curves show the recovery pattern by time for each of the four groups, divided on the basis of how far they were permitted to run after being shocked. The points are means for four days.

the four maze sections. Thus the solid line shows the pre-shock means for the four groups. The lowest curve is for the first 15 minute period after shock, and other periods show other patterns, gradually increasing. The last figure (31) is perhaps the most dramatic. It plots lines for each of the four groups across the six time periods. In this picture it is clear that the animals in the group retained in the shock compartment are slowest to recover, while the two groups allowed to escape either three of six sections away recover more rapidly. The largest difference occurs in the second 15-minute period after the shock.
These results are particularly meaningful since it is clear that neither
time correlated artifacts nor place correlated artifacts could account for the
results. This apparent since the group that was allowed to escape only to the
adjacent compartment shows a recovery pattern much like the animals retained
in the place where they had been shocked. The real difference in recovery time
occurred between two groups which were permitted to move, but which moved
different distances, 1 or 3 sections of the maze.

These results are important also because they suggest means of manip-
ulating the BRL value, and thus presumably the arousal level, in studies of the
effect of arousal level on learning and performance.

**Summary of Relations of BRL and Biological Drives.** The relations
between arousal and drive are so critical, that studies in this area were carried
out repeatedly, especially studies of the relation of hunger, thirst and fear to BRL.
The results were markedly different in the two cases. In studies of the effects of
hunger and thirst, a series of studies involving different pieces of apparatus,
different research designs, and different durations of deprivation were consistent
in failing to show any decrease in BRL with increased time of deprivation. The
conclusion seems inescapable that, in spite of the technical difficulties, there is
little or no relation to be expected in any study relating BRL to time of deprivation.

In the case of the studies of the effect of shock, the reverse appears to
be true. Shocking an animal appears to induce a state of fear that is relatively
unrelated to the intensity of the shock, and in a variety of pieces of apparatus,
with a variety of measuring techniques, and in a variety of designs, shock
induces an immediate and profound drop in skin resistance. Furthermore, the
rate of recovery can be manipulated through a procedure that seems likely to
have manipulated the fear-inducing properties of the situation.

While there seems to be some variation in BRL with estrus cycle in
female rats and also a correlation between GSR to stimulus change neither
seems related to the classic activity cycle. Since the BRL differences were not
significant, and only one GRS difference statistically significant, the reasonable
conclusion seems to be that there are no psychologically significant differences.
If one classes hunger, thirst and sex as appetitive drives, then the results are essentially negative with appetitive drives. If fear is classified as an aversive drive, then the results for aversive states is positive. The conclusion that one might draw, then is: Skin resistance does not vary with variations in the intensity of appetitive drives, but it does vary with the intensity of aversive drives.
5. BRL and incentives

Behavior can be manipulated effectively through the control of rewards. The mechanism through which rewards operate is open to debate, and definitions of what is rewarding that are not in terms of the postulated effect of rewards are difficult. The term 'incentive' is usually defined in terms of approach or avoidance behavior - a positive incentive being one that is approached and a negative incentive is one that is avoided. Some psychologists associate incentives with the reduction of biological drives - positive incentives are stimuli which reduce drives, while negative incentives are stimuli which induce or increase biological drives.

If skin resistance showed correlated variation with the application of incentives, it might then be possible to acquire information of critical value with respect to the reward-incentive mechanism. For example, if variation in drive does not produce correlated variation in BRL, but if an incentive does produce such variation, the relation between incentives and drive reduction would be called into serious question.

The pursuit of this problem with the techniques for measuring skin resistance developed by the Kaplans is technically very difficult. In order to obtain a useful measure of skin resistance using the standard shock grid floor, a two minute time sample is usually required. Occasionally one minute samples have yielded data of some value. Most events associated with the application of an incentive could be expected to occupy time intervals on the order of one or two seconds rather than one or two minutes. For this reason, any work on incentive must be done with the parallel stainless steel strips.

Even with the parallel stainless steel strips, movement artifacts are quite critical. For example, a large number of efforts were made to determine the effects of skin resistance of electrical stimulation of some portion of the limbic system. Animals were obtained from Dr. James Olds that had
chronically implanted electrodes and that would eventually undergo histological verification of the location. The animals were selected on the basis that the placement was in an area that produced self-stimulation. In every instance, the application of current appeared to produce slight movements. In the record, it was not possible to distinguish changes produced by the stimulation that could be attributed to the incentive properties from changes attributable to the movement-produced properties. Radical procedures such as the use of curare were not undertaken.

A rat's manner of eating also precludes a close temporal correlation between the ingestion of food and the observation of possible correlated changes in BRL. Typically, the rat will grasp food with the forepaws and assume a position, very slight movements, even so slight as the wiggling of the vibrissae, may produce variation in the pressure of the footpads on the floor and thus produce movement artifact.

Only two situations appear to yield information that has any usefulness or validity. The application of shock produces such large differences in skin resistance that the gross changes in skin resistance could not be artifactual. The second situation is one in which the animal is drinking from a standard watering tube. While drinking from a tube placed close to the floor, the animal tends to stand on all four feet very quietly and lap at the tube at a very rapid rate. Under such conditions, movement artifact is virtually absent from the record.

Fear reduction. As was noted in a previous section on the effect of shock on skin resistance, shock produces a dramatic drop in skin resistance, frequently of the order of 500,000 ohms. The amount of drop is dependent, of course, on the pre-shock skin resistance level. Typically, the drop is immediate and terminates in the vicinity of 75,000 ohms which appears to be a minimum value. It will also be recalled that individual difference data show high positive correlations between measures taken on the same animals at different times unless one of those measures was taken immediately after shock. Shock, and presumably the fear induced by shock, tend to eliminate individual
differences.

The data that were reported on the effects of shock in the previous section show two phases of recovery in the BRL record. There is a rapid recovery of about 25% of the pre-shock BRL within the first few minutes. If BRL is reflecting the arousal associated with fear, this fairly immediate recovery in BRL might be reflecting a functional reduction in fear.

Water consumption (Thirst reduction). A series of formal studies were devised to examine the effect of a period of water consumption on the BRL response. Since these studies have not been published, the procedure will be reported here in some detail.¹

Subjects. Twenty naive male hooded rats of the Long-Evans strain were selected which were 90 to 100 days of age at the beginning of the experiment.

Apparatus. The experiment was run in a straight alley that was 50 inches long, 2 3/4 inches wide, and 3 inches high. It was divided into a 10 inch goal box, a 10 inch starting alley, and a 30 inch maze section by two guillotine type gates. The walls were of unpainted wood, the top was hardware cloth, and the floor was two stainless steel strips separated by a 1/2 inch gap running the length of the maze. The goal box had a small hole in the end directly over the gap in the floor. A water bottle was fastened to the outside of the maze with the spout projecting through the hole. The water bottle was connected via a relay "drinkometer" to the event marker on the servo-recorder. This arrangement permitted the recording of the contact of the animal with the water, and the exact correlation with BRL changes was established.

Procedure. The animals were given 17 days of pre-training during which their ears were punched, they were placed on a water-deprivation schedule, given training in a different straight alley, and finally given 30

¹ This study was carried out by Donald A. Dewsbury and the discussion here is a revised version of an unpublished document, Dewsbury, D. A., and Walker, E. L. Basal Resistance Level (BRL) Changes as a Function of Drinking in Rats.
minutes of exploration in the experimental alley. On the water deprivation schedule, they were about 20 hours water deprived before each testing period and were given water for two hours per day beginning about an hour after each day's trial. Food was available at all times.

Each animal was given one trial on each of 12 days. The rat was carried to the experimental room, placed in the start box and confined there for a 10 second period. The gate was then raised and the animal allowed to run to the goal box containing the water bottle. The door was closed behind it, and a 30 sec. goal box period was allowed during which the animal was free to drink. Skin resistance was recorded throughout this period using the Kaplan method.

In experiments involving water deprivation and water reward, animals do not always drink when they reach the goal box. With 12 trials for each of 24 animals, there were 240 records. Drinking of some duration occurred on 199 of these trials, and on 41 trials no contact was made between the animal and the water tube.

Figure 32 is a photograph of a typical record of those trials on which the animal began drinking immediately on entering the goal box and continued through the 30 second period before it was removed. As the animal is placed in the starting box and runs down the alley, movement artifact due to variation in firmness of contact between the rat and the strip floor is evident. As the rat reaches the goal box and begins to drink, movement artifact disappears and an increase in skin resistance is seen throughout the drinking period.

If skin resistance at the beginning of drinking is compared with resistance at the end of drinking (regardless of the amount of drinking during the period) increases in resistance were found on 160 of the trials, no change on 14 trials, and decreases on 25 trials. The mean change, taking the sign of the change into account, on all trials on which any drinking occurred was an increase of 108, 200 ohms.

A set of drinking records was chosen on a limiting set of criteria. If the initial value of the record was below 3 megohms and if the animal drank
FIGURE 32

RECORD OF RUNNING AND DRINKING WHILE WATER DEPRIVED

Photograph of chart record of BRL while drinking. This same photograph appeared as a part of the section on the techniques of measurement.
continuously through the 30 second period, the record was chosen. Sixty-four records representing 17 of the 20 animals met these criteria. Another set was selected in which the animal did not drink at all during the 30 second period. The records of these animals were analysed for BRL in successive 3 second periods and means obtained for the two sets. Figure 33 shows the results.

The upper curve shows a continuously rising curve reflecting a steady increase in BRL over the 30 second period of drinking. This rise represents an increase of 154,000 ohms in a 30 second period. The lower curve undergoes no significant change. Since the two groups of trials differ only in whether the animal was drinking or not drinking, it seems highly likely that the rise in BRL during drinking is attributable to the drinking itself.

Consumption of water compared to consumption of liquids containing nutritive or tasty substances. While it has not been possible to measure skin resistance in precise correlation with the ingestion of dry foods because of the movement artifact involved, it should be possible to measure changes in skin resistance during the ingestion of a liquid food. If there is any additional effect of nutritive elements added to water, it should show in a comparison between drinking water and drinking milk. A study was designed based on this possibility.¹

Subjects. Thirty-two male Long-Evans hooded rats were obtained from the Windsor Biological Gardens. They were naive and 75-125 days of age at the beginning of the experiment. One animal died during the course of the experiment, and his data were discarded.

Apparatus. The apparatus used in this study was identical to that used in the water drinking study just discussed, except that it was 14 inches shorter (total length 36 inches).

Procedure. The procedure was the same as in the previous experiment

¹ This study was carried out and the data analysed by Donald A. Dewsbury with the help of Barbara Stoddard.
FIGURE 33
BRL RESPONSE WHILE DRINKING

Mean BRL values on trials during which rats drank continuously for 30 seconds (upper curve) compared to the BRL values on those trials on which the animals did not drink and stood still in the goal box.
except that pre-training was done with the appropriate liquid in the drinking bottles for each group. The animals were divided into Milk and Water groups, with 15 animals in the former and 16 in the latter.

These animals performed in a fashion very similar in all respects to the animals in the water drinking study. The animals running for water drank on 148 and did not drink on 44 of the 192 trials. Animals running for milk drank on 148 and did not drink on 32 of the 180 trials.

Among animals running for water, there were 72 trials from 13 of the animals on which 30 seconds of continuous drinking occurred. In the group running for milk, there were 79 trials representing 14 animals on which 30 consecutive seconds of drinking occurred. The effects of drinking milk and water are shown in Figure 34. Both curves rise over the 30-second period. The mean rise while drinking water was about 141,000 ohms, and the mean rise while drinking milk was about 122,000 ohms. The difference between the two curves is not statistically significant. One can conclude, perhaps, that there is no difference in the effect on BRL of drinking plain water or nutritive milk.

Another effort was made to determine whether the addition of a nutritive substance to water would affect the character of the change in BRL observed during drinking. In this study, a comparison was made between the records of animals drinking plain water with animals drinking a 7.5% solution of sucrose and animals drinking a 15% solution.

Subjects. Thirty male animals were chosen for this study. They were handled from birth but were otherwise experimentally naive.

Procedure. The apparatus and procedure were identical to those used in the previous study except for the training phase. These animals were given six consecutive weeks of training. They were divided into groups of 10 animals each, and during the first two weeks, one group was trained under each of the reward conditions - water, 7.5% or 15% sucrose - for the entire period. In the second two week period, each group was shifted to a different reward condition, and in the third two week period, each group was shifted to the reward conditions it had not yet experienced.
FIGURE 34
BRL RESPONSE WHILE DRINKING MILK OR WATER

Comparison of mean BRL changes for animals drinking water for 30 seconds continuously in the goal box with similar data for animals drinking milk.

In the analysis of the data, only the second week of the two week periods were analysed. This was an effort to maximize the proportion of trials on which a full 30 seconds of drinking occurred. With 30 animals and one trial a day on each of five days, 150 records were available under each reward condition. Of these, records showing 30 seconds of continuous drinking numbered 84 for water, 112 for 7.5% sucrose, and 96 for 15% sucrose.
Figure 35 shows mean rise in BRL under the three different reward conditions in this study. The largest rise is that which occurs while the animals are drinking water, approximately 192,000 ohms. A rise of about 182,000 ohms occurs while drinking 7.5% sucrose, and approximately 132,000 ohms while drinking the 15% concentration of sucrose.

![Graph showing BRL response while drinking sucrose or water.]

**FIGURE 35**

**BRL RESPONSE WHILE DRINKING SUCROSE OR WATER**

Mean values of BRL (in 100,000 ohm units) for animals drinking for 30 seconds consecutively in the goal box. The comparison is between animals drinking water with animals drinking two concentrations of sucrose.

If the addition of a nutritive substance to the water was to add to the arousal reduction value of the substance, then one would expect the results to be ordered, with water producing the least reduction, and 15% sucrose
the most. The order of the results was the reverse. It is also possible, with this design in which Figure 35 represents the second of two weeks on one substance, that the initial values reflect the arousal properties of the substances. These values do not follow any expected order. One would conclude, then, that there were no meaningful differences between plain water and the two concentrations of sucrose in the BRL increases observed.

Figure 36 shows the results of an earlier and less satisfactory experiment involving 12 days of single trial testing of 6 animals in each group with water compared to two values of sucrose and two values of saccharine. No simple ordered relationship was produced in this study.

![Figure 36](image)

**FIGURE 36**

BRL RESPONSE WHILE DRINKING SUCROSE, SACCHARINE, OR WATER

Mean BRL values of animals consuming water or two different concentrations of sucrose and two of saccharine for 30 consecutive seconds in the goal box.
**BRL and food reward in the monkey.** One effort was made to track BRL changes in a single rhesus monkey. This animal was being tested in a discrimination learning situation by Dr. Charles M. Butter. The animal was learning a standard three stimulus discrimination problem while seated in a permanent experimental chair. In the experimental context, the monkey faces a screen which can be raised to expose the stimuli. The correct stimulus will contain a reward, while the incorrect stimuli will not.

BRL was measured by use of the electrodes used in human research. They are zinc electrodes placed on top of corn pads into which zinc sulphate electrode paste has been placed. They work effectively with human subjects where the subject can be instructed to hold the hand that has electrodes attached immobile. The monkey tends to move both hands and the result is a large amount of movement artifact. Nevertheless, suggestive records were obtained.

In Figure 37, the 'stimulus change' trials are a series of 58 adaptation trials on which the screen was lifted but no rewards were provided. There is a rise of about 120,000 ohms in the 30 second period immediately after the raising of the door. On trials on which the animal chose the correct stimulus and received a reward of one grape, there is an initial drop of about 80,000 ohms while the animal is removing the stimulus and retrieving the grape. This is followed by a rise of about 110,000 ohms by the end of the 30 second period. The line for the grape reward trials in Figure 37 represents 132 such trials out of a larger number, many of which contained movement artifacts. The third curve is for extinction trials (33 trials) and they show an initial drop of about 190,000 ohms followed by virtually no change (at most a rise of 10,000 to 20,000 ohms). Thus, for what they are worth, the data on Charlier Butter's monkey, 'Watson,'seems to show a drop in resistance that is attributable to the exertion involved in making the choice, and a rise of about 100,000 ohms which is associated with the consumption of the food reward. Such a rise occurs from the stimulus change of the raised screen, but no such rise occurs on an extinction trial. It is also of interest to note that on a few occasions 'Watson' was rewarded with a non-preferred raisin.
FIGURE 37

MONKEY RESPONSE TO GRAPE REWARD

Mean BRL values for Charlie Butter's monkey, 'Watson,' on three kinds of trials in a discrimination learning problem. Two of the curves compare trials on which a grape reward was received with trials on which the exposure door was opened but no reward received. The third curve is for a series of extinction trials.

Summary of BRL and incentive. The application of an incentive substance, in this case water, milk, or water containing sucrose or saccharine, all produce a marked rise in skin resistance in the period during which the animal is consuming the liquid. While no such rise could be demonstrated in the rat associated with a dry food because of movement artifact and the data on a single monkey can only be taken as suggestive, it seems likely that there probably are skin resistance changes associated with food reward.
It seems likely that the changes in BRL reflect an emotional state change. This would seem to follow from two basic findings. No relationship could be shown between BRL and time of deprivation of food or water, yet the application of a relevant reward leads to a sharp rise in resistance. The second finding is that the amount of rise in resistance does not appear to be related to whether the liquid is plain water or is a liquid with nutritive or sweet taste properties. The best interpretation appears to be that when an animal receives a reward substance, he undergoes a change from a state of expectancy to one of satisfaction and certainty. It is this change that is reflected in the skin resistance measure.
6. Conditioning of BRL

Few psychologists would doubt that the application of shock to the rat produces a state of fear. It also seems certain that conditioned fear can be established by presenting a neutral stimulus that is followed within a few seconds by shock. The neutral stimulus will take on fear-inducing properties through a process of conditioning in a very few trials.

It should therefore be possible to condition the BRL response through the pairing of a neutral CS with shock. The difficulties associated with the demonstration of BRL conditioning are those indicated earlier involving the unreliability of short term samples of BRL records where there is likely to be movement artifact. Shock produces considerable movement in most cases and 'freezing' behavior in the others. A mixture of records showing extensive movement and freezing behavior could be expected to give highly variable estimates of skin resistance.

The first attempt to demonstrate conditioning of BRL was done by Donald A. Dewsbury. He attempted to set up an avoidance learning situation, which while ineffective in establishing avoidance, did provide a classical conditioning situation.

Subjects. Eight naive male hooded rats from the Psychological Laboratories colony were used. They were 90 to 120 days of age at the beginning of the experiment.

Apparatus. The four Grayson-Stadler Skinner Boxes were used. Turning off the house lights was used as the CS, and the shock UCS was delivered by a constant current stimulator that produced 5 milliamps with 120 square wave pulses per second.

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1Dewsbury, D. A. Basal skin resistance level of rats in an avoidance learning situation. (Unpublished document.)
Procedure. The eventual avoidance task was to be pressing the operant lever to turn off or to avoid shock. To make this response likely, a long procedure was used. They were handled extensively and then shaped to press the bar to receive food reward. They were continued in this training until they were pressing the bar at a stable rate.

For one day the animals were placed in the apparatus for 90 minutes with no experimentally introduced stimulus change. Then on days 2 through 4, after the first 30 minutes the house lights were turned off (the CS) and remained off for 10 seconds unless the lever was pressed to turn them on again. The animals remained in the boxes for 60 to 90 minutes after this trial.

On the next 12 days, 10 seconds after the house lights went off, shock was turned on for one minute. A lever press during the 10 second CS period would turn the house lights on and avoid the shock. A lever press during the shock period would turn the house lights on and permit the animal to escape the shock.

Avoidance occurred only four times in the 96 trials, but the procedure, without avoidance, fits the classical conditioning paradigm. Classical conditioning almost certainly occurred, but the results of this experiment are complicated by the fact that the animals tended to adapt to the shock. The major results can be seen in Figure 38.

The dashed line shows the course of BRL in the 10 second period immediately preceding the shock. It shows an erratic course, rising for about four days after the introduction of shock and then falling. The solid curve shows the course of the mean BRL measurements taken during the CS. It shows a somewhat erratic course over days as well, but on all days except the 14th shows a decrease in value upon introduction of the CS. In general, the decrease seems largest for the first four or five days after the introduction of shock. The third curve shows the post-shock BRL which is generally, but not always lower than the values obtained during the CS.

The effects of the classical conditioning procedure can best be seen in Figure 39. Here the difference between BRL in the pre-CS period and the CS
FIGURE 38
BRL CONDITIONING

Mean BRL pre-CS, during CS, and in the period immediately after shock (on days when shock occurred) in a classical conditioning situation.

period are plotted. The difference is large on day 2, when the CS was first introduced. By the fourth day the animals were fairly well adapted to the CS. Introduction of shock produced an increase in the difference (the expected effect of conditioning) which persisted until the 14th day before disappearing. Since the animals were being shocked repeatedly, and for as much as a full minute at a time, it is clear that they were undergoing adaptation to the shock and no longer feared it.
While there seems little doubt that the procedure produced classical conditioning of BRL, there are several reasons why the results appear to be less than satisfactory. Considerable variability is evident in the two figures. Some of this variability stems from the very short measurement period (10 seconds in each case). The shock was of such long duration that adaptation apparently occurred. It therefore seemed worth while to undertake a further demonstration of the conditioning of BRL.

In a pilot study for an experiment to be reported later on BRL and heart rate in a conditioned suppression situation, Jon L. Williams had constructed a
small plastic box just large enough to hold a rat and which could be fastened to the wall of the Skinner Box allowing the animal access to the lever. The box was constructed so that the animal's hind paws were firmly in contact with two stainless steel strips.

In this apparatus, four rats were shaped with food reinforcement to a stable VR 10 schedule. Conditioning was carried out with a 2000 cps tone of 60 seconds duration followed by a condenser discharge type shock of one milliamp intensity and with a duration of less than .01 seconds.

One trial was given with the CS alone, followed by six trials with the CS followed by the shock. Figure 40 shows the results. The left hand figure shows mean BRL on the single trial with the CS alone. The CS produces a drop in skin resistance. This figure also shows the mean course of BRL during the six conditioning trials. There is a clear drop in skin resistance during the CS followed by a further drop when the shock is introduced. The figure on the right converts these figures to percentage drop. Here it is quite apparent that the conditioning of BRL occurred in this situation.

One can conclude, therefore, that the conditioning of skin resistance occurs as one would expect if BRL measures arousal level or fear induced by shock.
FIGURE 40

CONDITIONED BRL IN CONDITIONED SUPPRESSION SETTING

Mean BRL for CS before conditioning and after conditioning for four animals in a conditioned suppression setting. The figure on the right converts these data to percentage change in BRL in the two situations.
7. Linear maze performance and the goal gradient

The "goal gradient" is the name given to the tendency for animals to increase speed while running a maze and then decreasing speed as the goal is approached. This phenomenon has been given two major interpretations. Hull\(^1\) proposed motivational and associative interpretations but never made a clear choice between the two. Spence,\(^2\) however, has given a clear motivational interpretation. Stimuli closer to the goal are assumed to be more strongly conditioned to \(r_g\), the fractional anticipatory goal response, and thus results in stronger \(K\), incentive motivation.

**Arousal and the goal gradient.** A series of studies were designed to investigate this phenomenon. The first of these was published by DiLollo and Walker.\(^3\)

Two methodological innovations are included in the present study. Since starting speed and running speed appear to be somewhat different functions of the number of reinforcements, and because BRL measurement increases in reliability with the length of the interval of measurement, the runway used in this study was

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segmented into six sections, and the animal retained in each section for 1 min. before the gate was opened permitting him access to the next section. This procedure yielded five measurements of starting latency, and at the same time gave a 1 min. time sample in each section of the alley for BRL measurement. The second innovation was a reward in both the 5th and 6th sections for one group and in the 6th only for another. If the goal gradient is related to $r_g$, the two goal gradients should show maximum speed in different sections.

Subjects. The Ss were 48 male hooded rats obtained from the Holtzman Co. They ranged in age from 140 to 170 days at the beginning of training, and they were housed in individual cages.

Apparatus. The apparatus consisted of six straight alleys 87 in. long, 3 in. wide and 5 in. deep. The walls were of 1/2 in. plywood, and the floors were made of brass rod. The rods were 1/8 in in diameter and were set 1/2 in. apart at right angles to the length of the alley. The top was of clear plastic. Five guillotine-type doors made of 1/8 in. clear plastic divided the alley into six sections: a starting box 12 in. long, and five other sections 15 in. long. The walls of the alleys were painted with black and white vertical stripes. In three of the alleys, the width of the stripes increased by 1/2 in. in each successive section, beginning with 1/2 in. in the first section (start box) and ending with a width of 3 in. in the last section. In the other three alleys, the order of the stimulus pattern was reversed. In sections five and six of each alley, a soft drink bottle cap, which acted as a food cup, was glued to the floor in the far right corner of the section.

A .01 sec. Standard Electric Timer was started when the gate for a section was raised, and it was stopped when S stepped on a treadle in the next section, 9 in. from the entrance door. This timing arrangement was repeated at each of the five gates permitting five separate measures of starting latency at different distances from the end of the maze.

Alternative rods of the alley floor were connected electrically. A current of 10 $\mu$A was applied through the grid floor. This circuit was completed through S's body when it stood on bars of unlike sigh. The S's resistance level (BRL) was
thus measured by the Kaplan technique through the floor and was recorded on a modified Varian G-11a recorder which served as a recording ohmmeter. The scale values plotted in the figures are in terms of units of 2,500 ohms. The mean values reported in the figures range from approximately 300,000 ohms to 600,000 ohms.

Procedure. Four weeks before the beginning of training, all Ss were placed on a 24 hr. feeding schedule with food available for 90 min. each day and water available at all times. During this four week period, each S was gentled for about 2 min. each day. The Ss were randomly assigned to two groups of 24 Ss each. Group RR was rewarded with two .045 gm. Noyes food pellets in both sections 5 and 6 of the alley. Group R received the two reward pellets only in section 6. Half of the Ss in each group ran in the alleys with increasing width of stripes, half in the alleys with decreasing width of stripes. The Ss were run by two Es, one of whom always ran Ss in the alleys with decreasing stripe width, thereby confounding the stripe progression and the E factor.

Each S was given one trial per day for 20 consecutive days. On each trial S was placed in the start box and, after a delay of 1 min., the first door was raised, thus allowing S to move to the second section of the alley. The first door was closed behind it and, 1 min. later, the second door was raised to allow entry into the third section, etc. The S was removed from section 6 1 min. after his entry into that section. The 1 min. detention period was introduced in order to obtain an adequate sample of BRL readings in each section. The S's BRL score, in a given section, on a given trial, was the lowest resistance reading recorded during the relevant 1 min. period. The assumption is made that firm contact with the grid is made at least once during the 1 min. delay period.

The goal gradient phenomenon is pictured in Figure 41. Starting latency at the successive gates rises to the fourth gate and drops at the fifth as the animals enter the final compartment. Skin resistance appears to follow a similar pattern, rising through successive sections of the maze to the fifth section and then showing a slight drop in the goal section. The changes with position in the maze are statistically significant in both cases, but the difference between groups is not significant in either case.
FIGURE 41

THE GOAL GRADIENT IN TERMS OF SPEED AND BRL

Mean starting speed (left) and mean BRL (right) as a function of position in a six-section, segmented alley. 'R' indicates the position of reward in both the 5th and 6th sections for one group (RR) and in the 6th section only for the other (R). BRL is in 2,500 ohm units.

The rise and fall in the figure appears to be the classical goal gradient. Both Spence's interpretation of the increase in speed along the runway, and Hull's interpretation of the downturn approaching the goal are associated with the position of the reward. Spence's interpretation was in terms of increasing vigor of \( r_g \) as the stimuli in the maze approach those of the goal box as a function of generalization. Hull's motivational interpretation of the decrease near the end of the maze was in terms of the interference between the fractional anticipatory goal response and the instrumental acts necessary to reach the reward. Thus both
interpretations are oriented to the position of the reward and the physical location of the consummatory response.

The data in Figure 41 seem to deny these interpretations. The goal gradient in the RR group that had rewards in both the 5th and 6th sections of the maze shows a goal gradient essentially identical to the R group with a reward only in the sixth section. The goal gradient in these data is anchored to the beginning and the end of the run rather than to the placement of the reward. This finding suggests that an explanation of the goal gradient, when one is found, must be sought elsewhere in the experimental situation.

Further analysis of the data were undertaken to determine the course of development of the goal gradient. Figure 42 shows the course of learning to run

![Figure 42](image)

THE DEVELOPMENT OF SPEED AND BRL

Mean starting speed (left) and mean BRL (right) as a function of successive blocks of four trials for both groups combined. BRL is in 2,500 ohm units.
the maze in terms of both speed and BRL. The lefthand figure shows that the speed rose to a maximum during the fourth block of four trials and then showed a drop. BRL showed a similar pattern. The drop during the final block of trials is not unusual. There are many situations in which performance increases and then decreases under continued reward.

The correlation between speed and BRL are of genuine interest. The most common treatment of the roles of drive and incentive during the course of learning is to invoke some kind of association of the drive to the stimuli of the situation and/or an association of the stimuli of the situation with the incentive substance. Thus the drive level associated with time of deprivation would not change, but any changes that would occur during learning would be an increase in the expression of the drive in the learning situation and an increase in the energizing function of the incentive. If BRL is an expression of the arousal level, by this reasoning, one would expect an increase in arousal over the 20 learning trials and thus a decrease in BRL - exactly the opposite of the picture seen in Figure 42. In that figure, it is clear that skin resistance rises as learning progresses. Thus it appears that the animal is most aroused on the first trial and undergoes a gradual decrease in arousal as his performance in the task becomes more and more efficient.

Figure 43 is an effort to combine the data of the two earlier figures into a single picture so that the development of the goal gradient in terms of both speed and BRL could be seen. In that figure, the speed curves show no goal gradient during the first block of four trials, but the gradient is apparent in the other four blocks. In the BRL curves, the rising skin resistance is apparent from the first, but the turndown at the end, increase in arousal, is not apparent until the last two blocks of trials.

A casual observation made during the course of running of this experiment suggested an alternative interpretation to the Hull-Spence approach. The animals in this experiment were being run in squads of 6 in 6 identical mazes, and they were being run as nearly simultaneously as possible. Since this was a difficult task for a single experimenter, two experimenters worked at the same time.
FIGURE 43

DEVELOPMENT OF THE GOAL GRADIENT

Plot of interaction between position in the maze and successive blocks of four trials (labeled 1 to 5 in the figure) for speed (left) and BRL (right). BRL is in 2,500 ohm units.

with each handling three mazes and the animals being run in them. The recording instruments were outside the experimental room. It was noted that three of the instruments recording BRL were giving substantially lower values than the other three. The effect was marked enough that any casual observer could separate one set of three from the other. To be sure of the source, a number of minor tests were attempted including shifting the channels back and forth matching the recording instruments with different mazes. The net effect was to determine that the three consistently low readings were being taken from the animals
handled by one of the experimenters and the three animals with high readings were being taken from the animals handled by the other experimenter. The effect was independent of the particular animals, the particular mazes, and the particular recording instruments. A third experimenter was substituted for the one whose animals gave the abnormally high readings of BRL. This experimenter produced BRL values (in his animals) that were lower than the readings obtained by the experimenter that was replaced, but still higher than the remaining experimenter.

Even though the observation was a casual one, it was clear that different animals produced different levels of BRL. The hypothesis that seemed worth entertaining was the different experimenters produced different amounts of fear while handling animals, and that the different levels of fear yielded different skin resistance values.

It also suggested that the classical 'goal gradient' might be an experimenter variable. It is well known among experimentalists who have worked with the goal gradient that it is an illusive phenomenon. Sometimes it is clearly apparent in a set of data and sometimes it seems to be absent. It is conceivable that the goal gradient is a product of an animal that has been frightened by his experimenter. He increases speed in getting away from the starting box as an escape reaction from the handling. After he has run enough trials to know that he will again be picked up by the experimenter from the goal box, a slight avoidance tendency begins to develop as the goal box is approached. This hypothesis appears to account for all of the data.

Three more experiments were devised to contribute information to the two major questions raised by the results of the goal gradient experiment. The first question concerned the replicability of the rise in BRL (thus decrease in arousal) that seems associated with learning. The second question concerned the possibility that the goal gradient might be an experimenter variable.

The disassociation of BRL and running speed through stimulus change. The primary objective of the next experiment in the series was to find a manipulation which would change BRL during the course of a learning experiment without major effect on running speed. It seemed possible that the rise in skin
resistance was a simple adaptation phenomenon, or it was possible that it was closely tied with running speed, however the running speed was produced. To determine whether the latter was the case, it was decided to carry out training in a maze with one set of stimuli, then shift the animals to a similar maze with another set of stimuli, and then return them to the first maze. If running speed was not seriously affected but BRL was affected by the stimulus change, then the correlation between running speed and BRL would not likely be an artifactual product of the rapid running.

It was decided at the same time to investigate two other associated variables. Since handling technique appeared to make a difference in the previous study, handling was made a variable in this one. Half of the animals were to be handled extensively for a number of days prior to the experiment, while the other half would not be. At the same time, individual or group housing seemed worth investigating for its effect on performance. The study was thus devised to investigate stimulus change, handling, and housing.¹

Subjects. The Ss were 16 black hooded male rats which were approximately 90 days old at the beginning of the experiment. They were experimentally naive.

Apparatus. Two of the six mazes used in the previous study were used in this one in slightly modified form. Each maze was 100 inches long, consisting of a black starting box which was 4 inches wide and 10 inches long. The six sections of the maze had black and white vertical stripes throughout, with the stripes 1/2 inches in width in one maze, and the second had stripes 1 1/2 inches in width. The floors of the mazes were brass rods separated by 1/2 inches and alternately wired. Skin resistance was measured by the standard Kaplan technique.

Procedure. One week prior to the beginning of the training in the maze, the animals were taken from group cages. Half were placed in individual cages

and half were placed in cages in pairs. Half of each group was handled, stroked, talked to, and thus "gentled" for two minutes per day during the week; the other half was not handled. Each of the four sub-groups thus formed was divided into two groups of two animals each, with one group started in the maze with the narrow stripes and the other group in the maze with the wide stripes.

The animals were deprived of water for 20 hours before each training trial. At other times they were permitted to drink and eat freely. A water reward was provided in the terminal segment of the maze on each training trial.

At the beginning of a trial, animals were taken from their cages and placed in the starting box. After one minute, the gate was raised, and the animal was permitted to enter the next section of the maze. After one minute retention in this segment, the next gate was raised, permitting the animal to proceed to the second section. This procedure was continued until the animal reached the goal box. Latencies were taken as the time from opening of the gate until the animal passed into the next compartment, and were measured with a hand-held stop watch.

Training consisted of one trial per day for 8 days in the original maze for each animal. For the next four days, each animal was run in the other maze. For the last two days, each animal was returned to the maze in which it had started training.

The major findings in terms of mean latency and mean BRL as a function of training are shown in Figure 44. The plotted mean latencies involve 96 values per point. They represent values for 16 animals at each of the six gates of the maze. Mean BRL's are also of 96 values per point. As in previous studies, as latency drops during the first stages of training, the mean BRL value tends to rise. Both trends are statistically significant in spite of the irregularity in the curve of mean BRL as a function of training. It will be noted that the shift from the orginal maze (either broad or narrow stripes) to the other for four days produced very little change in the mean latencies, but appears to have produced a drop in BRL for the first two days after the shift. The return to the original maze had no effect on starting latency, and produced a slight apparent but statistically
FIGURE 44
BRL AND LATENCY CHANGES IN RESPONSE TO CHANGE IN MAZE STIMULI

Plot of mean latency (left) and BRL (right) as a function of eight days of training in one segmented straight runway, four days of continued training in an adjacent runway with a different striped pattern, and a final two days of training in the original maze. BRL is in 20,000 ohm units.

non-significant drop in BRL. Thus the procedure of changing an animal from one maze to the other, with the two being almost exactly alike except for the stripe pattern on the maze walls, appears to have produced a shift in BRL while having little effect on running speed. In view of the objective of this operation, the irregularities in the BRL curve are worthy of special comment.

Spatial facilities at the University of Michigan are hopelessly inadequate. As one result, research and teaching space are of necessity combined. At peak periods in both research and teaching, it is necessary to store animals in an open hall within the animal facilities. When laboratory classes must use the facilities
there is no way to keep experimental animals from being exposed to the shouting and noise of horseplay of undergraduate students. The low values of BRL on days 4, 5, and 8 or original training and on day 2 in the other maze unfortunately coincide with those days in which heavy use of the facilities was made by the students in the elementary laboratory. Thus, Figure 44 confirms, to a degree, the correlation between running speed and learning seen in the previous study by Di Lollo and Walker. It also shows, however, that BRL can be modified, either by an adventitious and wholly unwanted set of disturbances in the laboratory environment or by the shift in maze, and thus a change in wall pattern, without a major change in running speed.

There were eight essentially negative but meaningful findings. No differences in latency or BRL were obtained that could be attributed to handling, pattern of housing, or whether training was initiated in the maze with broad or narrow stripes. Furthermore, no clear goal gradient curves emerged in any phase of training in either latency or BRL.

In separate analyses of variance on the three phases of training, two BRL differences approached the 5% level of significance. They are the social variable during original training and the handling variable during the four days of shift to the other maze. Both differences, however, were opposite the expected direction in that the non-handled and the animals caged singly showed the higher BRL values and thus less arousal. Since these were only two of a fairly large number of possible tests, it must be assumed that they arose by chance, and it must be concluded that none of these variables had a significant effect on BRL or latency.

When the data are examined for goal gradient effects, minimal effects were found. There was a tendency for the latency to be high and the BRL low in the starting box in relation to the values of these measures taken in other sections of the maze, but values beyond this point do not show a gradient pattern.

**BRL in learning, extinction and relearning.** The third study in this series was done by Walker and Walker.\(^1\) It had two basic objectives. The first was to

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try to measure the immediate effects of handling, and this was done by
retaining the animals in a delay box at the beginning of the maze for a period
of 5 minutes except that half of the animals were removed and handled during
the second minute and the other half during the fourth minute. The effects of
handling should be apparent in a comparison of BRL before and after handling.
The second objective was to produce learning, extinction, and relearning of
the response to determine whether BRL followed the learning pattern or continued
to rise as a function of repeated experience in the maze.

Subjects. The subjects were 24 naive animals raised in the Psychological
Laboratories colony at the University of Michigan. They were of mixed strain
but were hooded and had pigmented eyes. They were 130-140 days of age at the
beginning of the experiment.

Apparatus. The two mazes used were identical with those used in the
previous study except that the stimuli inside the maze had graded vertical black
and white stripes that were 1/2 inches at one end and 3 inches in width at the
other. One maze had the narrow stripes in the goal box end, while the other had
the broad stripes in that position. Skin resistance was measured by the standard
Kaplan technique.

Procedure. The animals were placed on a 23 hr. water deprivation
schedule three days before the beginning of the experiment. They were handled
for a few minutes each of these days when they were released on a sawdust table
for 30 min., 12 animals at a time.

During the experiment, a water bottle was installed in the final segment of
the maze. Animals were run in pairs, one animal in each maze, starting at about
8:30 a.m. They were given a second daily trial starting at about 1:30 p.m. They
were given access to water from approximately 4:00 to 5:00 p.m. each day.

During each run, an animal was placed in the delay chamber. It was held
there for 5 min., except that half of the animals were removed and handled gently
throughout the 2nd min., and half were removed and handled gently during the 4th
min. At the end of the delay period the gate was raised, permitting the animal
access to the starting compartment of the maze. The latency of its movement into
the next compartment was recorded in seconds. The animal was retained in each
compartment of the maze proper for 1 min. before the gate was raised permitting access to the next compartment.

Training was continued for 2 trials per day for 5 days (10 trials), extinction was carried out for 4 days (8 trials), and relearning for 2 days (4 trials).

The effect of handling was discussed in an earlier section of this report. There was a drop of 52,000 ohms in animals handled in the 2nd minute and a drop of 30,000 in the animals handled in the 4th minute. These results are shown in Figure 7. The larger difference was statistically significant and the smaller almost significant. Handling does produce 'arousal' even when, as in this instance, the experimenter in this case had an unusual ability to handle rats without disturbing them.

Figure 45 shows the effects of learning, extinction and relearning on mean starting latency and on BRL measured in the delay chamber before each run, or in the various sections of the maze during the run. The original acquisition curve appears to have reached an asymptote in 10 trials. Latency in extinction reached the starting latency in 8 trials. Four trials were sufficient to re-establish the short latency response. The low latency on the first day of the retraining occurred as a function of very short latencies at the last two gates. The animals were apparently able to see the reinserted water bottle through the clear plastic doors.

The figure also shows BRL scores as a function of days in the maze proper and in the delay chamber. The BRL scores in both instances are inversely related to latency and would therefore be positively correlated with speed as plotted in the Di Lollo and Walker study at the beginning of this section. It is clear, therefore that skin resistance in this maze situation varies with the learned performance and is not a simple expression of adaptation to the situation as the earlier results might have been interpreted.

If these skin resistance scores are reinterpreted in terms of arousal, Figure 45 seems to mean that at the beginning of training the animals are highly aroused. As training proceeds, the animals are starting from each compartment with greater and greater alacrity while the skin resistance measure is reflecting
FIGURE 45

LEARNING, EXTINCTION, AND RELEARNING

Mean gate latency (left), skin resistance in maze sections (center), and in the starting box (right) during acquisition, extinction, and reacquisition in a segmented straight runway. BRL is in 20,000 ohm units. Latency is in seconds.

a progressively lower state of arousal. Furthermore, during extinction, skin resistance falls as latency increases, indicating progressive increases in arousal as extinction proceeds. The relearning data indicate that the process is reversible.

It will also be noted that the skin resistance measures taken in the delay chamber prior to the run appear to be a close reflection of the measures taken in the maze itself. It would seem possible, then, to interpret these results as indicating that the arousal level reflected in BRL measures characterizes the state of the animal in the total situation rather than in a specific position in the maze.
This latter interpretation, in this study, is given additional support from plots of the latencies and BRL measures as a function of minutes in the delay chamber and sections and gates of the maze itself. These values in terms of means across the three periods, learning, extinction, and relearning, and in terms of over-all means are shown in Figure 46. No systematic goal gradient shows in any of these curves in this figure. A plot of a selection of individual days is shown in Figure 47 and there is likewise no apparent goal gradient.

FIGURE 46
THE GOAL GRADIENT
Over-all Means

Plots of skin resistance as a function of successive minutes in the starting chamber (left), skin resistance as a function of maze section (center), and starting latency as a function of gate position in a segmented straight runway. Values are means across all trials of original learning, all trials of extinction, all trials of relearning, and total trials. BRL is in 20,000 ohm units.
FIGURE 47
THE GOAL GRADIENT

Selected Days
Plots of skin resistance as a function of successive minutes in the starting chamber (left), skin resistance as a function of maze section (center), and starting latency as a function of gate position (right) in a segmented straight runway. Values are for selected days of learning (the 1st, 6th, and 10th trials), extinction (8th trial), and relearning (4th trial). BRL is in 20,000 ohm units.

The days selected are representative of all days with respect to the lack of a goal gradient phenomenon.

There are a number of differences in procedure between the Di Lollo and Walker study and the present one. It is tempting to try to account for the presence of a goal gradient in both running speed and BRL in the Di Lollo and Walker study and the absence of a goal gradient in this one in terms of the experimenter variable. It is a casual, and therefore untrustworthy, observation
that the experimenter in this study has an unusual ability to handle rats without disturbing them. No objective measures of experimenter differences are, however, available. The range of BRL values obtained in the two studies was different. In the Di Lollo and Walker study the mean BRL values ranged from approximately 300,000 ohms to 600,000. In the present study they ranged roughly from 250,000 to 1,750,000. The smaller values in the Di Lollo and Walker study indicate that throughout the study, the animals were more aroused than they were at the lowest arousal points in the present one. However, other differences in procedure might just as well account for the difference in BRL level. Some important differences are the drive used (hunger vs. thirst), the amount of reward, or even the method of handling the data (latency vs. speed). Therefore, the issue cannot be regarded as determined.

The present study can be taken to establish that handling can produce drops in BRL in rats. It also appears to establish a correlation between skin resistance and running speed that is a function of expressed habit strength. Both results can be offered in support of the interpretation of the goal gradient phenomenon in the Di Lollo and Walker study in terms of reaction to handling rather than to variation in the intensity of \( r_g \). The absence of a goal gradient in either running speed or in BRL in the present study can also be given such an interpretation.

The manipulation of the goal gradient through shock placement. The last study in this series was an attempt to use shock to exaggerate the effects of handling. The idea was that if handling aroused the animal and produced increased running away from the spot where the animal had been placed, and if anticipation of being handled again produced slowing near the goal box from which the animal was picked up, a frightening shock added to handling should exaggerate the effect. In order to make all of the effects of shock apparent, four groups of animals were run. One group with normal handling served as a standard. A second group was shocked each trial before being placed in the maze, a third group shocked each day after being removed from the maze, and the fourth group shocked both before and after the maze experience.\(^1\)

\(^1\)This study was designed and executed by Jon L. Williams.
Subjects. Thirty-two naive, male, hooded rats were selected from the colony of the Psychological Laboratories. They were 90-120 days of age at the beginning of the experiment.

Apparatus. The seven-section linear maze with the stripe pattern of decreasing widths was used. In addition, two delay boxes were built, one with a white interior and the other with a black interior. These were physically separated from the maze proper. Skin resistance was measured in the delay boxes and in the maze by the standard Kaplan technique.

Procedure. The animals were divided into four groups of 8 animals each and given the following designations.

NS - No shock given at any time.
SB - Shock before maze running.
SA - Shock after maze running.
SBA - Shock before and after maze running.

The animals were deprived of food for 20 hours before each trial, and they were given one trial a day for a two pellet food reward for six days.

Each animal was placed in one of the delay boxes (half in each color) for a period of 60 seconds before being placed in the maze. For the SB and SBA groups, a capacitor discharge type shock of one milliamp intensity with a duration of less than .01 seconds was delivered two seconds after they were placed in the delay box. At the end of the 60 seconds, each animal was placed in the first of the seven sections of the maze. The animal was delayed for 30 seconds in each section. Latency of leaving the section and BRL in the section was recorded in each instance. After the animal had consumed the two pellet reward, it was removed to the delay box. In this box, Groups SA and SBA were shocked 58 seconds after being placed in the box. The walls of the delay box were the same brightness as before for the NS and SBA groups, while they were of the opposite brightness for the SB and SA groups. Thus for animals that were given shock, only one level of brightness was paired with shock.

Figure 48 shows that one trial a day for six days was sufficient for significant learning to occur. The NS and SB groups show decreases in latency
LEARNING WITH THE EFFECTS OF HANDLING EXAGGERATED BY SHOCK

Mean running latency and mean BRL during six days of training in the linear maze. NS is the group that did not receive shock in the delay boxes, SB is the group that received shock before running the maze, SA received shock after running, and SBA received shock before and after running.

of a typical learning curve. Groups SA and SBA do not show latency decreases. Thus the animals that were not shocked learned to run fast in the maze. The animals shocked before being placed in the maze ran even faster. However those animals shocked after did not show improvement, and those shocked before and after actually decreased their running speed.

The BRL measures plotted on the right side of Figure 48 show that the animals which were not shocked showed the typical increase in BRL that accompanies learning. However, none of the groups that were shocked showed any real change.
Figure 49 would reveal goal gradient effects. The curves represent mean starting latencies for the last two days at each of the six starting gates, and Mean BRL values for the two delay chambers and the seven sections of the maze. The latency curve for the NS group shows a general trend toward faster starting as the goal is approached, and the BRL curve for this group rises over the same span. The effects of handling is evident in the drop in BRL for this group between the last section of the maze and the period in the delay box.

![Graph](image)

**FIGURE 49**

THE GOAL GRADIENT UNDER SHOCK MANIPULATION

Mean latencies and mean BRL values for the different maze gates and maze sections. BRL was measured during the last 30 seconds the animal was in the delay box chamber in the 'Before' condition and in the first 30 seconds in the delay chamber in the 'After' condition. Data are for the 5th and 6th days.
The curves for the SB group are similar to those for the NS group except that these animals are running faster and have lower BRL values.

It should be noted that the relation between BRL and running speed within each of the groups is one of higher BRL accompanying the faster running speeds. However, the reverse is true between groups. The SB group that is running significantly faster than the NS group, shows the lower BRL.

No simple interpretation for the results for the 'Shock After' or the 'Shock Before and After' groups is immediately apparent. The 'Shock After' group shows little change in running speed, while the 'Shock Before and After' group slows up significantly as it approaches the end of the maze. BRL for the three shocked groups remains low throughout training and throughout the maze.

As a final problem of the relation between BRL and running speed, the three shocked groups all have approximately the same skin resistance levels and are running the maze at very different speeds.

**Summary of Goal Gradient Studies.** The results of this set of four studies does not offer a simple summary. The goal gradient appears to be an experimenter variable and appears to be produced by rapid running to escape the handling just before entry into the maze, and anticipatory slowing up as the animal approaches the goal box where it will again be picked up and handled by the experimenter.

The evidence for this conclusion is substantial but not overpowering. Primary is the fact that in one study in which a marked gradient was found, it was oriented to the ends of the maze rather than to the position of reward. Some experimenters obtain a goal gradient and others do not in similar situations. It seems likely but not certain that the difference is attributable to the difference in experimenters. Handling does produce a drop in BRL and thus a probable increase in arousal. Therefore, the hypothesis that the goal gradient is a variable related to the experimenter rather than to the experimental subject or situation seems viable.

The relation of skin resistance and thus arousal to learning and performance is ambiguous. As performance improves in a straight runway, skin resistance rises indicating decreased arousal. Extinction seems to produce an increase in
arousal by this logic, and relearning a decrease. In the goal gradient situation, the correlation between speed of running and arousal appears to be the same. When speed is high, arousal is low. When arousal is high, speed is low. However, a change is the stimuli of the maze can produce a drop in skin resistance, increased arousal, without an accompanying decrease in speed of running. In the last study, when shock was used, there were large speed changes that were unaccompanied by arousal changes. A tentative conclusion that one might draw would be that the arousal measured by BRL relates to the state of certainty of the animal in the learning situation. If the animal is uncertain, then he will be relatively highly aroused. As learning proceeds and the animal becomes certain of the reward, arousal tends to drop. However, this relationship can be masked by other emotion-related aspects of the situation. When shock is used, the animals all become aroused and fearful. This condition is reflected in a uniformly low BRL and thus high state of arousal. Between the three groups, running speed could be manipulated by the position of the shock in the sequence.

The relationship between skin resistance and arousal on the one hand, and learning and performance variables on the other, is sufficiently complex to justify further exploration.
8. Approach-approach and avoidance-avoidance conflict

Conflicting action tendencies should produce arousal. In the classic analysis of conflict by Lewin, conflicting tendencies to approach two different situations should produce mild conflict and a mild increase in arousal. Conflicting tendencies to avoid two different situations should produce a maximum of conflict and thus a maximum of arousal. If BRL reflects the arousal state, BRL should be significantly lower in an avoidance-avoidance conflict situation than in an approach-approach conflict situation.

An experiment was devised\(^1\) to establish approach tendencies toward a set of stimuli and avoidance tendencies toward another set. Animals were then faced with a pair of stimuli to which they had acquired approach tendencies and a pair to which they had acquired avoidance tendencies in a situation in which they could be held in the presence of these stimulus sets long enough to measure their skin resistance. For comparison purposes, some animals were trained with food reward for a correct choice and non-reward for an incorrect choice, while other animals were trained with food reward for the correct choice and shock for the incorrect choice. Thus the difference in the arousal levels produced by the conflict situations could be compared with differences produced by the use or absence of use of shock.

Subjects. There were 24 animals that were approximately 120 days of age. They were naive male hooded animals from the local colony.

Apparatus. A special Y-maze was built for this study. In it all alleys were the narrow type with slightly over two inches in width inside. The floors were constructed of the stainless steel strips with approximately 1/2 inches separating the two strips in the middle of the alley.

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\(^1\) This study was designed and executed by J. Susan Frohman and reported in an unpublished paper, *Basal resistance level as a measure of conflict in approach-approach and avoidance-avoidance conflicts.*
The maze had a 10 inch starting alley with an opaque door. From this the animal could be released into an 8 inch delay chamber with a transparent door through which the animal could see the choice alleys and their associated stimuli. It was thus possible to detain the animal in the presence of conflict-inducing stimuli long enough to obtain a measure of BRL. When released from the delay chamber, latency of response could be measured as the time between opening of the delay chamber door to the animal’s crossing a point four inches inside each of the goal alleys. The goal box doors were hinged on the side and were pushed open by the animal to gain admittance to the goal box. The stimuli to be discriminated were black and white horizontal bars or vertical bars painted on clear plastic and attached to the goal box doors and to the walls of the goal boxes. The goal boxes were 14 inches long including the 3 1/2 inches from the choice point to the swinging doors.

A water bottle could be attached to the end of the goal box to provide water reward, and shock (a condenser discharge type with a maximum current of about .7 milliamp with a duration of about 8 milliseconds) could be delivered, when appropriate, through the floor. BRL was measured by the standard Kaplan technique.

Procedure. The animals were housed individually with animals receiving shock housed separately from those not receiving shock. They were placed on a 20 hour water deprivation schedule for a week prior to the beginning of the experiment and maintained on that schedule throughout. During the experiment, they were allowed free access to water for a one-hour period no less than 30 minutes after the conclusion of the day’s work.

In order to establish the running pattern and get the animals accustomed to running the maze and opening the doors, three days of preliminary training was provided. During this period, each animal had six massed trials with a one-minute intertrial interval. The first three trials were, and the last three were either free or forced as required to force equal entry to the two sides. All choices were rewarded with water during this period.

Training for half of the animals involved water reward for a correct
choice and non-reward for an incorrect one. For the other half, a correct choice yielded water reward and an incorrect choice led to shock. Half of each group was trained with horizontal stripes positive and half with vertical stripes positive. Position of the boxes was determined by a random sequence.

On each trial, the animal was confined in the starting box for 5 minutes to permit recovery from handling, retained in the delay box for one minute to permit measurement of BRL, and then permitted to choose. After choice, animals were retained in the goal boxes for 30 seconds on all trials with shock punishment, when appropriate delivered immediately after full entry into the incorrect box.

One block of animals was trained with two non-correction trials per day and another with four trials per day. Subsequent analysis revealed no difference between these two treatments. Animals were trained to a criterion of 12 successive correct choices. It is to be noted that in the shock groups, since shock occurred only on errors, it had been a minimum of three days in one block and six days in the other since the animals had been shocked by the end of the training period.

Testing consisted of trials on which both alleys had the same stimulus in place, either positive (approach-approach) or negative (avoidance-avoidance). Each animal was given two trials per day, one of each variety, with the order of trials reversed on successive days. There were ten days of such testing, but the results are reported only from the first two, since later test trials were affected by the fact that reward was given on both sides on the ++ trials and on neither side on the -- trials.

Table 9 shows that the response speeds were considerably faster in the approach-approach situation. Speeds were also faster (higher) when shock had not been used as punishment for the wrong choice, even though the animals that were shocked had not experienced shock for several days before the test trials. The type of conflict produced bigger differences than the presence or absence of shock.

Table 10 reveals that mean BRL also followed the expected pattern.
TABLE 9

RESPONSE SPEEDS IN CONFLICT SITUATIONS

(1/latency in seconds)

<table>
<thead>
<tr>
<th>Conflict Type</th>
<th>No Shock</th>
<th>Shock</th>
<th>Differences Due To Shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach-Approach</td>
<td>.295</td>
<td>.120</td>
<td>.175</td>
</tr>
<tr>
<td>Avoidance-Avoidance</td>
<td>.095</td>
<td>.035</td>
<td>.060</td>
</tr>
<tr>
<td>Difference Due to Conflict Type</td>
<td>.200</td>
<td>.085</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 10

BRL IN CONFLICT SITUATIONS

(in 100,000 ohm units)

<table>
<thead>
<tr>
<th>Conflict Type</th>
<th>No Shock</th>
<th>Shock</th>
<th>Differences Due To Shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach-Approach</td>
<td>3.03</td>
<td>2.95</td>
<td>.08</td>
</tr>
<tr>
<td>Avoidance-Avoidance</td>
<td>2.82</td>
<td>2.75</td>
<td>.07</td>
</tr>
<tr>
<td>Difference Due to Conflict Type</td>
<td>.21</td>
<td>.20</td>
<td></td>
</tr>
</tbody>
</table>
Animals in the approach-approach situation show higher skin resistance and thus less arousal than animals in the avoidance-avoidance situation. The differences are statistically significant for the type of conflict in both tables and for the shock variable with respect to speed, but the effect of shock on BRL is not significant.

Thus the expected effect of the two types of conflict on arousal was verified. The approach-approach conflict situation that should not create much stress yielded faster response speeds and higher BRL (thus lower arousal) than the avoidance-avoidance conflict with its slower response speeds and lower skin resistance (thus higher arousal).
9. Operant performance and arousal

One of the most fundamental phenomena in learning is the increased resistance to extinction exhibited by animals that have been rewarded only intermittently when compared to animals that have been rewarded continuously. If habit strength is associated with the number of rewards, then animals with the greater number of rewards should take longest to extinguish. In fact, animals that have been rewarded only a few times on a partial reward schedule will often press longer after reward has been discontinued than animals with the greater number of rewards, but on a schedule that yielded a reward for each performance of the response involved.

One class of explanation for the phenomena involves a redefinition of the response. Thus Mowrer and Jones\(^1\) suggested that a response was whatever the animal was rewarded for doing. If rewarded only 50% of the time, then a response was two presses. If rewarded only 25% of the time, then a response was four presses. They performed an experiment in which the results were analysed using this logic, and found that the number of response units was directly rather than inversely proportional to the number of rewards.

There have been a number of other investigators who have suggested that a part of the difference in performance of 100% and partial reward animals in extinction might be due to aspects of the motivation-emotion aspects of the situation. Partial reward is frequently described as a relatively frustrating condition. It is possible that the frustration involved motivates the response to increase the output during extinction. Among investigators who have argued in this matter are Adelman and Maatsch, Amsel and Roussel, and the team of Holder, Mark, Holder,

and Collier. ¹

If frustration or any other emotion produced by non-reward is related to arousal, and if arousal is inversely related to skin resistance, then animals in a partial reward situation should show lower skin resistance than animals receiving 100% reward. It might also be possible to relate the level of arousal during a partial reward schedule and the level of arousal during extinction to the number of responses produced.

**Skin resistance in a discriminated operant situation.** The first of three studies of the relationship between presence and absence of reward and skin resistance was done by Maurice Warner.² The subjects were 24 hooded rats from the Psychological Laboratories colony.

They were placed under 48 hours food deprivation and shaped to press the lever for food reward in the Skinner box situation. Each of the four Grason-Stadler boxes used was equipped with a speaker and a small light on the front wall. Skin resistance was measured through the grid floor by the standard Kaplan technique.

After shaping, the Ss were given two days of continuous reward with sessions lasting 45 minutes. Then, discrimination training was begun using alternating periods of continuous reward or non-reward. These reward conditions were correlated with stimulus changes, and all Ss were given the

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² Maurice Warner performed this experiment when he was an undergraduate at the University of Michigan and under the tutorial direction of Stephen Kaplan. The data presented here are presented in a form different from that in an unpublished paper by Warner, Demonstration of a nonrestraining BRL recording method for animals.
same schedule for a one hour session each day. Different Ss were given different combinations of stimuli.

The results of the discrimination training are shown in Figures 50, 51, and 52. The three figures represent three groups of animals run at different times and for four, four and five days of discrimination training. All combinations of assignment of light and sound to reward or non-reward conditions, either alone or together are represented in the three figures.

The plus and minus signs on the abscissae of the figures represent the alternating periods of rewarded and non-rewarded responses for each of the days of training. Examination of the figures suggests that there are correlated changes in BRL with the reward and non-reward conditions from the first day of training. BRL is relatively high during periods when the animal is being rewarded and relatively low when reward is absent. This phenomenon is especially apparent in Figure 50.

FIGURE 50
LIGHT-SOUND DISCRIMINATED OPERANT
In contrast, discrimination tends to develop somewhat later in the lever pressing response. As the lever pressing discrimination develops, the fluctuations in the curves for lever pressing and skin resistance tend to come into coordinated oscillation. When the animal is pressing and receiving food, the BRL values are high. When the negative stimulus is present and lever pressing is depressed, BRL values are low, indicating high arousal.

These results are consistent with the Walker and Walker runway results in which the performance of the well-learned habit was accompanied by low arousal, while extinction was accompanied by high arousal. It should be noted, however, that the two sets of results are consistent in predicting the
The reverse of the frustration expectation of partial reinforcement. If partial reinforcement produces frustration which increases arousal, indicated by a low skin resistance value, the number of responses should be lower, not higher than in the contrasting situation.

Fixed Ratio Reward and BRL.\textsuperscript{1} An experiment was designed to examine skin resistance in rats during fixed ratio training and a subsequent session of extinction or non-reward performance.

The subjects were 14 male hooded rats from the colony of the Psychological Laboratories. They were deprived of food until they reached 80\% of their initial weight and they were maintained at this level throughout the experiment. They were shaped on the first day in the Grayson-Stadler Skinner Boxes in

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure52.png}
\caption{LIGHT-SOUND DISCRIMINATED OPERANT
}
\end{figure}

\textsuperscript{1} The two studies discussed in this section were designed and executed by Jon L. Williams. They are discussed in an unpublished paper, Walker, E. L., and Williams, J. L. BRL during acquisition and extinction of a fixed ratio reinforcement schedule.
which skin resistance could be measured using the Kaplan technique. During the next two daily sessions, each animal was given 100 rewarded responses.

The animals were then divided into seven groups of two animals each. In the six training sessions that followed, the first group was given continuous reward, and the remaining six groups were gradually trained to fixed ratios of 5, 10, and 20, with two groups at each ratio. The fixed ratio groups were trained so that one group was given the same number of rewards as the 100% reward group, while the other was given the same number of responses, and thus a smaller absolute number of rewards. After the tenth day of training on the fixed ratio schedules, all subjects were tested for resistance to extinction.

Figure 53 shows BRL as a function of the various reinforcement conditions on the last day of training. With the number of rewards constant, and thus with the number of responses varying between groups in ratios up to 20 to 1, BRL rises to the .20 ratio, and falls through the .10 ratio to the .05 ratio. Thus the animals seem most aroused under the 20 to 1 condition, next under 10 to 1, and unexpectedly more under the 1 to 1 condition than under the 5 to 1 condition. With the number of responses constant, and thus with the absolute number of rewards decreasing to 1 in 5, 1 in 10 and 1 in 20, arousal increases to 1 in 10 and then rises at 1 in 20. One can conclude either that the results are randomly related to the reward schedule, or that the relationship is more complex than one would have thought.

Figure 54 shows the results during extinction. The number of lever pressings is shown on the left, and the BRL in the middle curve. On the right is a plot of response units as defined by Mowrer. That is, 5, 10, or 20 responses are calculated as a unit in the ratio groups, and the number of units is plotted.

The number of lever presses to extinction rises and then falls in both groups in the left hand figure. This is not an unexpected
finding since it has been reported a number of times before.\footnote{For example, see:}

\begin{itemize}
\item Grant, D.A., Hake, H.W., and Hornseth, J.P. Acquisition and extinction of a verbal conditioned response with differing percentages of reinforcement. \textit{J. exp. Psychol.}, 1951, \textit{42}, 1-5.
\end{itemize}
constant in the upper (solid line) curve. Thus a second factor is needed to account for the rise in output of lever pressings, and a third factor to account for the drop in the curve at the 1:20 ratio.

The curve for skin resistance shows a pattern roughly similar to the curve for the number of presses. High skin resistance (low arousal) goes with high output of responses, while low skin resistance (high arousal) goes with the lower output. This result fits, in a sense, with the results obtained in the linear maze where high skin resistance was correlated with a well-learned performance, while the low resistance measures were obtained during extinction.
As an aid to trying to develop an explanation of these results, the number of lever pressings was converted to response units. These data are shown on the right. Several facts are apparent from this figure. The upper curve does not fit the response unit hypothesis of Mowrer. Even when plotted in this fashion, the output at a ratio of 5:1 is nearly twice the output under continuous reward. Furthermore, there is what appears to be a better match between plots of lever pressing and skin resistance when lever pressing is plotted in response units.

The results plotted in Figures 53 and 54 are all statistically significant even though there are only two animals in each of the seven groups. However, the results are so unusual that a replication seemed desirable. It also seemed worth an effort to reduce the variability in the results as much as possible through experimental arrangements. To accomplish this, small boxes were constructed that held the animals in a lever oriented position. The construction was such that the hind paws of the animal rested on parallel stainless steel strips and the front paws could not reach the strips. Using this apparatus, the experiment was repeated with 28 animals permitting the assignment of 4 animals to each group. Otherwise the experiment was identical with the previous one.

Figure 55 is a plot of skin resistance during the last day of the acquisition phase. This figure looks remarkably like the similar figure (53) from the first replication except that the downward turn of the curve for a fixed number of rewards occurs at a ratio of 1:5 in the first study and at 1:10 in the second. Also, the two curves in the figure do not quite cross in the second study as they do in the first. Otherwise, the patterns are so similar that the possibility of a random relationship seems unacceptable.

In Figure 55, the solid curve involving the larger number of rewards is higher, indicating less arousal, than the curve for a constant number of responses (and thus fewer rewards). Within the constant reward condition, the higher resistance at ratios of 5:1 and 10:1 than at 1:1 or 20:1 was found in both studies. With the number of responses constant, the pattern is also very similar in the two studies indicating that the highest arousal
(lowest BRL) occurs at a ratio of 1:10.

Figure 56 shows the results in terms of number of lever presses and BRL for the second study, and here the results are somewhat different than they were in the first study. In the narrow confines of the box, the number of responses to extinction increases monotonically with progressively smaller ratios with the number of rewards constant. With the number of responses constant (and thus with the number of rewards decreasing progressively) the number of presses to extinction remains relatively constant. The trends in skin resistance do not show the inverted-U form as in the earlier study. The curve for the constant number of rewards and thus the greater number is consistently higher than the dashed line representing the progressively smaller number of rewards. There is no simple relationship between the
number of lever presses and BRL across the various ratio schedules. Table 11 is a conversion of the number of lever presses to response units. These figures show two regularly decreasing functions of the number of response units with the smaller ratios. These data do not show a simple relationship to the BRL values in Figure 56 either.

**Summary of operant performance and arousal.** The series of studies on operant performance and arousal were addressed to the possibility that partial reward affected the emotional state of the animal, and that the emotional state in turn affected the number of lever presses obtained in extinction.

In the discriminated operant situation, periods of non-reward produced high arousal from the beginning of training, so that alternating periods of the presence and absence of reward were accompanied by perfectly correlated high
and low BRL records. Partial reward of the fixed ratio variety produced low arousal with the higher absolute number of rewards during acquisition, but there was a suggestion that this generalization would not hold when reward ratios were much beyond 20:1. During extinction, both the number of lever pressings and the skin resistance measures showed complex, rather than simple, relations to each other and to skin resistance.

**TABLE 11**

**RESPONSE UNITS TO EXTINCTION**

<table>
<thead>
<tr>
<th>Reward Ratio</th>
<th>Responses Constant</th>
<th>Rewards Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td></td>
<td>214.3</td>
</tr>
<tr>
<td>1:5</td>
<td>47.9</td>
<td>108.6</td>
</tr>
<tr>
<td>1:10</td>
<td>20.6</td>
<td>71.3</td>
</tr>
<tr>
<td>1:20</td>
<td>17.4</td>
<td>44.4</td>
</tr>
</tbody>
</table>
10. Discrimination learning under manipulated arousal

The most direct way of approaching the problem of the role of arousal in learning and performance is to manipulate the level of arousal during the course of the learning of a simple task. Since animals appear to show recovery from the effects of shock on a predictable time course, then it should be possible to present a simple learning problem to groups of animals that differ in how long it has been since they experienced shock. If all training of one group is carried out under relatively high arousal produced in this manner and training of another group is carried out under lower levels of arousal, the effect of arousal on learning and performance should be revealed. ¹

In the study of the effects of shock on BRL, the recovery pattern over time showed a rapid recovery of about 25% of the total BRL change in the first three or four minutes. In the study of the effect on recovery rate of removal from the place of shock, it was found that animals permitted to run some distance from the place of shock recovered most of the BRL change in about 15 minutes. Based on these data, the general pattern of a study of discrimination learning under manipulated arousal took the following general form. A distinctive delay box was added to a simple Y-maze. Animals were placed in the delay box. Animals which were to learn under high arousal were retained in the delay box for 15 minutes, shocked, and then permitted access to the starting box of the Y-maze. They were permitted to make a choice between the two alternatives two minutes after being shocked. Animals of the low arousal group were placed in the delay box and shocked at the end of a two-minute period. They were then admitted to the starting box and retained for 15 minutes before permitted to choose. The difference in time since shock should have the effect of making the arousal levels at the time of choice very different for the two

¹ This study was carried out by Jon L. Williams, and the results have not been published.
groups of animals. The details of method in this experiment are the following.

Subjects. Twenty male black hooded animals from the colony of the Psychological Laboratories of the University of Michigan were used. They were naive and approximately 90-110 days of age at the beginning of the experiment.

Apparatus. The Y-maze used in this study was the maze used in the study of conflict. The delay box had black and white 1/2 inch vertical stripes. The start box and choice point were grey. The goal boxes were either solid black or solid white and were clearly visible from the choice point and start box.

Procedure. The animals were randomly assigned to high and low arousal groups at the outset. They then were handled daily for a two week period and received a hand administered drink of 10% sucrose solution every third day.

For five days each animal was placed in the appropriate goal box and allowed to drink the sucrose solution from the water bottle. For half of each group, the left goal box was ultimately to be the correct one and for half the right goal box was to be correct. Within each subgroup of five, the black goal box was on the left for three animals and the white on the left for two animals.

For the next two days, each animal was given a single trial with the doors to the goal boxes open.

For the next six days, each animal was given one trial a day with forced choices, three to one side and three to the other. This period of training was primarily for the purpose of allowing the animals to learn to open the swinging doors of the goal boxes.

Training consisted of eight days of free choices with one trial per day. During this time, shock was instituted in the delay chamber for both groups. The low arousal group was shocked by a condenser discharge type shock of approximately 1 milliamp for less than .01 seconds, two minutes after being placed in the delay box. Immediately after they were shocked,
they were admitted to the start box and were retained there for 15 minutes before being permitted to choose. The high arousal group animals were retained in the delay box for 15 minutes, shocked, and then admitted to the start box. They were retained for two minutes before being permitted to choose. BRL was measured in the start box and in the choice point area, and choice latency was measured.

The animals were under 10 hours of water deprivation during this phase of training and they received 30 seconds of drinking of the 10% sucrose solution as a reward for the correct choice.

Three of the animals in the high arousal group failed to leave the delay chamber during training, exhibiting the well-documented tendency of some animals to 'freeze' when shocked. The other animals all chose correctly by the eighth day.

The effort to manipulate skin resistance, and thus arousal level, was effective. Table 12 are mean BRL readings in the start box and the choice point. The BRL values for the high arousal group are consistently lower (thus indicating higher arousal) in both compartments than are the values for the low arousal group. In the start box the difference is approximately 48,000 ohms. In the choice point the difference is approximately 100,000 ohms.

The effect of the manipulation of arousal on learning and performance is shown in Figure 57. The curves showing per cent correct do not appear to be different between the two groups. The curves on the right, however, showing the mean latency of choice in seconds are different. Through the first four days of training, the low arousal group takes a much longer time to make its choices. In the last four days, there is no difference between the two.

Taken at face value, the results would appear to indicate that high arousal affected performance by producing faster running in this discrimination situation, but that it did not affect the rate of learning. The two conclusions should probably be given different weightings. The two groups did not differ in rate of learning, but this was an extremely simple problem and extensive
DISCRIMINATION AND MANIPULATED AROUSAL

Mean per cent correct choices and mean latency of choice for eight trials of a simple discrimination learning task for groups for which the arousal level at the time of choice had been manipulated through variation in time since shock.
preliminary training was provided. It is not certain what would happen if a much more difficult, and therefore much more discriminative, problem was used in a similar study. The effect of arousal on running speed, however, seems well-established. Highly aroused animals run faster. While this finding is clear, the range of conditions over which one might expect to find this result is not. As this study was designed, animals were running away from shock and toward a liquid reward. The faster running of the high arousal group could be interpreted as shock-escape behavior. The relatively short latency choices of the last four days of training in both groups appear to be rapid approach behavior.

Summary of learning and performance under manipulated arousal. High arousal appears to produce a faster, more vigorous performance of a simple running response but it does not appear to affect the rate of learning. This conclusion may be specific to the simple discrimination problem and the particular temporal sequence of shock escape motivation and sucrose reward.

**TABLE 12**

**EFFECT OF AROUSAL MANIPULATION DURING TRAINING**

(BRL in 100,000 ohm units)

<table>
<thead>
<tr>
<th>Trials</th>
<th>1-2</th>
<th>3-4</th>
<th>5-6</th>
<th>7-8</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start box</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Arousal Group</td>
<td>2.38</td>
<td>2.35</td>
<td>2.90</td>
<td>2.43</td>
<td>2.50</td>
</tr>
<tr>
<td>Low Arousal Group</td>
<td>2.83</td>
<td>2.72</td>
<td>3.11</td>
<td>3.26</td>
<td>2.98</td>
</tr>
</tbody>
</table>

| Choice Point |     |     |     |     |      |
| High Arousal Group | 2.40 | 2.60 | 3.17 | 2.30 | 2.62 |
| Low Arousal Group | 3.63 | 3.45 | 3.87 | 3.54 | 3.62 |
11. BRL and heart rate as indices of arousal in conditioned suppression

The phenomenon of conditioned suppression offers an excellent opportunity to establish the correlation between a physiological index of arousal and learned performance. In the conditioned suppression paradigm, the usual pattern is to set up an operant response for an appetitive reward, such as food, and then introduce punishment, usually shock, and observe the effect of the punishment on the operant rate of the instrumental response.

If the shock is introduced in an avoidance conditioning paradigm, the simultaneous effects of the introduction of the CS can be observed on the operant response and upon the index of arousal. If a differential stimulus (DS) is presented as well, then the development of discrimination between the CS and DS can be observed in both the instrumental response and the index of arousal.

If the delivery of the shock is made contingent on responding in one animal and made independent of responding in another, then the effect of the contingency can also be observed in both classes of measures.

The only physiological index of arousal reported so far in this sequence of studies is variation in skin resistance. Heart rate is also frequently employed for this purpose. If both skin resistance and heart rate are measured in the same situation, then one can potentially correlate the two indices of arousal with each other and with the instrumental response performance.

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This section is a brief and incomplete version of the dissertation of Jon L. Williams. References are:


A study to accomplish all of these objectives was designed and executed by Jon L. Williams. Because the design and procedure are both complex and elegant, there is justification for going into some detail here, even though the results have been published.

Subjects. Initially, there were 24 male albino rats which were naive and 120-140 days of age at the beginning of the experiment. One died during the course of the experiment, and since a yoked design was being used, the results reported here are based on two groups of 11 animals each.

Apparatus. Two boxes, each 3 1/2 x 3 1/2 x 7 1/2 in., were constructed for measuring the electrical skin resistance of rats. When one of these small units was placed inside a Grason-Stadler Skinner box, a rat inside the unit could poke its head through a 1 x 1 in. opening in the end wall of the unit to obtain pellets from the food compartment of the outer Skinner box. Inside the unit on the wall to the right of the opening to the food compartment was mounted a 1 in. wide lever which extended 1/2 in. from the wall. Depressing this lever a distance of 1/4 in. served to activate the Grason-Stadler reinforcement mechanism. The walls and the hinged top were made of clear plastic. The front half of the floor (i.e., beneath the lever and the opening to the food compartment) was also made of plastic, while the floor of the rear half consisted of two 1 1/2 in. wide stainless steel strips separated by a 1/2 in. gap. Thus, when S was placed inside the unit, each of its hind feet rested on one of the parallel strips. These strips were used as electrodes to deliver shock to S as well as to record skin resistance.

A 4 in. speaker was mounted on a front wall, and a 10 w. light illuminated the entire chamber. Each box was enclosed within a Grason-Stadler insulation chest with an exhaust fan built into the wall and a one-way window on the door. The boxes were placed in a 7 x 7 ft. soundproof Industrial Acoustic room. The experimenter could observe S's behavior through a window in one of the walls of the soundproof room. All of the programming equipment was located outside of this room. A Hewlett-Packard audio oscillator was wired to the speaker in each box, and a Grason-Stadler constant-
current shocker was used for shocking S's hind feet.

Skin resistance and heart rate were recorded on a Grass polygraph (Model 7). A Grass 7 P-1 pre-amplifier measured resistance to a sub-threshold 50-c current which was passed through S's body. The method used for recording heart rate was a modification of the body-strap electrode technique developed by Ferraro, Silver, and Snapper. A 1 in. wide x 6 in. long elastic belt, holding a set of Grass EKG electrodes, was fastened around the thorax of S. Recording electrodes were attached near the middle of the belt about 1 in. apart, and a single ground electrode was located exactly in the center of the belt. Standard EKG paste was applied to the electrodes to improve conduction. Cardiac electrical activity was amplified by a Grass 7 P-4 preamplifier. Tachograph units provided a direct read-out of the number of heart beats per minute.

Procedure. The animals were maintained on a food deprivation schedule at 80% of their free feeding weight throughout the experiment. All animals were housed in individual cages with free access to water. All animals were given the same treatment during the several phases of training that preceded aversive conditioning. After three days of handling, the hair was removed around S's midsection by an electric shaver. The Ss were given 3 more days of handling during which time a strap, which was similar to the electrode belt, was fastened around them. Next, Ss were shaped to lever press for food pellets in the previously described units while wearing the actual electrode belts.

Each S then proceeded through a series of steps, beginning with 1-hr. exposures to various fixed ratio schedules of reinforcement (FR 2, FR 5, FR 10, and FR 15). Finally, Ss received daily sessions of 1 hr. with variable interval schedules: VI 10 sec., VI 20 sec., and VI 30 sec. The terminal VI 30 sec. schedule was in operation for the remainder of the

experiment.

After Ss had received VI 30 sec. training for 10 days, they were given three daily habituation sessions during which tones of 2,000 and 6,000 cps at 70 db. were presented. Three 1 min. presentations of each of the two frequencies of tone were given each session, and the order of their presentation was randomized. The intertrial interval between tones was varied 10-15 min. The Ss were not removed from the boxes until 5 min. had elapsed following the last tone presentation. Between the running of each pair of Ss, the EKG electrodes and the strip electrodes on the floor of the boxes were thoroughly cleaned.

Upon the completion of the habituation phase, discrimination training was begun with six tone presentations (three of the high and three of the low frequency) per session. As during the habituation sessions, and interval of 10-15 min. separated each of these presentations. For half of the Ss, the high pitched tone served as a CS for shock (US) and the low tone as a neutral or differential stimulus (DS). The stimulus conditions were reversed for the other Ss. The Ss were run in pairs with the presentations of tone and shock occurring in each of the chambers at the same time. The partners were matched on the basis of the number of responses they made during the final habituation session. The assignment of the response-contingent and yoked conditions for a given pair of Ss was determined on a random basis.

At the beginning of each discrimination session, each S had the cardiac electrodes fastened about it and was placed into a box with the VI 30 schedule in effect. After 10 min. elapsed from the start of the session, the first tone presentation was given. Assuming that it was the CS value, after it had been on for 1 min., a "contingency period" was in effect for an additional minute with tone still being heard. During this contingency period both response-contingent and yoked Ss received a 1-ma. shock for .5 sec. after the contingent S pressed the lever. The offset of shock was accompanied by the termination of the CS, thus Ss received no more than one shock per CS presentation. If the contingent S did not press the lever during the contingency period, the CS
remained on for a total of 2 min. and neither S received shock.

Discrimination sessions were given every other day to each pair of SS until all the contingent Ss had learned to "passively avoid" the shock by not responding during the three CS contingency periods of a given session. Then, Ss received extinction sessions on alternate days. The presentations of tone and food were scheduled exactly as they were during the discrimination sessions, except Ss were never shocked. These sessions were continued until Ss in both groups failed to show a significant (p < .10) difference between the reduction in their response rates during the CS and DS presentations.

Data scoring. The number of lever responses, heart beats per minute, and the lowest deflections in basal skin resistance were determined for the 1 min. period prior to the stimulus (prestimulus); for the initial minute of the stimulus preceding the "contingency period" (stimulus); and for a 20 sec. period following the offset of the stimulus and/or shock (poststimulus). The response scores for each of these periods were means of the readings obtained during successive 10 sec. intervals. Since heart rate was recorded by means of a tachograph, a continuous measure was obtained in terms of the number of heart beats per minute, based on the size of the interbeat (R-R) interval.

The S's skin resistance score consisted of the mean of the lowest resistance readings recorded during each of the intervals. It was assumed that relatively firm contact was made with electrode strips at least once every 10 sec.

In order to determine the magnitude of each of the CR's, the mean response value for the prestimulus period was subtracted from the mean for the stimulus period. The peak of the UR's for the different response measures was found to occur at least within 20 sec. following the termination of the CS and shock. Thus, the magnitude of the URs was obtained by subtracting the mean prestimulus value from the mean reading for the two 10 sec. intervals following the offset of shock.

While this procedure and apparatus produced a maximum in reliability in the three measures, lever pressing, heart rate, and skin resistance, it also produced a degree of stress in the animals. The very small compartment
coupled with the procedures necessary each day to attach electrodes tended to produce a general state of arousal. When shock was instituted as an additional source of stress, the arousal level became very high.

Figure 58 shows the general course of the three measures throughout the period of the experiment. The basic data of the figure are the values of each measure during the 60 second periods prior to presentation of the CS and DS stimuli. The adaptation period data are used as a reference and other values are plotted in terms of their relation (in %) of the value during this period. In absolute terms, the mean lever pressing rate at the end of the adaptation period was about 58 presses per minute; the mean heart rate was about 490 beats per minute, and the mean BRL was approximately 220,000 ohms. It would be difficult to estimate what the lever pressing rate might have been under less confined circumstances. Heart rate may reflect arousal, but no comparative data are available. The skin resistance value, however, is quite low. If the animal was less confined, one might expect values between 400,000 and 500,000 ohms. Therefore, even though such cross comparisons between different situations are hazardous, it seems probable that the animals were showing an arousal state somewhat higher than normal.

With the introduction of shock at the beginning of the training period, BRL dropped to about half of its former value, down to about 100,000 ohms. Since this value is very close to the minimum value of about 70,000 ohms observed immediately after shock, it is obvious that once shock is introduced into this confining situation, the arousal level, as indexed by skin resistance, attains a high and chronic level that endures throughout the experimental period. Heart rate drops only slightly during the course of the experiment, and lever pressing rate actually increases during the periods of stimulus absence. If one regards the data of Figure 58 as indicating the effect of conditioning to the stimuli of the general situation, then the situation is conditioned to increased lever pressing, a slightly decreased heart rate, and a markedly decreased BRL. The levels of each of the measures in Figure 58 represent the levels that are baselines for conditioning to the specific CS, and the levels which must show differential response to show discrimination learning.

176
FIGURE 58

RELATIVE GENERAL CHANGE IN LEVER PRESSING, HEART RATE, AND BRL FROM ADAPTATION TO DISCRIMINATION TRAINING AND EXTINCTION

The curves show the relative effect of the introduction of shock on the three measures of performance during the course of the experiment. The measurements were taken during the 60-second period prior to the onset of the CS and DS and therefore represent the general effect of the avoidance training involving shock.
Figure 59 shows the course of discrimination learning and the course of conditioning in the three measures. In the case of discrimination learning, the difference between the response to the CS and the DS was taken as the measure of learning. The maximum difference found during the course of the experiment was taken as 100% and all other differences expressed as a percentage of the maximum. Since the response to the DS could be greater than the response to the CS, negative values are possible and did occur. It is clear in the figure that discrimination in terms of lever pressing was maximum at the end of the training phase, while discrimination in terms of heart rate is at a maximum only near the end of the extinction period. Furthermore, when the lever pressing response no longer shows discrimination at the end of the extinction period, there is a very clear discrimination between the CS and the DS in heart rate. The onset of the CS produces a marked slowing of the heart rate, while the onset of the DS does not produce such a slowing. BRL, on the other hand, appears quite variable because the maximum absolute effect which was observed in extinction is quite small. Real evidence of discrimination in BRL did not appear until the last eight sessions of extinction and is quite apparent in the records of BRL when there is no longer evidence of discrimination in the lever pressing response.

The lower curve represents conditioning and is a comparison of the responses in the 60 seconds before the CS with the response in the first 60 seconds of the CS. Here the skin resistance change appears to occur first with heart rate changes and lever pressing somewhat behind. During extinction, the conditioned suppression of lever pressing disappears completely in the 11th and 12th days, while both heart rate and skin resistance continue to show substantial conditioning.

The absolute differences involved in conditioning are larger in all three measures than they are in discrimination learning. Conditioning produces a suppression of virtually all of the lever pressing from 57 to .5 presses per minute. It produces a maximum decrease of 75.5 beats per minute in heart rate and a drop of 12,000 ohms in BRL. Discrimination learning produced a
FIGURE 59
RELATIVE COURSES OF LEARNING IN THREE MEASURES

The upper curve shows the development and extinction of discrimination learning. The measures were taken during the second 10-second period after onset of the CS. The difference in response to the CS and DS was taken as the index of discrimination. With each measure, the maximum difference is taken as 100%. The data are for the contingent group only.

The lower curve is conditioning data for the same group. The difference in response between the 60-second pre-CS and the 60-second CS period is taken as the index of conditioning. The maximum difference found with each measure is taken as 100%.
maximum differential of 6.6 lever presses, 45 beats per minute in heart rate, and 7,000 ohms in skin resistance. It is obvious why the discrimination learning curves are more variable than the conditioning curves.

The differential rates of conditioning and extinction of the three measures, along with the differential development of discrimination between the CS and DS with its extinction, all argue that the skeletal and autonomic responses are at least partially disassociated. If either heart rate or skin resistance are taken as indices of arousal or fear, then one would have to conclude from these results that fear is essentially independent of the instrumental responses and fear reduction could not be the basis for acquisition of the response.

Williams reported in detail on the comparison between the contingent and yoked animals. In essence, the yoked animals showed fear in terms of heart rate and skin resistance changes that was equal to or greater than the contingent animals, yet they did not show as much conditioned suppression and did not show as complete discrimination. In his conclusions, Williams says that his results do not support the so-called 'noncontingent' theories of punishment such as those of Estes\(^1\) which claim that the relationship between the CS and the punishment rather than between the response and punishment is critical in suppressing behavior. He also says that the fact that the two groups did not differ in autonomic behavior to the CS is contrary to the two-factor theories such as those of Mowrer.\(^2\)

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12. Skin resistance, arousal, and behavior in the rat

The concept of arousal, as the term was defined in an earlier section, was not coordinated with any particular physiological measure. However, the sequence of experiments on the relation between variations in skin resistance in the rat and various aspects of the behavior of the animal were an obvious effort to determine whether arousal and skin resistance could be related. If one makes the assumption that there is a linear relation between skin resistance and arousal, then one can interpret the results of the foregoing experiments in terms of arousal. Each of the following statements should be initiated with the phrase, "If skin resistance is an index of the arousal level."

Motivation and emotion are sometimes treated as quite different states and sometimes treated as different points on an intensity dimension. In the latter case, an emotional state is regarded as being the product of intense motivation. Between these two positions, the arousal index makes a clear choice. Variation in the classical manipulations of appetitive drives, time of food and water deprivation and the estrus cycle in the female rat, are not accompanied by variation in arousal. On the other hand, a series of manipulations which could be related to the emotional dimension do show such variation. If an animal is kept in an unvarying environment, his arousal level goes down. If he is placed in the same environment a number of times, his arousal level is lower each time he is placed in the boring environment. If the animal is shocked, his arousal level goes extremely high. There is an immediate partial recovery followed by a slow 'calming down' that can last an hour or more. Handling the animals increases the arousal level, and simply stimulus change sometimes does and sometimes does not increase the arousal level.

The consumption of water and the removal of shock both produce gross decreases in arousal level. One can therefore probably assume that most consummatory acts are followed by decreased arousal. If so, then most of the situations that have been interpreted as involving need reduction do
involve arousal reduction. However, since arousal does not vary with the need or drive level as manipulated through time of deprivation, the observed arousal reduction reflects a change in the emotional state rather than in the need state. One would have to conclude from these data that reward consumption and escape from noxious stimulation are emotionally satisfying, but are not demonstrably related to an immediate reduction in a need. The findings suggest, but do not establish, that the efficacy of reward in learning is related to the emotional aspects rather than to the motivational aspects as far as the immediate effects of the reward are concerned.

Arousal can certainly be conditioned. It also varies with the state of learning, but the relationship is exactly the reverse of the traditional treatment of drive and learning. Arousal is high before learning and in extinction, and low when the act has been learned. However, arousal can be manipulated during the process without major effect on the learned performance. It would seem then that arousal is the product of the state of learning rather than the driving force. This conclusion is supported by a number of other findings. Arousal is lower in an approach-approach conflict situation than it is in an avoidance-avoidance conflict situation. When the arousal level during choice in a discrimination learning situation is manipulated, it appears to affect the speed of the performance and not the accuracy. There is sometimes a goal gradient in runway data and sometimes not. If there is a goal gradient in running speed, there appears to be one in the arousal measurement. If there is no goal gradient in speed, there appears to be none in arousal. This phenomenon appears to be related to the effects of handling of the animal by the experimenter. Partial reinforcement schedules are accompanied by different arousal levels as one might expect if the different schedules were differentially frustrating. However, the relationships are complex.

Finally, the rate of acquisition and extinction of conditioned arousal and conditioned suppression appear to be disassociated. Arousal (in terms of skin resistance) is conditioned more rapidly and extinguished more slowly than the skeletal response. Discrimination is quite apparent in the skeletal response. Discrimination is quite apparent in the skeletal response while the
indices of arousal show an indiscriminately high level.

In the one study in which both skin resistance and heart rate were measured, heart rate made discriminations when skin resistance showed indiscriminately high arousal. In terms of rate of acquisition and extinction, heart rate and skin resistance showed about the same level of disassociation as skin resistance and the skeletal response. One can conclude that the three measures probably reflect a common state, but that the relationship between the three measures is not causal. If they are not causal, then it is unlikely that theories of learning involving such dynamics as the conditioning of arousal and the motivation of the skeletal response by the arousal and its learning through arousal reduction, can be supported.

One can then ask whether variation in skin resistance is a good measure of arousal. There are at least two senses in which it is a good measure. The variety of results make any explanation in terms of artifact of measurement untenable. Skin resistance does reflect some aspect of the state of the organism. In a second sense it is a good measure because it is consistently manipulable through a variety of variables with varying degrees of face validity as manipulations of emotion, activation, or arousal conceived as a dimension through sleeping and waking.

It is a poor measure of arousal for several reasons. It is relatively labile and varies with situations one would like to ignore. Animals can be upset by minor incidents associated with their handling, or they can be aroused by something so simple as people moving around in the environment. It is a poor measure because it has a ceiling. With skin resistance at a low level, other measures show discriminations when skin resistance does not. It is a poor measure because, since it does not vary with differences in appetitive drive, it doesn't relate directly to drive theory and learning theory based on drives and drive reduction. Furthermore, since it shows low arousal when a response is well-learned and high arousal when it is not, it contradicts the assumed relation between effective drive and stage of learning.

The status of arousal and skin resistance at this point of time should be something like this. Skin resistance does measure some meaningful
aspect of the state of the organism and it does it sufficiently well to justify its use as a measure of arousal. The assumption of a logical coordination between skin resistance as a measure and arousal as a theoretical concept yields statements that are sufficiently meaningful that the coordination seems justified. Therefore, it is reasonable to interpret the empirical results of these studies as relating arousal aspects of behavior.
SECTION III
AROUSAL IN ELECTRIC FISH

1. Introduction

The desirability of a continuous and contemporaneous measure of arousal induced a developing interest in the work on the weak electric fish. Some species of fishes transmit electrical pulses at very low voltages. They also bear receptors which are sensitive to some aspect of the electrical field that is produced. A few of the species appear to vary the frequency of their electrical pulses under conditions which suggest that the frequency might reflect the arousal level of the animal. If this turned out to be true, then it might be possible to monitor the arousal level of the animal by the fairly simple expedient of placing electrodes in a tank containing such a fish and amplifying the output of the fist into some sort of recording device. The record then might be a continuous record of the arousal level of the animal. If the behavior of the animal could be observed accurately, then a correlation could be established between the arousal level and the behavior.

This somewhat exotic possibility led to a minor program of research that has produced two doctoral dissertations and one publication. The following material on the general characteristics of this rather esoteric fish and the empirical studies of arousal and behavior is taken from these two dissertations, including liberal quotations.

\[1\] Dewsbury, Donald A. Some correlates of electric organ discharge frequency in three species of electric fishes. Ph. D. dissertation, University of Michigan, 1965.

Dewsbury, D. A. Stimulus-produced changes in the discharge rate of electric fish and their relation to arousal. Psychol. Rec., 1966, 16, 495-504.

The following is a quotation from Dewsbury on the place of the electric fish among other species.

"It appears that on at least six different occasions, fishes have evolved organs which are capable of generating appreciable currents outside their bodies (See Keynes).\(^1\) Today fish with electric organs are known to exist around the world, in salt water and in fresh, and in quite unrelated taxonomic groups. The two salt-water, elasmobranch families, the electric rays (Torpedo and Narcine) and skates (Raia) are found in most temperate oceans and seas. The lone marine teleost, the electric stargazer (Astroscopus), is found off the Atlantic and Pacific coasts of southern North America. The electric catfish (Malapterurus), which was known to the ancient Egyptians, is found in the Nile and other African rivers. The maximum recorded discharges from the above-mentioned electric fishes range from four to 350 or more volts according to Keynes.\(^1\) In those fishes with the more powerful discharges it is clear that the electric organs serve as a potent offensive and/or defensive weapon. For those above-mentioned species which emit discharges of somewhat lesser intensity, the functions of the electrical systems are not understood. In all of these species the electric organs discharge during only a rather small portion of the animal's life."

"Two groups of electric fishes, the Mormyridae of Africa and the Gymnotidae of South America, possess electric organs which are almost continuously active. With the exception of the electric eel (Electrophorus electricus), which is a member of the gymnotid family, the maximum intensity of the discharge of these fishes as recorded in water is less than one volt. Both groups of fishes are found in turbid tropical rivers and both have evolved means of swimming which enable them to move while keeping a straight backbone."

**Function of the electrical discharge.** Quoting now from Mortenson, "Extensive work now exists on the physiological mechanisms of electrogenesis and electroreception in the knifefishes and mormyroids. Compared to this, the volume of research on the behavioral significance of the weakly electric systems has been meager. Nonetheless, three hypotheses about the behavioral meaning of

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the electric systems may be readily discerned in the modest literature."

"One hypothesis holds that the knifefishes and mormyroids can discriminate the conductivity of objects in water. Lissmann\(^1\) has developed this view. Briefly:

'The electric current generated by the fish may be pictured as spreading out into the surrounding water in the pattern of lines that describes a dipole field. In a large volume of water containing no objects the field is symmetrical. When objects are present the lines of current will converge on those that have better conductivity and diverge from the poor conductors. Such objects alter the electric potential over the surface of the fish. If the fish could register these changes, it would have a means of detecting the objects (Lissman\(^2\), p. 52).'

Consistent with this view is the observation by Lissman and Machin that Gymnarchus niloticus can learn to discriminate objects immersed in water on the basis of their conductivity."

"Presumably such a system could be used in navigation. There is an apparent limitation to such a function for knifefish at least: some evidence exists that conductors or nonconductors can only influence the electrosensory system if they are very near to the fish. For example Hagiwara and his colleagues (Hagiwara, Kusano, and Negishi, \(^3\) and Hagiwara, Szabo, and Enger\(^4\) found that conductors

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and nonconductors could enhance or depress lateral line activity in knifefishes only if the stimulus objects are fairly close to the animals. Perhaps then the knifefishes can only use their electrosensory system to navigate, discriminate, explore, and so forth when objects are close.

"A second hypothesis is that the discharge may have a function in social behavior (Marler and Hamilton\(^1\)). Recently, an abstract (Cleworth\(^2\)) reporting a relationship between discharge rate and aggressive behavior has provided the first concrete evidence for this view. In one threat display, a dominant fish may cease discharging briefly and then resume firing. If the threatened fish does not retreat, it will then be attacked. Another threat display involves the production of an increase in rate. The attack of a larger or resident fish may be avoided if there is a cessation of discharge. Further research in this area of social behavior may be benefited by the popularization of certain species of weakly electric fish among the tropical fish enthusiasts. If the hobbyists succeed in breeding the animals, then it will be possible to relate discharge to sexual and possibly parental behavior."

"A third hypothesis concerns those species of weakly electric fishes with a variable discharge rate. It has been stated that the rate of discharge changes with the 'state of excitement' (Lissmann\(^3\)). All kinds of casual observations consonant with this view have been reported.

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2. General methodology and procedure

Dewsbury studied three species, Gymnotus carapo, Steatogenys sp., and Hypopomus artedii. There were differences between the electrical and behavioral characteristics of the three species, but none that were related to the problem of arousal. Mortenson studied only Gymnotus carapo. As a consequence, only the results of the studies of the one species, Gymnotus carapo will be discussed in any detail.

Figure 60 is a tracing of an oscillographic record of a single pulse of Gymnotus carapo. It is a diphasic pulse, and the direction of the initial deflection from zero is a function of the orientation of the fish relative to the electrodes. The recorded voltage varies as a function of the size of the tank and the distance from and orientation with respect to the electrodes. It is therefore meaningless to attempt to interpret voltage differences. The recorded voltage in Figure 60 is approximately one millivolt, and the maximum recorded is about 10 millivolts.

The frequency of output varies between the three species. In Gymnotus carapo mean values tend to range from about 35 cps to 55 cps. In Steatogenys sp., the frequency tends to be about 10 cps greater, while in Hypopomus artedii, the resting frequency is much lower, about 6 cps to a maximum near 20 cps. The output of Gymnotus carapo was consistently the most variable of the three.

Apparatus. The fish were generally isolated in an experimental room, and the apparatus associated with either stimulating the fish or recording its output were in an adjacent room. Storage aquaria were in still a third room.

The experimental aquarium was a 15-gallon tank with internal dimensions of 11.5 x 11.2 x 23.8 inches. In the later Mortenson research, the tank contained two inserts which blocked off the two front corners that could not be seen on the television monitor because of the camera viewing angle. The two corners to which the fish did not have access contained an underwater filter on one side, and a thermometer for monitoring water temperature on the other.
FIGURE 60
SINGLE ELECTRIC ORGAN DISCHARGE PULSE OF GYMNOTUS CARAPO

The tank was enclosed by a shielding cage of copper screening that could be opened from the top. Mounted on top of the tank, and inside the shielding, was a frame that supported the electrodes. The electrodes were strips of 20 gauge stainless steel that were 1 x 10 inches. Smaller electrodes were used in earlier studies. The electrodes extended to within one inch of the bottom of the tank. In the later studies, the tank rested on a one inch layer of sand in order to reduce the transmission of building vibrations to the tank.

The electrodes were attached to the wires of a shielded cable which was grounded to the shielding cage. The cable was then led through the building wall to the recording room.

The signal from the fish was then amplified and modified in several ways. It was fed into a loudspeaker in the recording room and thus provided auditory monitoring of the signal frequency. It was fed to an oscilloscope (Type 531, Textronics, Inc.) and could be displayed visually. It was also fed into a frequency-to-voltage converter that permitted a continuous record of the output frequency of the fish. Nearly all of the data reported in these studies were read from this written record. Some data was collected by photographing the oscilloscope face.
Visual observation of the fish was a very difficult problem that required several years for solution. *Gymnotus carapo* is apparently nocturnal. Whenever there is light in the room, the fish tends to sink to the bottom and rest without movement. In the dark, the fish is quite active most of the time. Numerous efforts were made to provide illumination that would permit the human observer to see while the fish remained active. After many failures, a solution was reached through the use of infrared illumination and remote TV observation.

The television camera employed was an RCA PK 301 with a 8134/V1 vidicon. The sensitivity of this system measured in terms of microamperes/microwatt of radiant energy has a maximum (.10) at a wavelength between 500 and 600. The sensitivity drops to about .01 at a wavelength of 800 and drops to virtual zero at about 850. After much searching, it was discovered that Kodak Wratten Gelatin filter No. 87 had useful transmission characteristics. This filter has an absorption curve that cuts out all light below about 750, and allows through only a very narrow band of energy that is within the camera range. The fish did not respond to this illumination.

It was therefore possible to place the TV camera about four feet from the test tank, and to place a battery of filter-covered bulbs behind the tank. The result was a clear picture of the fish on the TV monitor. It was then possible to provide scoring grids on the light system which showed up on the monitor in whatever pattern the problem called for.

The later studies by Mortenson and the benefit of this visual observation system, while the earlier studies by Dewsbury did not.

Both the storage room and the experimental room were lighted by regular flourescent lights. In later work, they were controlled by simple 24 hour timers to produce whatever pattern of day and night simulation desired. The fish were maintained at a temperature between 72° and 74° F. with an occasional guppies for the larger fish.
3. Light-dark cycle studies

The first of these studies has been reported by Dewsbury. The subjects were three Gymnotus carapo obtained from the Paramount Aquarium Inc., Ardsley, New York. They were 19.8, 20.1, and 21.0 cm. long. While it is known that they came from Central or South America, nothing else is known about their age or sex.

These fish were put on an 8-16 light-dark cycle with the lights on at about 9:00 a.m. and off at approximately 5:00 p.m. They were maintained on this schedule for a period of six months before testing. Testing consisted of tuning on the recording apparatus just before 5:00 p.m. and allowing it to run for 72 hours. The recorder moved at its slowest speed, 6 inches per hour. It was read by taking the momentary value every 1/4 inch. thus every 2.5 minutes, and averaging the readings by the hour.

The results are seen in Figure 61. While these results represent three days for three fish, and they show clear evidence that the output frequency is depressed during the light period, they are not statistically significant. The test was an analysis of variance using the data from the middle four hours of the light and dark periods and a 3 x 3 x 2 analysis of variance. This failure to obtain significant differences is probably attributable to the small N and the fact that one of the three fish showed very little light-dark difference in output. Analyses run on individual fish showed that two of the three did show statistically significant differences and the other did not.

The light-dark difference is so obvious to the listener, that the borderline statistical significance was truly puzzling. With the audio system functioning and the light in the experimental room on, the output has a characteristic low tone. When the light is turned off, the sound of the fish undergoes an abrupt rise that is unmistakable.

The problem appeared to lie in two areas. It seemed possible that the frequency-to-voltage converter that was being used at the time was not
sufficiently accurate or reliable. This problem was reduced by the construction of a more sophisticated converter by C. M. Wintzer working in the laboratory as an electronic technician. Figure 62 is a sample record obtained with this 'frequency meter.' The details of the design of this instrument is contained in Mortenson.

Several characteristics of the output are apparent in the record. When the light is turned off, the fish immediately becomes more active, and the frequency of his discharges becomes more variable. Furthermore, there appear to be shifts from the resting frequency of about 40 cps to a higher frequency of about 45-50 cps in the last 30 minutes or so of the record shown. If a frequency of 40 cps represents an inactive state, and frequencies of 45-50 cps represent
an active state, then the fish appears to be oscillating between active and inactive states. If this is true, then Dewsbury's measurement technique would compare an inactive state in the light with an oscillating condition between active and inactive in the dark.

Since Mortenson was able to observe the fish in the dark by means of infrared illumination and the remote TV camera, he was able to verify the fact that the oscillations seen in the left side of the record in Figure 62 actually did represent shifts between active and inactive states. While fish were almost totally

![Chart of frequency record for 90 minutes for one Gymnotus carapo including the point at which the light was turned off.](image)

**FIGURE 62**

**DISCHARGE FREQUENCY CHART**

Chart of frequency record for 90 minutes for one *Gymnotus carapo* including the point at which the light was turned off.
inactive in the light, when the fish was in the dark, periods of activity during which the fish swam around the tank and periods of inactivity during which it rested on the bottom tended to follow each other. Furthermore, each of these two activity conditions was characterized by a different frequency pattern. Mortenson therefore designed an experiment to verify and quantify the relationship.

Six fish, 16.5, 20.3, 24.0, 24.0, 26.6, and 27.9 cm. were obtained from a Florida supplier. Nothing is known of their age or sex. They were immediately put on a 12-12 hour light-dark cycle in the storage room. Three days before the observational period, a single fish would be taken to the experimental room and continued on the 12-12 cycle. Each fish was observed six times, three during the light portion of the cycle and three during the dark portion. Each observation period consisted of three ten-minute observation periods, separated by ten-minute rest periods, and each set was timed to coincide with the midpoint of the particular phase of the light-dark cycle.

The observer viewed the TV monitor in a room separated from the recording room so that he was unable to see the frequency meter, and the auditory channel was switched off. During the ten-minute observation periods, he depressed an event marker key whenever the fish was in an inactive behavioral state. The fish was judged to be inactive when it was motionless with its anal fin in contact with the bottom of the tank. All other behaviors were considered active. It was then possible to correlate the active and inactive states as determined from observation of the behavior of the fish with the frequency records during those same periods. Two methodological notes should be mentioned. The record shown in Figure 62 was taken with the Varian recorder operating at its slowest speed, 6 inches per hour. In correlating active and inactive states with frequency of output, the chart was driven at its fastest speed which would cover Figure 62 in 2.25 minutes. This record was read by measuring the frequency of output every 3.85 seconds. Secondly, to be sure that designation of behavioral state truly represented that state, the three scores nearest the transition points were omitted from analysis.

The first result of the behavioral observation reveals that there are enormous individual differences between fish in the frequency of active and
inactive states. Furthermore, the dichotomy between active and inactive states does not necessarily correspond with the dark light cycle. The data are in Table 13. Here it is seen that one fish, C17 is recorded as being active 100% of the time in the dark and as never being active in the light. C20 is almost always active in the dark, but is also active 28.43% of the time in the light. C22 is active only 28.96% of the time in the dark and 1.50% in the light.

**TABLE 13**

**PERCENTAGE OF TIME ACTIVE**

**IN DARKNESS AND LIGHT**

<table>
<thead>
<tr>
<th>Fish</th>
<th>Dark</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>C17</td>
<td>100.00</td>
<td>0.00</td>
</tr>
<tr>
<td>C18</td>
<td>15.85</td>
<td>0.06</td>
</tr>
<tr>
<td>C19</td>
<td>95.46</td>
<td>11.90</td>
</tr>
<tr>
<td>C20</td>
<td>99.80</td>
<td>28.43</td>
</tr>
<tr>
<td>C21</td>
<td>48.22</td>
<td>1.87</td>
</tr>
<tr>
<td>C22</td>
<td>28.96</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Table 14 gives the mean frequencies of discharge in the four conditions, active and inactive, and in the light and the dark. The frequencies are generally the same for the active state whether it occurs in the light or the dark, and the same is true of the frequencies of the inactive states.

Table 14 also gives a measure of the variability of the readings. Lambda is the average absolute difference between successive scores. The higher variability in the active states as compared to the inactive states is quite apparent. Furthermore, the difference in variability is related to the state rather than to the light-dark cycle.
TABLE 14
MEAN RATE OF DISCHARGE AND MOMENT-TO-MOMENT VARIATION (LAMBDA) OF *GYMNOTUS CARAPO*

<table>
<thead>
<tr>
<th>FISH</th>
<th>DARK ACTIVE</th>
<th>Mean</th>
<th>Lambda</th>
<th>DARK INACTIVE</th>
<th>Mean</th>
<th>Lambda</th>
<th>LIGHT ACTIVE</th>
<th>Mean</th>
<th>Lambda</th>
<th>INACTIVE</th>
<th>Mean</th>
<th>Lambda</th>
</tr>
</thead>
<tbody>
<tr>
<td>C17</td>
<td>40.87</td>
<td>1.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C18</td>
<td>36.43</td>
<td>1.74</td>
<td></td>
<td>30.33</td>
<td>1.05</td>
<td></td>
<td>30.39</td>
<td>0.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C19</td>
<td>43.09</td>
<td>1.21</td>
<td></td>
<td>38.87</td>
<td>0.36</td>
<td></td>
<td>43.53</td>
<td>1.10</td>
<td></td>
<td>35.50</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>C20</td>
<td>41.90</td>
<td>1.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40.75</td>
<td>0.90</td>
<td></td>
<td>34.43</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>C21</td>
<td>46.27</td>
<td>1.55</td>
<td></td>
<td>39.44</td>
<td>0.56</td>
<td></td>
<td>47.29</td>
<td>1.41</td>
<td></td>
<td>35.96</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>C22</td>
<td>48.64</td>
<td>1.64</td>
<td></td>
<td>41.97</td>
<td>0.71</td>
<td></td>
<td>55.09</td>
<td>1.88</td>
<td></td>
<td>39.33</td>
<td>0.47</td>
<td></td>
</tr>
</tbody>
</table>

Comparisons of mean differences and lambda values in Table 14 makes it clear that frequency differences between the two states are clearly statistically significant without formal test. It is also apparent why Dewsbury was unable to establish statistical significance in the absence of the capacity to see the animals in the dark and thus to classify their behavior.

The two states are thus clearly distinct. When the fish is behaviorally active the discharge frequency tends to be relatively high and variable. When the fish is behaviorally inactive, the discharge frequency tends to drop 6 to 16 cps representing reductions of 15-25% from the active state and to become much less variable. This finding generally tends to fit the expectations from arousal theory.
4. Response to auditory stimuli

Dewsbury tested the response of Gymnotus carapo to auditory stimuli, either the sound of a buzzer, the sound of the aerator in the tank, or the two stimuli in combination. The buzzer was just outside the tank, while the air stone rested on the bottom of the tank.

He tested each of his three subjects on two days between 10:30 a.m. and noon in the light. Within each day, each stimulus was presented nine times alone and nine times in combination for a total of 27 stimulations. Each stimulus was on for 10 seconds. Within each block of nine trials, each stimulus pattern was presented three times in an order determined by a table of random numbers for each block for each animal. Intertrial intervals of 60, 75, 90, 105, and 120 seconds were randomly assigned to adjacent blocks of five trials. The records were read by taking the maximum frequency in successive 10-second periods beginning 30 seconds before stimulus onset to 50 seconds after.

The effect of the stimuli is to produce a large increase in the discharge frequency as shown in Figure 63. Either stimulus alone produced an increase of about 12 or 13 cps, while both together produced an increase of 17 or more cps. Somewhat surprisingly, there was little or no adaptation to the stimuli within a days 27 trials of testing or between the two days. An analysis of variance showed that the differential effect of the two stimuli together was significantly different from the effect of either alone, but no effect of repeated experience was significant.

Mortenson conducted a number of preliminary studies using various tones for stimuli. With a single animal as subject, he found habituation. He used 300 or 400 cps tones and presented a series of 20-second stimuli. The series contained 30 stimuli with an average intertrial interval of 82.5 seconds. On the basis of this pilot work, a formal experiment to demonstrate habituation to auditory stimuli seemed appropriate.

In the experiment, a Hewlett-Packard, Model 200AB audio oscillator was used to generate 300 cps tones through a speaker located 7 inches from the
Mean maximum electric organ discharge frequency as a function of stimulus and successive ten-second intervals surrounding stimulus onset.

center of the back of the aquarium. The duration of each tone was 20 seconds. A test session consisted of a block of 30 tones with interstimulus intervals of 5, 10, 20, 40, 80, and 160 seconds presented in random order within a block of six intervals. Each of the six subjects was given six testing sessions, midway in the light and dark periods for three successive days. The data for one S was lost due to apparatus failure, and only five fish are represented in the results. The results were measured by comparing the discharge rate in the two-second period before the stimulus onset with the discharge rate during the first two seconds of the stimulus.
The primary result is shown in Figure 64. The tone produces a significant increase in discharge rate in both the active and inactive states. The increases are not as great as those observed by Dewsbury, but the stimuli were very different in the two studies. The data in Figure 64 display some interesting secondary characteristics. When the tone is presented while the fish is in an inactive state, the response is large, but the animal never became active in response to the presentation of the tone. If the inactive state is analogous to sleep, then the animal never woke up in response to the alarm clock of the tone. The tone was greeted by a rise of 3 or 4 cps in the discharge frequency followed by an immediate return to the resting frequency of the inactive state. When the tone was presented while the fish was in an active state, the response was an increase of from 1 to 2 cps.

It was also observed that the size of the response to the stimulus was in part a function of the frequency at the time of onset of the stimulus. The correlations run on the data for each fish for the two states independently are contained in Table 15.

**TABLE 15**

**CORRELATIONS BETWEEN INITIAL DISCHARGE RATE AND MAGNITUDE OF INCREASE IN RESPONSE TO THE TONE FOR ACTIVE AND INACTIVE STATES**

<table>
<thead>
<tr>
<th>Fish</th>
<th>Inactive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>C17</td>
<td>-.56</td>
<td>-.46</td>
</tr>
<tr>
<td>C18</td>
<td>-.54</td>
<td>-.69</td>
</tr>
<tr>
<td>C19</td>
<td>-.53</td>
<td>-.37</td>
</tr>
<tr>
<td>C21</td>
<td>-.65</td>
<td>-.63</td>
</tr>
<tr>
<td>C22</td>
<td>-.69</td>
<td>-.66</td>
</tr>
</tbody>
</table>
FIGURE 64

DISCHARGE FREQUENCY CHANGES IN RESPONSE TO TONES

Highest rate during two seconds preceding and following stimulus onset during active state (upper pair of curves) and inactive state (lower pair of curves).
The simplest conclusions possible from these data appear to be that there is a controlling mechanism governing the upper level of response to stimulation. Thus the active state is represented by a narrow range of response frequencies and the inactive state is represented by another relatively narrow band, and that the two ranges do not overlap. In an analogy with sleep and waking, the two states appear to represent a two state system, with control mechanisms to hold the arousal level within upper and lower limits within each state.

Figure 64 shows some evidence of adaptation to the repeated presentation of the tone in contrast to Dewsbury's results. One possible explanation for the discrepancy between the two results could be in terms of stimulus intensity. There is little profit in attempting to compare the physical intensities of a buzzer, a tone and an areator, but the magnitudes of response in the two studies would tend to indicate that the stimuli in the Dewsbury study were more intense. If so, adaptation might have occurred with a more extended series of stimuli.

In the Mortenson study, there was experimental control of the intertrial interval with separations within a day ranging from 5 seconds to 160 seconds. Between days there was a separation of 40,000 or so seconds. Figure 65 shows the differential effects of intertrial interval variation. Very little effect is evident, and what little there appears to be in the figure is not supported by statistical test. Intertrial intervals in this range seemed to have no demonstrable effect on the magnitude of the response to the tone.
FIGURE 65

EFFECT OF INTERTRIAL INTERVAL ON RESPONSE TO TONES

Highest rate in the two seconds preceding and following stimulus onset as a function of intertrial interval.
5. Response to solid objects

One hypothesis concerning the function of the electrical discharge in the weak electric fish is that solid objects distort the electrical field produced by the electrical discharges, and that the fish can detect such disturbances. It might therefore be able to use this sensory system to detect the presence and character of objects in the immediate environment.

Dewsbury devised a test of the response to the presence of a solid object, in this case a metal spoon, and made an especial effort to determine whether adaptation in the response to this object might occur. The spoon was attached to a piece of string and suspended over the tank so that it could be lowered gently into the water from outside the room.

A trial consisted of lowering the spoon into the tank and withdrawing it ten seconds later. Six trials were given each day for the first 30 days of the study, in the light phase of the cycle between 12 noon and 5:00 p.m. This phase was designated as Part I. During this phase the six trials were separated by 4, 5, 6, 7, or 8 minutes with the interval randomly assigned. In Part II, 20 trials per day were given for six days with the same intertrial intervals again randomly assigned. In Part III, 20 trials per day for six days were again given, but the intertrial intervals were now shortened to be 60, 75, 90, 105, or 120 seconds. These intervals were again randomly assigned within 5-trial blocks. The records were read by taking the maximum discharge frequency in each of 10 intervals of 10 seconds each beginning 30 seconds before the spoon was lowered into the tank.

The response of the fish to the introduction of the spoon in the tank in the three parts of the study are shown in Figure 66. In each part of the study there is a marked increase in the discharge frequency produced in response to the insertion of the spoon in the tank. Analysis of the effects of repeated introduction of the spoon into the tank did not reveal a statistically significant adaptation to the stimulus even in the third part of the study in which the 20 trials per day for six days were given with an average intertrial interval of 90 seconds.
RESPONSE TO METALLIC OBJECT

Mean maximum electric organ discharge frequency in successive ten-second intervals surrounding stimulus onset as a function of successive parts of the study, with parts differing in number and spacing of stimuli.

Mortenson carried out a series of experiments involving the introduction of aluminum or plexiglas objects in the tank in an effort to establish a correlation between exploratory behavior, which he could observe even in the dark, and discharge frequency. By introducing the object at a fixed point in the center of the tank, and then observing the physical position of the fish, he could determine the orientation of the fish to the object and the distance between the object and the fish. In the preliminary studies there was some difficulty in determining the first sensory
contact between the fish and the object because the silhouette character of the observation situation did not yield information on the relative depth (distance from the camera) of the fish and object. Nonetheless, there were consistent findings for all subjects.

The fish spent more time in the vicinity of the stimulus in the first ten minutes after it was observed to make first contact with ('discover?') the object than it had spent in the same environment prior to contact. The time spent in that vicinity during the first five minutes after contact was greater than the time spent in the second five minutes. Thus in all cases, the introduction of a novel aluminum or plexiglas object produced investigative behavior that declined over a ten-minute period. These behavioral relations were exactly paralleled in discharge rate. The rate went up on first contact with the objects and slowly declined during the ten minutes after contact while the fish was exhibiting rapid oscillations in approach and avoidance behavior.

On the basis of these preliminary findings, a formal experiment was designed. A frame was built to fit the top of the tank that would permit a plexiglas plate to be dropped into a fixed position in the center of the tank from left to right and extending from the front to the back of the tank in the line of sight of the TV camera. Before dropping, the plate was suspended 3 inches above the water. After it was dropped, it rested 1 1/2 inches below the surface with its lower edge 4 1/2 inches from the bottom. The grid that was on the paper covering the lights divided the tank into 14 squares, each 3 x 3 inches. These were in two rows of seven squares each, and the plexiglas plate, when dropped, came to rest with its lower edge in the center of the middle square in the upper row. The fish was said to be in contact with the stimulus when it appeared in the same square as the stimulus.

Each of the six fish were observed three times in the light and three times in the dark on three successive days. Observation periods were for 30 minutes in a session, and the period was divided into a 10-minute pre-stimulus period, a 10-minute stimulus period, and a 10-minute post stimulus period. The only deviations from this pattern were minor ones arising from the rule that
the stimulus was neither introduced nor withdrawn while the fish was in the stimulus square (that occupied by the stimulus). The plate was introduced by releasing it from outside the room. It could then drop the 3 inches to the water and 1 1/2 inches below the surface, a drop of a total of 4 1/2 inches. These characteristics of stimulus presentation were apparently important, for the results of the formal study were quite different than the results of the preliminary observations.

In the dark, only one of the six fish showed the expected pattern of exploring the stimulus in the ten minute period following its introduction with the exploration accompanied by an elevated discharge frequency. Four of the fish showed a reverse pattern at least once. The reverse pattern was to become inactive within fifteen seconds of the presentation of the stimulus. The fish would sink to the bottom of the tank in the characteristic position with the anal fin in the sand. Assumption of this position was accompanied by a reduction in discharge frequency to the rate characteristic of the inactive state. One fish became inactive once, one twice, and the other two became inactive three times. The average duration of the inactive state was 281.33 seconds. The sixth fish showed still a different pattern. It remained active, but it avoided the stimulus square. It spent an average of 83 seconds in the stimulus square before the introduction of the stimulus, but while the stimulus was present, it spent only an average of 28 seconds there.

When the stimulus was introduced during the light period, and thus when the fish were nearly universally inactive, an interesting effect was observed. Introduction of the stimulus produced a reduction in the variability of the discharge. Mean lambda before the introduction of the plate was about .65 and in the 10 minutes of stimulus presentation and in the ten minutes after its withdrawal, the mean lambda was about .35. If those few occasions when the fish was in an active state before stimulus presentation are eliminated, then the mean lambda before stimulus presentation are eliminated, then the mean lambda before stimulus presentation was about .55 lambda and again about .35 in the other two periods. These differences are all statistically significant.
Thus the introduction of the plexiglas plate by dropping it into the tank with a splash tended to make active fish inactive, and tended to make inactive fish less variable in the discharge frequency. Thus the stimulus tended to produce a hushed, freezing behavior. This behavior could be similar to the freezing behavior observed in many animals in response to sudden stimuli, or to the death feigning behavior of some marsupials. Freezing behavior is generally rigid and alert, while death feigning behavior appears abnormally relaxed. There is no obvious basis of choice between the two in this case.

Thus the introduction of foreign objects into the tank produced two patterns of behavior. One was an exploratory investigation of the object that was accompanied by an increase in the discharge frequency. The other was an immediate change to an inactive behavioral state accompanied by a reduction of discharge frequency and a reduction in its variability, a hushed state like either the freezing behavior of startled animals, or the feigned death of marsupials.
6. Discharge frequency and food deprivation

If the discharge frequency of Gymnotus carapo is related to the level of arousal, and if the level of arousal is related to the intensity of the biological drive of hunger, then discharge frequency should vary with the classic manipulation of hunger, time of deprivation of food.

Dewsbury conducted two separate experiments with Gymnotus carapo to test this possibility. In the first of these studies, the procedure consisted of feeding the three fish liberally, removing food from the tank, and then observing the discharge frequency four times a day for four days, two observation periods during the light and two during the dark. The procedure was then repeated four times for each fish.

The detailed procedure began with the regular feeding schedule in which food was placed in the tank each afternoon just before the lights were turned off to begin the 16 hour dark cycle. Food was removed, if any remained, shortly after the lights were turned on at 9:00 a.m. the following morning. On the night before the testing began, each fish was fed three guppies, and on the first night of testing, each fish was given an ample supply of white worms. The records were then read for frequency at 11:00 p.m., 8:00 a.m., 1:00 p.m., and 5:00 p.m. for five consecutive days, thus giving values for 0, 1, 2, 3, and 4 days of food deprivation. The record was read by taking a value for discharge frequency every 15 seconds for a period of 5 minutes. The 24 readings were then averaged to represent that test point. Immediately after testing on the fourth day of deprivation, the fish were given an excess of white worms to begin another cycle. Four consecutive cycles completed the first experiment.

Time of deprivation did not seem to affect the discharge frequency in any significant manner either in the light or in the dark as can be seen in Figure 67. There was a slight rise on the fourth day in the dark, but it was not statistically significant, and it was in part compensated for by a slight drop in frequency in the dark.
FIGURE 67

DISCHARGE FREQUENCY AND TIME OF FOOD DEPRIVATION

Mean electric organ discharge frequency as a function of time of food deprivation.
In order to be sure that the slight upturn in the dark curve did not represent the beginning of a deprivation effect, a second experiment was devised to extend the period of deprivation, and to increase the stability of the mean values by taking 120 readings at each test point rather than the 24 used in the first study. The procedure was identical in the second experiment except that time of deprivation was extended to six days, readings were taken only at 8:00 a.m., just before the end of the dark period, and readings were taken from the record every 7.5 seconds for 15 minutes.

No effect of time of deprivation was apparent in the results of this study. The mean discharge frequency at 0, 2, and 4 days of food deprivation was approximately 43.5 cps. At 6 days, it was 41.5 cps. Therefore there was no increase in frequency with time of food deprivation.

It is worth noting that extensive efforts to find changes in skin resistance in the rat as a product of time of food and water deprivation also yielded negative results. Therefore, if skin resistance in the rat is an index of arousal, and if discharge frequency in Gymnotus carapo is an index of arousal, then arousal does not vary with time of deprivation.
7. Discharge rate changes at feeding

One of the most reliable changes in discharge rate in Gymnotus carapo is that associated with the feeding response. If one drops a meal worm in the tank there is soon a very marked rise in frequency of discharge, and for a period of several seconds there is marked variation in frequency.

Before it was possible to observe the feeding response, it was not possible to determine whether the increase was associated with the search phase, with the consumption phase, or with a post-consumption phase. The interpretation of the frequency change could differ depending on which phase was associated with the increased output. If the increased frequency was associated with the search phase, it might be considered evidence that the variation in frequency represented a kind of echo-ranging use of the electrical discharge similar to the echo-ranging of bats and porpoises. If it is associated with the consumption or post-consumption phase of feeding, then it is more likely to be related to the emotional condition of the animal.

There are several technical problems associated with research on the correlation between the phases of feeding and the discharge frequency of these fish. The most common food consists of small worms. If an experimenter enters the room and drops a worm into the tank, the fish is disturbed by the presence of the experimenter. It is therefore difficult or impossible to separate the effects of the presence of the experimenter from the activity induced by the presence of the worm. The obvious answer would be to construct an automatic worm ejector that could drop a worm into the water without producing any other effect on the behavior of the fish. Unfortunately, even though several such devices were designed and built, none worked well enough to permit use in a formal study. The operation of some disturbed the fish, while some failed to deliver worms on cue. Figure 68 is a photographic record of the response of one of Mortenson's fish while feeding. In this record, the chart is moving at a rapid speed, and the fish is in a continuously active state throughout. When the experimenters
FIGURE 68

CHART RECORD OF RESPONSE TO FOOD

Photograph of chart record of response of one Gymnotus carapo to entrance of experimenter into room and dropping of worm into the tank. The chart speed is four inches per minute, thus 15 seconds for each vertical division line. The record reads from right to left.

walked down the hall and one enters the room, there is an associated increase in frequency that rises from 49 pps to 68 cps, drops immediately to about 49 pps, and then slowly descends to the baseline of 49-50 pps. The fish can be observed to search the bottom for the worm with a slightly elevated frequency of output. When he finds it, typically, he sucks the worm into his mouth, forces it out, sucks it in, and may repeat the process two or three times before swallowing the worm. In this instance the fish swallowed the worm immediately and, the peak frequency of about 91 pps is associated with swallowing the accepted worm. One would therefore guess that Gymnotus carapo does not use his electrical discharges
as a prey-locating device, but that it is more likely that the increased frequency represents some aspect of the excitement of the chase. This conclusion, however, is highly speculative. The nature of the necessary experiment is clear, and the means of carrying it out almost at hand, but the experiment has not been done for lack of time, energy, and money.

The one experiment on feeding that was carried out was done by Dewsbury without benefit of a capacity to observe the fish while feeding. He was able to compare average discharge frequency during fairly long feeding periods with comparable non-feeding periods.

He tested his three animals each on three days, with the tests separated by three days. Testing consisted of recording discharge frequency continuously for five hours, from 5:00 to 10:00 p.m., and thus during the first five hours of the dark cycle.

The animals were fed generously in their storage tanks on a given evening. The following morning they were placed in the experimental tank that was devoid of food. They were then without food for 2 1/2 days until tested. On the first test day, the lights were turned out at 5:00 p.m. Midway in the recording period, at 7:30, the experimenter entered and placed a generous supply of white worms in the tank. He entered again at 9:30, exactly as before, except that no worms were placed in the tank. In the morning, excess worms were removed from the tank, and the fish was not fed again for 2 1/2 days later, the second test day. On this day, the experimenter entered again at 7:30 p.m. and did everything but place the worms in the tank. At 9:30 p.m., he entered as before and placed worms in the tank. Continuing as before to a third test day, he entered at both 7:30 and 9:30 but delivered worms only at 7:30. The records were read for every half hour period from 5:00 to 10:00 p.m. The entrances at 9:30 on the first and third test days and at 7:30 on the second test day permitted an assessment of the effect of entering the experimental room without delivering the worms.

Figure 69 shows the discharge frequencies by half hour periods on each of the three days. When food is delivered at 7:30, the mean frequency rises and remains elevated during the following two hours which presumably represents
FIGURE 69

DISCHARGE FREQUENCY CHANGES AT FEEDING

Mean electric organ discharge frequency changes in response to feeding on three days with feeding at 7:30 p.m. on two days and at 9:30 on the other. Experimenter entered room at both times on all days to control for experimenter disturbance.

continuous feeding. When the experimenter entered at 7:30 on the second day, or at 9:30 on the first and third, no effect is apparent. On the second day, there is a marked elevation in discharge frequency associated with feeding at this unusual hour.

Figure 70 is a somewhat finer grained analysis. Readings were taken from the original record every 75 seconds during the 5 hour feeding period. These readings were averaged in pairs, so that each value represented a 2 1/2 minute interval. The mean values for each of the three fish across each of the three
FIGURE 70

DISCHARGE FREQUENCY BEFORE AND AFTER FEEDING

Mean electric organ discharge frequency within the half hour before and the half-hour after feeding.

test days were then combined to record the 30 minutes before feeding and the 30 minutes after feeding regardless of whether the animals were fed at 7:30 or 9:30. The gradual rise after the introduction of food probably represents differential latency in the beginning of feeding. That is, some fish, on some days, found food immediately and began to feed immediately. Others began feeding with latencies of several minutes. Combining the records of animals that were and animals that were not feeding in the early part of the period during which food was available, probably accounts for the apparent rise in the curve.

These data establish highly significant increases in discharge frequency in Gymnotus carapo during feeding as opposed to non-feeding periods. The increase
output is probably associated with increased arousal and probably is not associated with the search for food itself, although good, unambiguous, experimental data are not available on the point.
8. Response to shock

Shock produces an increase in arousal in the rat when skin resistance is used as an index of arousal. In that case, it is interpreted as reflecting a fear reaction, largely because the shock intensities employed are not intense, and the response is generally the same to several different shock levels. If fear is the correct interpretation in the case of the rat, it is probably related, in part at least, to the fact that shock is a foreign and thus a strange stimulus to the rat. Since Gymnotus carapo is an electric fish, it was felt worth attempting to determine the response of this fish to shock.

Dewsbury placed stainless steel plates in the tanks to serve as shock electrodes. Shock was a 60 cycle per second constant current shock set to deliver one milliamphere and was of momentary duration. Each of the three fish was subjected to 6 shock per day for three days with intervals of 4, 5, 6, 7, and 8 minutes separating the shocks with the intervals randomly distributed within a block of shocks for each animal on each day.

The record was read by taking the maximum discharge frequency in each of the three 10-second intervals preceding the shock and each of the six 10-second intervals following the shock at each delivery. This experiment was carried out during the light portion of the light-dark cycle.

Figure 71 shows a clear increase in frequency of output following the shock and a rather quick return to the pre-shock baseline. The three fish showed large individual differences in the response to shock. The largest change was about 13 pps on the average, a second fish increased output by about 7 pps on the average, while the third fish, C3, increased its output only 2.6 pps on the average.

C3 was therefore subjected to a fourth test day in which the shock intensity was increased to 10 milliamperes, a tenfold increase. The increase in frequency in this animal on this day was now 4.2 pps. It therefore seems unlikely that the increase in frequency is closely related to the intensity of the stimulus.

In any case, electric shock produces a significant increase in the discharge frequency of Gymnotus carapo.
FIGURE 71
RESPONSE TO SHOCK

Mean maximum discharge frequency as a function of successive ten-second intervals surrounding shock.
9. Discharge frequency and arousal

It is tempting to attempt to relate the active and inactive states in Gymnotus to the awake and sleeping states. The mutually exclusive categories of the behavior, and the non-overlapping discharge frequencies, clearly establish a two-state system, analogous to the near dichotomy between the sleeping and waking states. If one accepts the analogy, then there is clear evidence of a general tendency for the fish to be in either one of two arousal level states with the arousal, indexed by the discharge frequency, held within relatively narrow variation around the mean state. These data, given the analogy, would verify the hypothesis that sleeping and waking represented two arousal states that characterized the organism most of the time. Transitional, or in-between states, are rarely seen. Such an interpretation must be accepted with caution, since other correlates of sleeping and waking, such as EEG and arousal probability under stimulation, are not available in the fish.

The fish responds to auditory stimuli with an increase in frequency which would fit the arousal interpretation, but the comparison of the response in the active and inactive states gives some pause. When a sleeping organism is stimulated he generally tends to awaken fully. The fish tend to respond with an increase in frequency that is large, but which does not bring him into the active state range. The fish adapt to repeated presentations of a tone, but do not seem to adapt readily to stimuli which might be interpreted as being strong.

The introduction of objects into the tank also yields somewhat conflicting results in relating them to arousal. Active exploration of a novel stimulus is accompanied by an increase in discharge rate as if the novel stimulus had produced an increase in arousal. The interpretation of 'novelty' in this case makes sense simply because of the obvious unfamiliarity of these fish with metal spoons, aluminum strips, and plexiglas plates. Since the discharge frequency underwent little if any adaptation to repeated presentation of these stimuli, the term 'novelty' seems inappropriate. Perhaps the word 'foreign' would be better.

When these fish respond to the introduction of a 'foreign' stimulus by becoming inactive and assuming what has been referred to as a state analogous
to the sleep state, then one has a difficult problem of interpretation. If the behavior is interpreted as akin to fright behavior, then this organism appears to be frightened into a state distinguishable from its regular sleep state only by a subtle, but genuine, reduction in the variability of its discharge rate - thus a super-sleep state. Thus novel objects appear to elicit excited exploration or a super-sleep state unique to this organism.

Deprivation of food did not produce a change in the discharge frequency, but the introduction of food led to an elevation that appears to be related to the general level of excitement rather than to function as a food seeking mechanism. Shock also produced an elevation in discharge frequency. Thus no change occurred with differences in appetitive drive, but changes did occur with food consumption and in response to a fear inducing stimulus. These results parallel the finding with rats when skin resistance is used as a measure of arousal.

The studies in this section were addressed to the possibility that discharge variation in Gymnotus carapo might reflect the state of excitement or level of arousal of the animal. The conclusion is that, in this species at least, there is a good basis for this interpretation. These experiments were not designed to examine the other interpretations, that the discharge is related to navigation or social behavior, and make no contribution to these possibilities.
SECTION IV

STIMULUS COMPLEXITY AND PREFERENCE

1. Introduction

Some of the most basic hypotheses of theory concerning arousal are related to complexity theory. In complexity theory, it is hypothesized that there will be an optimal complexity value on any given dimension for any given subject. In arousal theory it is assumed that there is an optimal arousal value associated with any arousal dimension. Presumably, optimum arousal will correspond with optimum complexity. Since the organism seeks optimum arousal and complexity, then both should be indexed by expressed preference, the verbal analog of approach or seeking behavior. The theory also states that continued commerce with a stimulus dimension should lead to a migration of the optimum complexity level to a more complex portion of the continuum, and optimum arousal level should move with it.

The research reported in this section could be described as a series of studies designed to provide the background for a program of research on the theoretical statements in the paragraph above. A number of experiments were carried out with complex visual stimuli using human subjects. Another set of experiments was carried out using rats as subjects. Because the problems in the two sets are quite different, the two sets will be discussed separately.

1A number of people worked on the stimulus complexity and preference studies from time to time. Much of the work was done by F. Joseph Mortenson, Howard Gadlin, Kathy Nagy, Daneen Hart, and Rivka Fine.
2. Stimulus complexity and preference in human subjects

**Introduction.** Most of the work that has been done by others in efforts to investigate stimulus preference and complexity has involved either one of two approaches to the selection of stimulus materials. One approach is to select stimulus materials that differ in complexity on the basis of a simple kind of face validity. This approach is handicapped because one cannot plot preference against such non-metricized stimuli. The second common approach is to generate a set of stimuli with a known physical or quantitative dimensionality. An example would be the use of differing number of dots where the number of dots forms a physical dimension with at least an expectation of a monotonically increasing relation to complexity. There are also a number of stimuli which have been generated by some simple rule. For example, a square might be laid out on a fine grid of regular points. The rule might then be to choose a point at random and move it one step in any of the eight possible directions. The sequence of figures generated in this way would be presumed to increase in complexity as more and more dots are moved repeatedly. This approach also yields a meaningful physical dimension, but profoundly uninteresting stimuli.

An alternative approach is to select sets of psychologically interesting stimuli and to subject them to one or more of the psychological scaling techniques. The result might be a set of materials of much more interest than any previously available, and a set of materials for which there might be meaningful quantitative dimensions.

In the studies to be discussed in this section, there are generally three aims:

1. To develop sets of visual stimuli with established complexity values based on psychological scaling techniques.
2. To develop methodology for employing these stimuli with human subjects.
3. To investigate the relation of complexity and preference.
These objectives have generally been accomplished. Advancement to problems of relating arousal to these stimuli and verifying changes in optimum complexity and arousal with experience lie in the future.

The stimuli employed in these studies were derived from four sources.
1. Tartan patterns. A number of tartan patterns were photographed in black and white to serve as stimuli. These had several virtues as stimuli, but one of the most important was that the number of squares in the pattern gave a physical measure of complexity. It was thus possible to check psychological scaling techniques with a physical scale with this one set of stimuli.

2. Stage set designs. A number of drawings of stage set designs were photographed for use as stimuli. They had the virtue of representing well-established styles in set design that differ in apparent complexity.

3. Black and white graphics. A large set of black and white graphics which were all highly representational and symbolic and which were done by well-known artists were also selected. These had the advantage of being well known to individuals who had studied art but were not well known to most individuals.

4. Modern art. A large set of modern paintings were selected. They were chosen so that they contained no symbolic material and were generally not identifiable in origin. They are colored prints.

All sets of stimulus materials were either chosen in its original form or photographed and reduced to a 4 inch by 6 inch picture. Each was then given a randomly selected code number which was placed on the back. Finally, each was encased with plastic contact acetate to preserve the original quality during handling.
**Tartan patterns.** The tartan patterns used in these studies were taken from a volume by Innes.\(^1\) From a larger list, the patterns listed in Table 16 were selected and tested. As can be seen in the table, the number of squares in the sample photographed varied from 91 to 2680.

In the first study, subjects were asked to rate each of the 21 tartan patterns from simple to complex. They were to use a scale of 1 to 100 with 1 representing the least complex and 100 the most complex. They were then asked to rate each with respect to how much they like the pattern. Again they were to use a scale ranging from 1 to 100 with 1 representing the least liked and 100 the most liked pattern.

The ratings of complexity are compared to the physical properties of the tartan patterns in Figure 72. The number of squares is plotted on a log scale as an approximation of the psycho-physical function that is probably involved in judging differences in number of squares. The physical scale and the psychological scale are in fairly good agreement in the figure. Since there are other possible physical dimensions in the stimuli, such as grey-scale and relative proportions, this level of agreement seems satisfactory. In fact, it seems possible that the psychological scale might come closer to representing complexity than does the physical scale.

The relation of the psychological scale of complexity and a similar psychological scale of liking is shown in Figure 73. There is an obvious relation between the two measures with the subjects expressing a greater liking for the more complex tartan patterns. There is no evidence of an optimum in the middle range of values of complexity.

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\(^1\)Innes, T. *The tartan of the clans and families of Scotland.* Edinburgh and London: Johnston, 1938.
<table>
<thead>
<tr>
<th>Code No.</th>
<th>Tartan</th>
<th>Number of Rectangles</th>
<th>Number of Rectangles in a Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Royal Stewart</td>
<td>1350</td>
<td>625</td>
</tr>
<tr>
<td>2</td>
<td>Forbes</td>
<td>759</td>
<td>841</td>
</tr>
<tr>
<td>3</td>
<td>MacArthur</td>
<td>187</td>
<td>81</td>
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<tr>
<td>4</td>
<td>Skene</td>
<td>945</td>
<td>169</td>
</tr>
<tr>
<td>5</td>
<td>Brodie</td>
<td>117</td>
<td>121</td>
</tr>
<tr>
<td>6</td>
<td>Anderson</td>
<td>2680</td>
<td>1369</td>
</tr>
<tr>
<td>7</td>
<td>MacDonell of Glengarry</td>
<td>2109</td>
<td>625</td>
</tr>
<tr>
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<td>MacKay</td>
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<td>121</td>
</tr>
<tr>
<td>9</td>
<td>MacAulay</td>
<td>195</td>
<td>121</td>
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<td>Sutherland</td>
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</tr>
<tr>
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<td>49</td>
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<td>165</td>
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<td>MacDonald of Clanranald</td>
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</tr>
<tr>
<td>21</td>
<td>Maclachlan</td>
<td>405</td>
<td>121</td>
</tr>
</tbody>
</table>
FIGURE 72

PHYSICAL VERSUS PSYCHOLOGICAL SCALES OF COMPLEXITY IN TARTAN PATTERNS
FIGURE 73
COMPLEXITY AND LIKING FOR TARTAN PATTERNS
As a part of the same study, the subjects were asked to make a second evaluation of the extent to which they liked the tartan patterns. In this case, the patterns were offered in pairs. Subjects were asked to assign a value to the difference in their liking for the two. If the difference in liking was maximum, a value of 10 was to be assigned. If it was minimum, a value of one was to be assigned. Such data can be computer analysed using the Shepard-Kruskal technique.

There are two major advantages to the Shepard-Kruskal scaling and scaling analysis technique. Data collected in this way can be analysed for any number of dimensions. If a variable such as complexity, liking, or preference is actually multidimensional, the Shepard-Kruskal technique could potentially reveal that fact. The second advantage is that the data collected from a single subject can be subjected to multidimensional analysis. A disadvantage is that a one-dimensional solution is not necessarily the 'best' solution. The computer program simply projects a line through the multi-dimensional space from an arbitrary starting point. It is the best line from that point but not necessarily the best starting point. It is often therefore necessary to ask the computer for an n-dimensional solution and try to match each of them to some criterion. A second disadvantage of the analysis technique is that there are no internal criteria for determining how many dimensions are meaningful. For these reasons, we adopted the arbitrary practice of asking the computer for ten different analyses, specifying numbers of dimensions from 1 to 10 in each case. The data from each individual and the group were analysed separately.

After the subjects had finished their ratings of how well they liked the patterns, they were asked for extensive explanations of the reasons for their liking of a given pattern. Many hours were spent in an effort to match individual Shepard-Kruskal dimensions with the verbal protocols, but the effort was fruitless. Liking seemed to be a single dimension, and elaboration of the basis for liking did not improve understanding of the dimensions.

Figure 74 is a sample of the Shepard-Kruskal analysis. In that figure,
FIGURE 74
SHEPARD-KRUSKAL LIKING DIMENSIONS AND COMPLEXITY
a two dimensional solution for liking is plotted against the complexity ratings. The first dimension shows little or no relationship between the two variables. The second dimension shows a clear relationship very similar to that shown in Figure 73.

Figure 75 is an effort to determine the relationship between the liking scale derived from the simple rating on a 100 point scale and the Shepard-Kruskal analysis of preference. The one-dimensional Shepard-Kruskal solution yields no relationship. When the two dimensions of a two-dimensional solution are plotted, the first dimension shows little or no relationship, while the second dimension shows a rather high correlation.

One further study was carried out with the Tartan patterns that was methodological in character. We wished to know what effect the range of stimuli had on ratings of complexity. To determine this, arrangements were made to have subjects rate 10 tartan patterns representing the simpler designs, rate 10 representing the more complex designs, and rate 10 representing the whole range.

The subjects were 15 males and 15 females of college age. They were divided into three groups of 10 Ss each.

Three sets of stimuli were made up from the tartan patterns that had been rated for complexity in earlier studies. The high complexity set included those rated 1, 2, 3, 4, 6, 7, 8, 9, 10, and 12. The low complexity set included those rated 11, 13, 14, 15, 16, 17, 18, 19, 20, and 21. The full range set included those rated 1, 3, 6, 8, 11, 12, 15, 17, 19, and 21.

Each group rated all three sets. One group rated the low set, then the high, and then the full range set. Another group rated the high, then the low, and then the full range set. The third group rated the full set first and was then split with half of the Ss rating the low complexity set first and the other half the high complexity set first. This arrangement comes pretty close to counterbalancing order of presentation. Tests for order effect revealed that there was no systematic order effect, and order was therefore ignored in further analysis.

231
FIGURE 75
COMPARISON OF TWO SCALING PROCEDURES
Figure 76 is a plot of the results of the three sets of ratings. It is apparent that when subjects rate a restricted range of stimuli they tend to use more of the range than they do when rating a wider range. Thus the middle range stimuli were rated as more complex when in a set of low complexity, and less complex when in a set of higher complexity.

Figure 77 is a plot of the second result of this study. In addition to the complexity ratings, the subjects were asked to rate each pattern for 'interestingness.' Subjects showed very little consistency in their ratings of this variable. What little there is shows the more complex patterns rated as being more interesting. Since earlier subjects had expressed a liking for the simpler patterns, the two variable, liking and interestingness do not appear to be closely related and what relationship there is appears to be inverse.

Summary of Tartan studies. This set of materials was selected because it offered a physical dimension, number of squares, with a degree of face validity as a complexity dimension. The physical scale and a simple psychological rating scale showed good agreement.

The relation of complexity and liking was a simple monotonic one with subjects expressing the greater liking for the simpler patterns. Ratings of 'interestingness' and ratings of liking were essentially unrelated.

Comparison of a simple scaling of liking, and results from a more complex Shepard-Kruskal scaling technique yielded no advantage of the more complex technique, either in terms of the establishment of more than one dimension of liking, or in terms of individual difference analysis.
FIGURE 76

COMPLEXITY RATINGS AS A FUNCTION OF RANGE OF STIMULI
FIGURE 77
COMPLEXITY AND 'INTERESTINGNESS'
Stage set designs. The design of stage settings is subject to classification with respect to style, and the various styles differ in complexity as one of the descriptive dimensions. In conjunction with a doctoral dissertation on differences in audience reaction to styles of stage setting, a group of 30 photographs of drawings of stage sets became available.

This group of 30 photographs was subjected to two kinds of preliminary appraisal. They were submitted to a panel of scholars in drama for quantitative evaluation of the extent to which each represented any of several styles. They were also rated by a small group of subjects for complexity and preference using a simple rating procedure. On the basis of these two preliminary procedures, a set of 12 drawings were selected for use in the dissertation. The criterion of choice was primarily that the panel of scholars be in agreement on the style designations.

The settings selected represented three styles, romantic, classical or formal, and baroque. The romantic settings were: one by Chaperon for Faust, one by Adloph Appia for Little Eyolf, one by Karl Fichot for Parsifal, and one by P. L. Ciceri for Ali Baba. The formal or classical settings were: one from Karl Czeschka for King Lear, one from Norman Bel Gedes for Hamlet, one from T. C. Pillart for Oedipus, and one from Adolph Appia for Orpheus. The baroque settings included one from Fabrizio Galliari, one from Ferdinando Bibiena, and two from Carlo Bibiena. The plays for which they were designed were not designated in the source.

The 12 stage set drawings were then rated four different times by a group of subjects consisting of 9 undergraduates and 7 graduate students.

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1 This study was done in conjunction with a doctoral dissertation project of Warren Pickett in the Department of Speech and Drama at the University of Michigan. The dissertation, tentatively titled An experiment in audience response to set design style, is to be completed in the Fall term, 1969.
They were rated for complexity and preference on a simple 7-point scale, and rated for both again using the Shepard-Kruskal technique of rating the difference between pairs on a scale of 1 to 10.

The results of the simple rating are in Figure 78. The three styles are distinguished in terms of complexity almost without overlap. The four baroque settings are rated as much more complex than the others. The four classical-formal settings are rated on the simple end of the scale. The romantic are in the middle except for one setting that is classed with the formal in terms of complexity.

These subjects express a preference for the baroque settings. The classical-formal are least preferred, but the styles are not differentiated in terms of preference to nearly the extent they are in terms of complexity. Thus the relationship between complexity and preference is a monotonically increasing preference for settings of increasing complexity. It might be noted that this is the reverse of the relationship between complexity and preference noted in the studies of tartan patterns.

The Shepard-Kruskal ratings were extensively analysed using six dimensions in both the analyses of individual data and in the analysis of the group data. Again, the efforts to rationalize the individual data proved utterly fruitless. The analysis of group data was equally frustrating. When the Shepard-Kruskal analyses of complexity were compared with the results of the 7-point scale, the only systematic relationship that emerged was a U-shaped functional relationship with one of the Shepard-Kruskal dimensions. Sets rated both high and low in complexity on the 7-point scale were at one end of the Shepard-Kruskal dimension and those in the middle were on the other end.

With six dimensions of complexity and six of preference available, 30 possible pairs can be matched. Figure 79 is a plot of the one pairing that showed a systematic relationship. This plot is so linear that one would think the two dimensions were measurements of the same variable. The other possibility is that this relationship is a chance one drawn from a set of 30.
FIGURE 78
COMPLEXITY AND PREFERENCE IN STAGE SET DESIGNS
7-point scales
FIGURE 79
COMPLEXITY AND PREFERENCE IN STAGE SET DESIGNS
Shepard-Kruskal scales
The methodological conclusion drawn from these efforts is that the simple rating scale functions as well or better than the more complex multidimensional one, since the latter added no information concerning either variable or the relation between the two.

Complexity, preference, and experience with graphics. Theories that relate preference to stimulus complexity generally agree in predicting that a subject will prefer a stimulus of moderate complexity rather than an extremely simple or an extremely complex stimulus. The theory stated earlier predicts that with increased experience with a class of stimuli, the preferred stimulus should tend to be chosen from a point closer to the more complex end of the scale.

This study is an attempt to verify the existence of an optimal complexity level in the middle range of a scale of complexity and to determine if the optimal point is higher for subjects with more experience with the range of stimuli. The basic design was to choose a set of graphics that are highly representational in character and which were produced by well known artists. These were then rated for complexity and preference by a group of law students who were naive with respect to graphic prints, a group of art history students, and a group of graduate students in art. The later two groups could be expected to recognize many, if not all of the graphics and to be able to identify the artist in each case.

The first step in the process was to choose 30 prints of graphic art by seven recognized artists. All of the prints were black and white, were the same size (4.5" x 5") mounted on slightly larger white cardboards and covered with clear acetate for protection.

In the first phase of the study, this set of 30 prints was given to 40 subjects, individually. The group of subjects was equally divided between students in law school and students either in art or art history. They were asked to look through the entire set, and then to assign a whole number rating of complexity from 1 to 7.

Mean ratings for the 30 prints were then used as a basis for choosing a set of 15 prints for the second phase of the study. Five prints each were choosen

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1This study was planned and executed by Kathleen Sinclair and submitted as an Honors Thesis entitled Optimal complexity and aesthetic preference, University of Michigan, 1967.
from the high, mid, and low portions of the range of ratings with the additional prescription that the standard deviations of the ratings should be minimal.

In the second phase of the study, 60 subjects forming three groups of 20 subjects each were used. A "Naive" group consisted of 20 law students with little experience with graphic materials of the kind used in the study. Few of these subjects were able to recognize any of the prints or identify any of the artists. An "Art" group was composed of 20 senior or graduate students in Art. An "Art History" group was composed of 20 graduate students majoring in art history. That the "Art" and "Art History" groups had had considerable more experience with the stimulus materials is demonstrated by the fact that all of the members of both groups recognized all of the artists and most of the prints used in the study. The list of prints ordered from most to least complex in terms of the mean complexity score obtained in the first phase of the study is contained in Table 17.

Table 18 gives the results of the second phase of the study along with the complexity ratings from the first phase. The stability of the complexity ratings is quite apparent. The correlation (rho) between the ratings in the two phases is .94. The correlations between the ratings given by the three groups are .93, .94, and .94.

A plot of complexity against preference in which all 15 points of each curve possible from Table 18 yields a plot that is difficult to read. As a simplification, the 15 values for complexity were ordered and grouped in sets of three within each group. A mean was obtained for the set of three, and a mean value for preference for that set was also obtained. A plot of complexity versus preference using these values as shown in Figure 80.

The curves in Figure 80 are obviously different, and the differences are statistically significant. The curve for the naive subjects is relatively flat and they tend to use most of the range of complexity. However, the flatness of the curve indicates that they do not show very consistent preferences except that there is a general preference for the more complex end of the scale.
TABLE 17

LIST OF GRAPHIC PRINTS

The prints that were rated by subjects for complexity and preference in the second phase of the study, arranged in order of the mean complexity values obtained in the first phase.

<table>
<thead>
<tr>
<th>Mean Complexity Rating</th>
<th>Artist and title of print</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>Durer, &quot;The Men's Bath.&quot;</td>
</tr>
<tr>
<td>6.2</td>
<td>Durer, &quot;The Sea-Monster,&quot; 1500.</td>
</tr>
<tr>
<td>5.9</td>
<td>Breughel, &quot;The Donkey at School,&quot; 1556.</td>
</tr>
<tr>
<td>5.6</td>
<td>Durer, &quot;Les Trois Graces,&quot; 1491.</td>
</tr>
<tr>
<td>4.3</td>
<td>Durer, &quot;Portrait of the Artist's Mother,&quot; 1514.</td>
</tr>
<tr>
<td>4.0</td>
<td>Chagall, &quot;David Gives Vent to his Grief,&quot; 1931.</td>
</tr>
<tr>
<td>3.6</td>
<td>Picasso, &quot;The Ball,&quot; 1904.</td>
</tr>
<tr>
<td>2.7</td>
<td>Matisse, &quot;Portrait of Prof. T. Whitmore,&quot; 1937.</td>
</tr>
<tr>
<td>2.6</td>
<td>Chagall, &quot;The Musician,&quot; 1919.</td>
</tr>
<tr>
<td>2.4</td>
<td>Chagall, &quot;My Mother,&quot; 1919.</td>
</tr>
<tr>
<td>1.5</td>
<td>Matisse, &quot;The Princess N.&quot;</td>
</tr>
<tr>
<td>1.4</td>
<td>Matisse, &quot;Henri de Montherlant,&quot; 1937.</td>
</tr>
</tbody>
</table>
TABLE 18

COMPLEXITY AND PREFERENCE SCORES

Mean Complexity and Preference scores for the 15 prints by each of the three groups of subjects. The prints are arranged in the same order as they are in Table 17, with the most complex print first.

<table>
<thead>
<tr>
<th>Mean Complexity Phase 1</th>
<th>Naive Pref.</th>
<th>Comp.</th>
<th>Art Pref.</th>
<th>Comp.</th>
<th>Art History Pref.</th>
<th>Comp.</th>
<th>Mean Complexity Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>4.8</td>
<td>6.5</td>
<td>3.4</td>
<td>5.6</td>
<td>3.3</td>
<td>6.4</td>
<td>6.2</td>
</tr>
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<td>4.2</td>
<td>6.2</td>
<td>3.2</td>
<td>5.6</td>
<td>3.5</td>
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<td>5.8</td>
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<td>5.0</td>
<td>3.4</td>
<td>4.7</td>
<td>3.6</td>
<td>4.3</td>
<td>4.7</td>
</tr>
<tr>
<td>4.3</td>
<td>4.8</td>
<td>4.4</td>
<td>5.7</td>
<td>4.3</td>
<td>4.7</td>
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<td>3.9</td>
<td>3.8</td>
<td>3.9</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
<td>3.95</td>
<td>4.3</td>
<td>3.4</td>
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<td>4.5</td>
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<td>3.8</td>
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<td>3.9</td>
<td>3.9</td>
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<td>4.6</td>
<td>5.3</td>
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<td>3.7</td>
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<td>4.1</td>
<td>3.1</td>
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<td>2.7</td>
<td>4.1</td>
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<td>3.3</td>
<td>3.5</td>
<td>3.2</td>
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<tr>
<td>2.4</td>
<td>2.8</td>
<td>2.3</td>
<td>3.8</td>
<td>3.0</td>
<td>3.5</td>
<td>2.9</td>
<td>2.6</td>
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<tr>
<td>1.5</td>
<td>3.3</td>
<td>2.1</td>
<td>3.7</td>
<td>2.4</td>
<td>4.3</td>
<td>2.9</td>
<td>2.5</td>
</tr>
<tr>
<td>1.4</td>
<td>3.1</td>
<td>1.5</td>
<td>4.7</td>
<td>2.6</td>
<td>5.1</td>
<td>2.2</td>
<td>2.1</td>
</tr>
</tbody>
</table>

243
FIGURE 80
OPTIMAL COMPLEXITY AND EXPERIENCE
The curves for the more sophisticated subjects are constricted in range on the complexity scale. They tend to see the graphics in a context that makes them more nearly alike in complexity. Both curves show major preference for the middle range of complexity values, an optimum in the middle of the range.

The location of the optimum as a function of the amount of experience is in the direction predicted by the theory. The art history students have considerably less experience with graphics than the graduate students in art. The arts students show an optimum that is to the right of that for the art history students. However, this apparent difference is not sufficiently great to accept as evidence. A clear demonstration of the movement of the optimum up the complexity scale with increased experience is yet to be demonstrated unequivocally with these materials.

**Modern art.** The most extensive work on measurement techniques and methodology was devoted to the development of a set of materials representing modern abstract art. A large set of stimulus materials was prepared, and from this set, 42 abstract paintings were selected. These were all in color, they were abstract in the sense of being non-representational and generally devoid of symbolic material. Table 19 contains a list of the paintings used in the preliminary study. The objective was to develop a standardized set of stimulus materials that would then be available for use in studies of complexity and preference, especially studies involving extensive exposure and possible changes in preference with exposure.

The tasks given to subjects involved making four ratings of the paintings. They were to rate complexity and preference on seven-point scales. Then they were to perform the Shepard-Kruskal scaling task, rating differences in complexity or preference between pairs on a scale of 1 to 10. With 42 stimulus items, the task of rating all possible pairs twice, once for complexity and once for preference, proved to be almost beyond the patience of willing subjects. They complained about the difficulty of the task and the growing unpleasantness. Fifteen subjects agreed to perform the scaling task, and only seven completed the entire sequence of judgments. Each of these seven subjects was then
### TABLE 19

**MODERN PAINTINGS**

<table>
<thead>
<tr>
<th>Set Number</th>
<th>Complexity Rating</th>
<th>Painter</th>
<th>Painting</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.6</td>
<td>Jackson Pollack</td>
<td>#1</td>
<td>1949</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>Jo Schreiter</td>
<td>Execution of the hope</td>
<td>1957</td>
</tr>
<tr>
<td></td>
<td>4.1</td>
<td>Singier</td>
<td>Les Amoureux et la Plage</td>
<td>1954</td>
</tr>
<tr>
<td>G</td>
<td>3.2</td>
<td>Sugai'</td>
<td>Yamato</td>
<td>1956</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>Tobey</td>
<td>Tatouage</td>
<td>1958</td>
</tr>
<tr>
<td>2</td>
<td>6.1</td>
<td>Singier</td>
<td>L'Ete</td>
<td>1945</td>
</tr>
<tr>
<td>3</td>
<td>3.4</td>
<td>Hofmann</td>
<td>Pompei</td>
<td>1959</td>
</tr>
<tr>
<td>4</td>
<td>2.4</td>
<td>Sugai'</td>
<td>Yayoi</td>
<td>1958</td>
</tr>
<tr>
<td>5</td>
<td>5.8</td>
<td>Willi Baumeister</td>
<td>Animated landscape</td>
<td>1946</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>Stamos</td>
<td>Avignon II</td>
<td>1958</td>
</tr>
<tr>
<td>6</td>
<td>1.4</td>
<td>Piet Mondriaan</td>
<td>Composition</td>
<td>1927</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>Max Ackermann</td>
<td>Jubilation</td>
<td>1954</td>
</tr>
<tr>
<td>F</td>
<td>3.4</td>
<td>Piet Mondriaan</td>
<td>Composition</td>
<td>1913</td>
</tr>
<tr>
<td>7</td>
<td>5.5</td>
<td>Corneille</td>
<td>Tropical splendour</td>
<td>1958</td>
</tr>
<tr>
<td>8</td>
<td>5.3</td>
<td>Wassily Kandinsky</td>
<td>Pink Composition</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2.3</td>
<td>Soulages</td>
<td>Peinture</td>
<td>1957</td>
</tr>
<tr>
<td></td>
<td>4.9</td>
<td>Corneille</td>
<td>Landscape of America</td>
<td>1958</td>
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<td></td>
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<td>Dubuffet</td>
<td>Table</td>
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<td>E</td>
<td>4.7</td>
<td>Vieira Da Silva</td>
<td>Red Interior</td>
<td>1951</td>
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<tr>
<td>10</td>
<td>5.5</td>
<td>Marca-Relli</td>
<td>Summer noon</td>
<td>1956</td>
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<tr>
<td></td>
<td>4.4</td>
<td>Bram Van Velde</td>
<td>Collection Marie Cuttoli</td>
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<td>4.9</td>
<td>Bram Van Velde</td>
<td>Composition</td>
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<td>4.0</td>
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<td>Month of R. Rega III</td>
<td></td>
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<tr>
<td>11</td>
<td>6.4</td>
<td>Goodnough</td>
<td>Summer</td>
<td>1959-60</td>
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<td>12</td>
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<td>Stamos</td>
<td>Persian Bride</td>
<td>1958</td>
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<td>13</td>
<td>4.3</td>
<td>Le Moal</td>
<td>Ocean</td>
<td>1959</td>
</tr>
<tr>
<td>D</td>
<td>3.3</td>
<td>Singier</td>
<td>Soleil et sable</td>
<td>1956</td>
</tr>
<tr>
<td></td>
<td>3.3</td>
<td>Sugai'</td>
<td>Oni</td>
<td>1958</td>
</tr>
<tr>
<td>14</td>
<td>5.1</td>
<td>Prassinos</td>
<td>Le Clown</td>
<td>1960</td>
</tr>
<tr>
<td>15</td>
<td>1.5</td>
<td>Mark Rothko</td>
<td>Number 10</td>
<td>1950</td>
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<tr>
<td>C</td>
<td>4.5</td>
<td>Schneider</td>
<td>Peinture 65 B</td>
<td>1954</td>
</tr>
<tr>
<td>B</td>
<td>5.8</td>
<td>Dubuffet</td>
<td>Garden Bleche Grignotte</td>
<td>1956</td>
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<tr>
<td>16</td>
<td>3.8</td>
<td>Poliakoff</td>
<td>Oil</td>
<td>1953</td>
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<td>17</td>
<td>2.8</td>
<td>Sugai'</td>
<td>Sugata</td>
<td>1958</td>
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<td>18</td>
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<td>1955</td>
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<td>Intersection</td>
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<td>Pacific Circle</td>
<td>1956</td>
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<td></td>
<td>3.5</td>
<td>Soulages</td>
<td>Peinture</td>
<td>1958</td>
</tr>
<tr>
<td>20</td>
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<td>Pierre Soulages</td>
<td>Composition</td>
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<td>Summer</td>
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<td>21</td>
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<tr>
<td>A</td>
<td>2.8</td>
<td>Tobey</td>
<td>Yellow Harvest</td>
<td>1956</td>
</tr>
</tbody>
</table>

246
interviewed at length concerning the bases of choices. This interview provided a lengthy protocol against which to compare the scales derived.

The abstract paintings are rich in complexity. They vary in color, technique, degree of homogeneity of line and shape, number of transitions from one color or brightness to another, suggestiveness of meaningful material, etc. It was felt that ratings of complexity and preference with such materials might well be multidimensional. If they did prove to be multidimensional, the Shepard-Kruskal analysis should reveal dimensions that could be matched against the verbal protocol for each subject.

The general procedure in pursuing this objective was to obtain Shepard-Kruskal analyses from the computer in a number of degrees of detail. Thus for each subject the computer generated ten solutions for one dimension through ten dimensions, thus 55 dimensions for complexity and 55 for preference for each of 7 subjects.

Analyses of the data for an individual subject tended to take the following form. The one-dimensional solutions and the two dimensions of the two dimensional solutions for complexity and preference were plotted for each individual. The resulting plots varied in the extent of apparent of apparent relations, but examination of a large number of such plots revealed nothing that was meaningfully different than the later analysis of the group data. The second step was to use the Shepard-Kruskal dimensions in pairs to arrange the paintings in two-dimensional arrays. A room wall was utilized for this purpose. A vertical scale was fastened to the wall from floor to ceiling, and a horizontal scale was fastened to the wall from left to right. Then, for example, the two dimensional Shepard-Kruskal solution for an individual subject would be used to place each of the 42 paintings on the wall in accordance with their assigned values from the analysis. If the scales were complexity scales, then the array would be examined to see whether there was any way of making sense of the dimensions in terms of complexity. If the array represented preference, then they were examined to determine whether the basis of preference along each of the dimensions could be determined. These examinations were aided by the protocols taken from the subjects in an
effort to determine why a given painting should occupy that particular position in the array. Several experimenters spent a great many hours at this task. Many arrays were photographed in color and examined later in an effort to establish meaningfulness. Although it was not done systematically, a number of arrays were examined by the subjects who had provided the original data. The net outcome was the conclusion that multidimensional analyses of these data did not yield more than one dimension of either complexity or preference in the data of individual subjects.

For a variety of reasons, it was decided that working with 42 stimuli was unnecessarily cumbersome. The mean 7-point complexity values for the 15 subjects was then used to reduce the set of 42 paintings to a set of 21 experimental paintings and a practice set of 6. Table 19 contains the mean complexity values. It also contains the code number assigned to the 21 paintings of the experimental set, and the latter’s A through G for the practice set that could be used in instructing future subjects.

This small set was then rated by 15 subjects, both on 7-point and Shepard-Kruskal scales in an effort to determine the extent of agreement of the two scaling techniques, and whether any advantage accrued from the use of the more complicated Shepard-Kruskal procedure.

Figure 81 shows a comparison of the 7-point ratings of complexity compared to the one-dimensional and both dimensions of the two-dimensional Shepard-Kruskal solutions. In all three cases there is good agreement in these grouped data. If a stimulus is rated complex on one scale, it is likely to be rated as complex by use of the other method. The two dimensions of the two-dimensional Shepard-Kruskal solution both show good agreement, suggesting that they are highly correlated dimensions within the Shepard-Kruskal analysis.

Figure 82 is a plot of the 7-point complexity and preference values. Almost no trend is apparent in the data beyond a minor tendency for mean preference for some of the more complex stimuli to be somewhat low. Figure 83 shows a comparison of the Shepard-Kruskal one dimensional solutions for complexity and preference. Again, no reliable trend is apparent.
COMPARISON OF 7-POINT AND SHEPARD-KRUSKAL SCALES OF COMPLEXITY

Figure 84 contains the plots of 7-point complexity ratings and three Shepard-Kruskal dimensions of preference. None show relationships.

Two conclusions seem justified on the basis of these studies. The first is that it is probable that when one asks a subject to rate a set of abstract paintings for complexity or preference, he does just that. It is a simple pair of dimensions from the standpoint of the subject and it is thus not composed of contributing sets of underlying dimensions. The second conclusion is that in these data, no systematic relationship between complexity and preference could be demonstrated.

A possible explanation for the lack of relationship between complexity and preference in these data might lie in the experience factor. The theory of complexity predicts that there will be changes in complexity and preference
with experience. It could be that such changes were occurring rapidly enough that the mean judgments represented valid judgments from different points in time that were not coordinate because of the order of presentation and the amount of experience provided in the experimental situation.

Based on this possibility, an effort was made to introduce a simple control of experience within the setting, and collect a new set of data with a larger number of subjects. The simple 7-point scaling procedure was used. The demonstration set of six paintings was used to explain the procedure. The 40 subjects were then asked to rate each of the 21 pictures for complexity and preference. In an effort to exert some additional control over amount of experience with the stimuli, half of the subjects rated
them for complexity and then preference.

The major results in terms of complexity and preference is plotted in Figure 85. There is a definite relation between the two, with preference being expressed for the more complex of the paintings. Figure 86 is a pair of plots that are identical with Figure 85, but the means plotted are for those subjects who made the ratings in the two orders separated. If complexity is rated first and preference second, little or no relationship is apparent in the data as seen in the upper figure. If preference is rated first and complexity second, then a relationship is clearly apparent.

It is not immediately apparent why the two orders should give different results. The amount of experience in the two groups differ when they are making each of the ratings, and this seems the probable cause, but the explanation might prove to be more complex when a satisfactory explanation is developed from future research.

![Figure 83](image)

**FIGURE 83**

COMPLEXITY VERSUS PREFERENCE FOR MODERN PAINTINGS

Shepard-Kruskal scales
FIGURE 84

COMPLEXITY VERSUS PREFERENCE FOR MODERN PAINTINGS

7-point scales of complexity versus Shepard-Kruskal preference solutions
FIGURE 85
COMPLEXITY VERSUS PREFERENCE FOR MODERN PAINTINGS
FIGURE 86

COMPLEXITY AND PREFERENCE AND ORDER OF RATING
Summary of results from human studies of complexity and preference. The major effort in this area was to develop several sets of visual stimulus materials for use in future research. The research has produced four sets, each of which yields reliable ratings of complexity and preference.

The methodological conclusions are simple and somewhat disappointing. Multidimensional analysis of ratings of complexity and preference does not seem fruitful. The simplest rating tasks in which the subject is asked to assign an absolute rating from 1 to 7, from 1 to 10, or from 1 to 100 seems to yield results that are as functional for future research as the more complex scaling techniques. The Shepard-Kruskal technique imposes a very difficult task on the subject and requires that the subject be exposed to the stimuli a number of times and for considerable periods. It seems likely that the complexity value and preference for the stimuli are undergoing extensive change during the process of rating with the result that the over-all results are relatively useless. The effect of order of judgment, whether complexity or preference was rated first, at least suggests extreme care in designing future studies so that even brief experience with the stimuli is adequately controlled.

The search for an optimum preference value along the complexity dimension yielded rather varied results. The 'best' result with each of the four sets of stimulus materials is plotted in Figure 87. Subjects express maximum preference for the simplest of the tartan patterns. They show a maximum preference for black and white graphics in the middle range of complexity. Maximum preference is expressed for the most complex of the stage settings, and the abstract paintings.

The effect of experience on complexity and preference was explored systematically in only one study. In that one, the more experienced art students used a more restricted range of complexity ratings than naive subjects. The experienced subjects showed optima in the middle of the complexity range and used a greater range of preference judgments than the naive subjects. In other studies, it seems likely that very short experiences with stimuli affected ratings so that ratings of complexity and preference appear to be quite labile over short periods of experience.
SUMMARY OF COMPLEXITY AND PREFERENCE RELATIONS
3. Stimulus complexity and preference in animals

It is easy to ask a human subject how complex he thinks a given stimulus is and then to ask him to rate his preference for it. It is more difficult to ask an animals to distinguish between the two questions. If one presents an array of stimuli to an animal and if the animal approaches one element of that array, it is reasonable to assume that he prefers that stimulus to the others. If the array is composed of stimuli which have a dimension of complexity that is obvious to the experimenter, then one can infer that the animal has expressed a preference for the chosen stimulus on the basis of its relative complexity. However, the inference is not a strong one. If in the pattern of successive choices, the animal behaves in a manner that is orderly along this complexity dimension, the inference that is the complexity of the stimulus to which he is responding seems strengthened.

The lack of independence of the judgments of complexity and preference is the major disadvantage to working with animals on this problem. The advantage lies in the assumed relative simplicity of the animal and the degree of control that the experimenter can exercise. Animal research on complexity and preference was undertaken in the light of the obvious advantages and disadvantages.

Two-dimensional versus three-dimensional complexity in the rat.¹ The first study of this series was an effort to explore the question of whether repeated experience with two sets of stimuli (two-dimensional and three-dimensional) would produce a progressively changing preference toward more complex stimuli. One stimulus set consisted of simple wall patterns composed of a uniform grey, a set of horizontal stripes, a set of vertical stripes, and a checkered pattern. The three-dimensional patterns consisted

of an empty compartment, a compartment with one baffle, a compartment with two baffles, and a compartment with complex set of baffles greater than two. It was assumed that these two sets of stimuli represented two dimensions of complexity, both of which were anchored on the empty grey compartment.

Subjects. 32 naive male rats were used. They were all bred in the University of Michigan colony, and were all hooded derivatives of the Long-Evans strain, most being brown hooded but a few faun hooded, and all had pigmented eyes. They were 95 to 108 days of age at the beginning of the experiment.

Apparatus. Two mazes were used which were identical in basic structure but which differed in internal detail. Each maze was basically a box 4 ft. x 4 ft. square and 2 ft. high. Each was divided into four sections with 6 in. high dividers extending from the middle of each wall 18 in. toward the center of the box. These dividers created four equal sections about 2 ft. x 2 ft. with an open area in the center of the large box which permitted free access to the four sections created by the dividers.

The sections of the wall pattern maze were distinguished by the treatment given the walls. One section was painted grey as was the floor of the entire maze. One section had a horizontal pattern of one in. black and white stripes on all four walls. Another section had a vertical pattern of similar stripes. The fourth section was painted with black and white checkerboard pattern with one in. squares.

The sections of the baffle pattern maze were distinguished by the number of baffles. The entire maze was painted grey. One compartment was free of baffles and was identical with the one grey compartment of the wall pattern maze. A second section had one vertical, 4 in. high baffle projecting 12 in. from one of the exterior walls. A third section had a similar baffle from the center of the other exterior wall. The fourth section had two 12 in. baffles arranged in a complex pattern.

Procedure. Half of the animals were run only in the wall pattern maze, and half were run in the baffle pattern maze.

Animals were introduced to the maze individually. Each was placed
in the center of the maze facing the least complex grey compartment. The animal remained in the maze for a period of 30 min. at the same time of day on each of 5 days. Observation was through a one-way vision mirror from an adjacent room. A record was kept of the amount of time spent in each compartment and the sequences of choices of compartment.

The animals were run 16 at a time on successive weeks during a vacation period when the laboratory was relatively quiet. Four were run each morning and four each afternoon in each maze. Food and water were available in the home cages at all times.

Scoring. The various patterns were intended to constitute different levels of stimulus complexity. On a priori grounds each was assigned a complexity index number. The two grey compartments were given the value of 1. The horizontal stripe pattern and the one-baffle compartment were given the value 2. The vertical stripe pattern and the compartment with two baffles were given a value of 3. The compartment with the checkered pattern and that with the multiple baffles were given the value 4.

Each daily experimental period of 30 min. was divided into five periods of 6 min. each. A complexity interaction index was obtained by multiplying the number of minutes the animal spent in each compartment by the arbitrarily assigned complexity index value. Thus, if an animal spent the entire 6 minutes in the grey compartment with an index value of 1, his score for that period would be a minimum value of 6. If he spent the entire 6 minutes in the most complex compartment, his complexity interaction index score would be 6 x 4=24, the maximum value.

A similar complexity interaction index value was obtained for the 30 min. daily period. This value could range from a minimum of 30 to a maximum of 120.

The theory predicts that interaction with one of the sections should produce an increase in the ideal and thus a choice of a more complex section. Such shifts would produce an increase in the complexity interaction index and thus a rise in a curve of mean values. Figure 88 is a plot of the mean complexity interaction indices for the two mazes within days, and Figure 89 is a similar plot over the five days of the experiment.
Mean preferences in successive 6-minute blocks within days. The complexity interaction index is produced by multiplying the time spent in a quadrant by an arbitrary set of values ranging from 1 for the grey compartment to 4 for the checkered wall pattern and for the compartment with the multiple baffles. Values can thus range from 6 to 24.
The differences in scores between the two mazes are so large that no statistical test is required. Analyses of variance for the two mazes independently yield the following results. In the baffle pattern maze, the increase in the complexity interaction index over days is significant < .025. The increase within days for this maze approaches but does not reach the .05 level. The interaction does not approach significance. In the wall pattern maze, the increase between days approaches but does not reach the .05 level, while the within days difference and the interaction do not approach significance. Thus the three-dimensional baffle pattern manipulation of stimulus complexity proved effective, while statistically significant increases in the complexity level chosen in the wall pattern maze could not be demonstrated.

A simple way of analysing the data is to determine which compartment each animal spent most of his time in on each day. That compartment is then designated as his preferred compartment for the day. Table 20 presents the results.

**TABLE 20**

**PREFERRED COMPARTMENTS BY DAYS**

<table>
<thead>
<tr>
<th>TRIALS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wall Patterns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Grey</td>
<td>16</td>
<td>16</td>
<td>14</td>
<td>13</td>
<td>7.5</td>
<td>66.5</td>
</tr>
<tr>
<td>B Horizontal Stripes</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4.0</td>
</tr>
<tr>
<td>C Vertical Stripes</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3.5</td>
<td>5.5</td>
</tr>
<tr>
<td>D Checks</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td><strong>Baffle Patterns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Grey</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>B One Baffle</td>
<td>6.5</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>10.5</td>
</tr>
<tr>
<td>C Two Baffles</td>
<td>4.5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.5</td>
<td>6.0</td>
</tr>
<tr>
<td>D Three-plus Baffles</td>
<td>5</td>
<td>13</td>
<td>15</td>
<td>15</td>
<td>14.5</td>
<td>62.5</td>
</tr>
</tbody>
</table>
In the wall pattern maze, the simplest compartment with grey walls is preferred by every animal for the first two days. On subsequent days, increasing number of animals express preference for increasingly complex wall patterns. In the baffle maze, preference is expressed for the more complex patterns on the first day. By the second day the animals are almost universally expressing a preference for the most complex of the quadrants.

Some of the problems of interpretation of these results may be seen more clearly if the data are plotted on a hypothetical scale of stimulus complexity. This had been done in Figure 90, from the data plotted in Figure 89. Each number represents the mean preference for the day (number of animals x the arbitrary complexity value/ N). The animals exposed to the wall patterns show a predominant preference for the grey compartment on the first two days, then move to a slight preference for more complex patterns on the third and fourth days and make a significant shift upward only on the fifth day. The animals with the baffle patterns show a preference midway on the scale on the first day, and move very close to the top by the second.

The scale in Figure 90 is dependent on the arbitrary assignment of complexity scale values of '1' for the grey compartment in each case, a value of '2' for the next most complex, and a value of '3' and then '4' for the next two. These values assume equal metric values for the horizontal stripes and for the one baffle, equal value for vertical stripes and two baffles, and equal weights for the checkered pattern and the multiple baffles. Without an appeal to the theory there is no simple way to determine which set of stimuli, the two-dimensional or the three-dimensional is the more complex.

If we take the theory seriously, then we could reason in this fashion. Since the animals took several days to venture at all into the more complex two-dimensional patterns in contrast to the immediate approach to the baffle patterns, then the wall patterns are probably the more complex and should be assigned complexity values greater than those assigned the baffle patterns. However, there is no simple way to determine what scale values to assign to the stimuli.
FIGURE 89

COMPLEXITY INTERACTION INDEX BETWEEN DAYS

Mean complexity index values by days. Since the exposure period within a day was 30 minutes, the complexity interaction index could range from 30 to 120.
FIGURE 90
STIMULUS COMPLEXITY SCALE
An alternative is to combine into one maze representatives of the two types of stimuli. To do this, the same maze compartments were redesigned with the following stimulus patterns.\(^1\)

1. Grey wall, no baffles  
2. Grey walls, one baffle  
3. Horizontal stripe walls, no baffles  
4. Vertical stripe walls, three baffles

The first of these, the grey walls without baffles, seemed to be an obvious choice for the simplest stimulus pattern we could devise. The fourth, the vertical striped pattern with the three baffles was a combination of the two most complex of the two previous sets of stimuli. The other two seemed to be middle values. If one had to guess, on the basis of previous results, one would guess that the one baffle pattern would be the simpler of the two.

Only three rats were used in the study, but each of the three was exposed to the stimuli for continuous sessions of 100 minutes each on six consecutive days. It was hoped that the much longer exposure times would be adequate to permit significant changes in preference.

In order to analyse the data, each session was arbitrarily divided into 10 periods of 10 minutes each. For each such time block, the quadrant in which the animal spent the majority of his time was designated as the preferred compartment.

Table 21 is a tabulation of the number of blocks out of 30 (10 each for 3 animals) in which each quadrant was preferred, on each of the six days. The data are generally orderly, in spite of the small number of animals. The initial preference is clearly for the simplest of the quadrants, and the final preference clearly for the most complex. The guess that the baffle pattern

\(^1\)This study was done by Bruce E. Walker and is unpublished. Its title might be Scaling of two-dimensional and three-dimensional stimulus complexity in the rat.
would be less complex than the horizontal stripes seems supported by the fact that the preference for the horizontal stripes is expressed later in the time sequence.

**TABLE 21**  
**PREFERRED STIMULI BY DAYS**

<table>
<thead>
<tr>
<th>Day</th>
<th>Grey</th>
<th>1 Baffle</th>
<th>Horizontal Stripes</th>
<th>Vertical Stripes and 3 Baffles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>9</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>17</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>15</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>12</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>13</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>8</td>
<td>7</td>
<td>15</td>
</tr>
</tbody>
</table>

The data can be analysed within days as well. This has been done in Table 22. Again, the data seem orderly despite the handicap of the small number of animals and the fact that the preference is changing markedly from day to day as shown in Table 21. Looking down the columns, the preference for the one baffle quadrant declines in the 100-minute period, while the preference for the two more complex patterns increases slightly. Looking across the rows, the theory would state that if the stimuli are ordered by complexity,
TABLE 22
PREFERRED STIMULI BY SUCCESSIVE 10-MINUTE PERIODS

<table>
<thead>
<tr>
<th>Minutes</th>
<th>Grey</th>
<th>1 Baffle</th>
<th>Horizontal Stripes</th>
<th>Vertical Stripes and 3 Baffles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>2</td>
<td>14</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>11-20</td>
<td>1</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>21-30</td>
<td>4</td>
<td>9</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>31-40</td>
<td>3</td>
<td>9</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>41-50</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>51-60</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>61-70</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>71-80</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>81-90</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>91-100</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

then one could expect either a declining pattern, a pattern that increased and then decreased, or a pattern that increased. The pattern one would not expect would be one that declined and then increased. In only two of the 30 instances is the expectation not met. Thus there is a general tendency for the animals to move from less complex to more complex stimuli during the day.

Analysis of sequences of choice. The theory relating complexity and preference indicates that the expressed preference should be for progressively more complex stimuli. In the simplest form of the theory, there should be no regressions. That is, if an animal first prefers the grey compartment and
then progresses to a preference for the compartment with one baffle, he should not again express a preference for the plain grey compartment. The prediction does not contain a statement concerning variability or error. It simply states that if we number the quadrants from 1 through 4, the preference sequence should be 1, 2, 3, 4, and no sequence such as 1, 2, 3, 2, 3, 4 should be observed. Rigid adherence to the complexity sequence seems too much to expect, yet the theory makes no prediction related to the variability in the sequence.

Analysis of sequences has an inherent problem. One way of analysing the data would be to list a sequence of choices, in this case compartment entries, and then analyse the sequence for sequential dependencies. However, such a sequence of choices would not take the amount of time spent in each compartment into account. An alternative analysis would simply be the total amount of time spent in each compartment. This analysis yields no information on sequences of choices. A compromise analysis is in terms of arbitrary time blocks. In this case, one can use the 10-minute time blocks that were used in the previous analysis. For each time block, the quadrant in which the animal spent the most time can be designated as the preferred stimulus for that time block. Such an analysis loses data on brief visits, and differs slightly from analyses in terms of total time spent in each quadrant. However, it does have the advantage of representing the sequence of choices made and the time spent in each compartment and therefore in the presence of each stimulus.

In this study, if one takes the sequences of designations of preferred stimuli for each animal over the six days, the sequences consist of 60 successive designations of preferred stimulus for each animal. Each sequence can then be analysed by tabulating the frequency with which each designation of preference is followed by each other designation. The frequencies can then be converted to first order transitional probabilities. This has been done for each animal in Table 23. It has been done for all three animals but for Days 1 and 2, Days 3 and 4, and Days 5 and 6 in pairs in Table 24. Table 24 also contains the summary table of transitional probabilities for all six days for all three animals.
TABLE 23
TRANSITIONAL PROBABILITIES OF STIMULUS PREFERENCE BY ANIMAL

Animal X

<table>
<thead>
<tr>
<th>FROM</th>
<th>Grey</th>
<th>One Baffle</th>
<th>Horizontal Stripes</th>
<th>Stripes and Baffles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey</td>
<td>.08</td>
<td>.07</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>One Baffle</td>
<td>.05</td>
<td>.17</td>
<td>.05</td>
<td>.00</td>
</tr>
<tr>
<td>Horizontal St.</td>
<td>.00</td>
<td>.05</td>
<td>.44</td>
<td>.03</td>
</tr>
<tr>
<td>Stripes and Baffles</td>
<td>.02</td>
<td>.00</td>
<td>.02</td>
<td>.00</td>
</tr>
</tbody>
</table>

Animal Y

<table>
<thead>
<tr>
<th>FROM</th>
<th>Grey</th>
<th>One Baffle</th>
<th>Horizontal Stripes</th>
<th>Stripes and Baffles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey</td>
<td>.08</td>
<td>.02</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>One Baffle</td>
<td>.02</td>
<td>.41</td>
<td>.03</td>
<td>.07</td>
</tr>
<tr>
<td>Horizontal St.</td>
<td>.00</td>
<td>.03</td>
<td>.05</td>
<td>.00</td>
</tr>
<tr>
<td>Stripes and Baffles</td>
<td>.02</td>
<td>.03</td>
<td>.00</td>
<td>.24</td>
</tr>
</tbody>
</table>

Animal Z

<table>
<thead>
<tr>
<th>FROM</th>
<th>Grey</th>
<th>One Baffle</th>
<th>Horizontal Stripes</th>
<th>Stripes and Baffles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey</td>
<td>.15</td>
<td>.08</td>
<td>.02</td>
<td>.00</td>
</tr>
<tr>
<td>One Baffle</td>
<td>.07</td>
<td>.29</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>Horizontal St.</td>
<td>.03</td>
<td>.02</td>
<td>.12</td>
<td>.00</td>
</tr>
<tr>
<td>Stripes and Baffles</td>
<td>.00</td>
<td>.02</td>
<td>.00</td>
<td>.14</td>
</tr>
</tbody>
</table>
TABLE 24
CHANGING PREFERENCES FOR STIMULUS COMPLEXITIES
OVER TIME IN TERMS OF TRANSITIONAL PROBABILITIES

<table>
<thead>
<tr>
<th></th>
<th>Days 1 and 2</th>
<th></th>
<th>Days 3 and 4</th>
<th></th>
<th>Days 4 and 5</th>
<th></th>
<th>Days 1 through 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TO</td>
<td></td>
<td>TO</td>
<td></td>
<td>TO</td>
<td></td>
<td>TO</td>
</tr>
<tr>
<td></td>
<td>Grey</td>
<td>One Baffle</td>
<td>Horizontal</td>
<td>Stripes and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey</td>
<td>.34</td>
<td>.11</td>
<td>.00</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One Baffle</td>
<td>.12</td>
<td>.27</td>
<td>.04</td>
<td>.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal St.</td>
<td>.00</td>
<td>.02</td>
<td>.09</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stripes and Baffles</td>
<td>.02</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FROM</td>
<td></td>
<td></td>
<td>FROM</td>
<td></td>
<td>FROM</td>
<td></td>
<td>FROM</td>
</tr>
<tr>
<td>Grey</td>
<td>.00</td>
<td>.04</td>
<td>.02</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One Baffle</td>
<td>.02</td>
<td>.37</td>
<td>.05</td>
<td>.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal St.</td>
<td>.04</td>
<td>.02</td>
<td>.37</td>
<td>.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stripes and Baffles</td>
<td>.00</td>
<td>.00</td>
<td>.02</td>
<td>.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey</td>
<td>.00</td>
<td>.04</td>
<td>.02</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One Baffle</td>
<td>.02</td>
<td>.23</td>
<td>.02</td>
<td>.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal St.</td>
<td>.00</td>
<td>.02</td>
<td>.18</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stripes and Baffles</td>
<td>.02</td>
<td>.05</td>
<td>.00</td>
<td>.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey</td>
<td>.11</td>
<td>.06</td>
<td>.01</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One Baffle</td>
<td>.05</td>
<td>.29</td>
<td>.04</td>
<td>.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal St.</td>
<td>.01</td>
<td>.03</td>
<td>.20</td>
<td>.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stripes and Baffles</td>
<td>.01</td>
<td>.02</td>
<td>.01</td>
<td>.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The major individual differences in Table 23 are that Animal X rarely entered the most complex quadrant with the vertical stripes and the multiple baffles. Animal Y, on the other hand, visited the horizontal striped compartment rather infrequently. If the complexity ordering in the table is correct, this animal jumped directly from the one-baffle pattern to the most complex. There appears to be no simple way to unfold a scale based on nothing but sequences to order the stimuli for individual animals, but it could be that for Animal Y, the complexity order of the one-baffle and the horizontal stripes is reversed from the order in the table.

The analysis of transitional probabilities by days in Table 23 shows a clear progression given the a priori ordering of the stimulus patterns. The action is relatively confined to the two simpler stimuli on the first two days. It moves to the second and third stimuli on the next two days, and progresses to include the most complex stimulus on the final two days.

While complexity theory does not predict the amount of variability in choice sequence one might expect, it does make some predictions concerning a table such as that on the bottom of Table 23. If the progression of preferences was ordered absolutely, then all of the probabilities of the table would be along the diagonal except for three transitions, from 1 to 2, from 2 to 3, and from 3 to 4, and there should be no reversals, e.g., from 3 to 2. It is apparent that the preference sequences are not ordered absolutely.

A weaker prediction would be that the transitional probabilities would depart from a chance distribution. It is obvious, without test, that this prediction is fulfilled. The theory also makes a prediction concerning the character of the dependency. If the animals are responding to the stimuli, and are reacting to them as they have been ordered on an a priori basis, then the interaction between adjacent stimuli should be greater than more remote stimuli. The sum of the probabilities in the diagonals adjacent to the main diagonal is .20. The sum of the more remote interactions (the three in the lower left and the three in the upper right) is .08. This result would tend to confirm that the animals were indeed responding to the complexity scale and that they were responding to it as it is ordered in the tables.
Generalized complexity satiation. Complexity theory predicts that with continued exposure to a stimulus dimension, the organism should show preference for stimuli of increasing complexity, and this prediction has been repeatedly verified in the previous studies. If there is generalization of the effects of exposure to one stimulus on a dimension, it should have an influence on the relative preference for stimuli on the same dimension to which the organism has not been exposed.

To test this proposition, a study was designed in the following pattern. Five stimuli were constructed that should represent a dimension of stimulus complexity to the rat. The five patterns were all vertical stripe patterns of black and white and they varied in width. The widths were:

- Most complex: 3/16 inch stripes
- Middle complexity: 3/4 inch stripes
- Least complex: 1 1/2 inch stripes

The basic plan was to vary the amount of prior exposure of groups of animals to the middle stimulus, and then to observe the effect of the different durations of exposure on the preferences of the animals when given choices among the other four.

It was felt that the total amount of exposure in the maze should be held constant, in this case at one hour, but that the duration of exposure to the 3/4 inch stripe pattern should be varied. To do this, the four compartment maze was employed, and all three groups were initially placed in the maze with the walls a uniform grey. A short exposure group was created by leaving the animals in the grey condition for 50 minutes, removing them while the stripe pattern was installed and then putting them back for 10 minutes to complete the hour of exposure. This group could be referred to as the 50G10S group.

---

1 This study was carried out by Bruce E. Walker and is unpublished. It might be titled Effect of prior exposure to one stimulus on preference for other stimuli on the same dimension.
because it was exposed to grey for 50 minutes and to stripes for 10 minutes. A middle exposure group was created by exposing them to the grey for 30 minutes and to the stripes for 30 minutes. This group is designated the 30G30S group. The long exposure group was exposed to grey for 10 minutes and to the stripes for 50 minutes, and is designated the 10G50S group.

At the end of the hour for each group, the 3/4" stripes were removed and the other four stripe patterns were introduced, one in each of the quadrants of the maze. The animals were then replaced, and their choices over a period of an hour was recorded. There were six animals in a group, a total of 18 in the experiment.

Figure 91 is a plot of complexity scores by groups over the two hours. The complexity scores are achieved by multiplying the number of minutes in a 10-minute block by the arbitrary complexity value for that stimulus, ranging from 1 to 4 for the four stimuli in the order of their a priori complexity with 4 representing the most complex. Thus scores could range from 10 to 40. The left side of the figure is a calculation of preference scores during the successive 10-minute exposure periods as if the test stimuli were in place. This was done to reflect performance before the test stimuli were in place and serves as a sort of control. The small vertical lines indicate the point at which the group was shifted from grey to the 3/4 in. exposure pattern. The right side of the figure shows the expressed preferences of the three groups during the one-hour test period, again divided into 10-minute blocks.

Figure 92 shows the three groups combined to stress the progressive increase in preference for the more complex patterns over the hour of test compared to the exposure hour. Figure 93 replots the data to stress the differential effects of the exposure on the three groups.

The results are in part expected from complexity theory and in part were quite at variance with the expectation. During the one-hour test period, there is a progressive change in preference upward on the complexity dimension. The shift of nearly 10 points in Figure 92 indicates a shift of about one whole step across the 'big' interval. In the first 10 minutes the pre-
FIGURE 91

AMOUNT OF PRIOR EXPERIENCE AND GENERALIZED STIMULUS PREFERENCE

Mean complexity scores by 10-minute periods during two hours of testing for three groups exposed for different periods of time to a standard stimulus. See text for explanation.

dominant preference was for the compartment with the 1 1/2 inch stripes, and in the last 10 minutes, the predominant preference is for the compartment with the 3/8 inch stripes. This finding is in agreement with complexity theory.

The finding portrayed in Figure 92 is not explicable from the theory. The animals exposed to the 3/4 inch stripes for 30 minutes show a preference for more complex stimuli than either the group exposed for 10 minutes or the group exposed for 50 minutes. The locus of the problem may lie in small part in the wide gap between 3/8 inches and 1 1/2 inches, but why the three
FIGURE 92

CHANGES IN STIMULUS PREFERENCE WITH TIME

Data of Figure 91 replotted with groups combined.

groups should react to that gap as they did is not clear.

The first order transitional probabilities for the three groups is contained in Table 25. If one compared the probabilities in the diagonals immediately adjacent to the main diagonal with the three values in each case in the lower left and upper right corners, some support for the 'gap' problem is there. The outer corners show higher probabilities than the adjacent diagonals. This is the reverse of the case in the previous tables. It indicates a tendency to go from one extreme to the other rather than from one stimulus to one that is adjacent on the a priori scale.

One might conclude from this analysis that the animals were not reacting
to the stimuli as representing four values on a single dimension. However, since the progression from simple to complex is quite clear, that evidence would argue that they were reacting to the stimuli as if on a complexity scale. The only post hoc explanation that has emerged is that the gap creates a situation in which the animals react as if there was only two points on the scale, narrow and wide.
TABLE 25
FIRST ORDER TRANSITIONAL PROBABILITIES

50G10S Group

<table>
<thead>
<tr>
<th>FROM</th>
<th>3 in.</th>
<th>1 1/2 in.</th>
<th>3/8 in.</th>
<th>3/16 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 in.</td>
<td>.27</td>
<td>.03</td>
<td>.13</td>
<td>.07</td>
</tr>
<tr>
<td>1 1/2 in.</td>
<td>.00</td>
<td>.03</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>.13</td>
<td>.03</td>
<td>.10</td>
<td>.03</td>
</tr>
<tr>
<td>3/16 in.</td>
<td>.00</td>
<td>.00</td>
<td>.07</td>
<td>.03</td>
</tr>
</tbody>
</table>

30G30S Group

<table>
<thead>
<tr>
<th>FROM</th>
<th>3 in.</th>
<th>1 1/2 in.</th>
<th>3/8 in.</th>
<th>3/16 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 in.</td>
<td>.00</td>
<td>.00</td>
<td>.07</td>
<td>.03</td>
</tr>
<tr>
<td>1 1/2 in.</td>
<td>.00</td>
<td>.00</td>
<td>.03</td>
<td>.07</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>.00</td>
<td>.03</td>
<td>.13</td>
<td>.03</td>
</tr>
<tr>
<td>3/16 in.</td>
<td>.03</td>
<td>.07</td>
<td>.00</td>
<td>.50</td>
</tr>
</tbody>
</table>

10G50S Group

<table>
<thead>
<tr>
<th></th>
<th>3 in.</th>
<th>1 1/2 in.</th>
<th>3/8 in.</th>
<th>3/16 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 in.</td>
<td>.27</td>
<td>.03</td>
<td>.17</td>
<td>.07</td>
</tr>
<tr>
<td>1 1/2 in.</td>
<td>.10</td>
<td>.10</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>.07</td>
<td>.07</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>3/16 in.</td>
<td>.00</td>
<td>.00</td>
<td>.03</td>
<td>.03</td>
</tr>
</tbody>
</table>

Effect of stimulus range on complexity and preference. In the studies of judged complexity and preference in tartan patterns discussed earlier in this report, human subjects tended to respond to the range of stimuli presented to them. If they had a narrow range of stimuli on the less complex end of the

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1This study was carried out by Wade Boykin as a masters level research project, 1968-1969. It resulted in a paper entitled The effects of level and range of complexity values on visual preferences in rats.
scale, they tended to judge the upper end of their stimulus set as more complex than a group with the full range. If subjects judged only a set of more complex stimuli, they tended to judge the middle absolute range as less complex than subjects with the full range. From a variety of studies, it seemed possible that rats also responded to the range of stimuli presented to them rather than to respond on an absolute basis.

Boykin divided 18 naive, male Long-Evans rats at about 100-150 days of age into three groups of 6 animals each. One group (A) was to be exposed to a narrow range of relatively simple stimuli, a second group (B) was to be exposed to a narrow range of stimuli of high complexity, and a third group (C) was to be exposed to the full range. The stimuli selected on a priori grounds along with the items used with each of the three groups are the following:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple end</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-inch horizontal stripes</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>2-inch vertical stripes</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 checkers per 4x4 square</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>9 checkers per 4x4 square</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 checkers per 4x4 square</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>25 checkers per 4x4 square</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>49 checkers per 4x4 square</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>81 checkers per 4x4 square</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Complex end</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>144 checkers per 4x4 square</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

The experimental apparatus was a circular device with a center compartment from which radiated six doors permitting access, from the center, to six equally sized truncated pie-shaped compartments. The maze was 28 inches in diameter and the central compartment was 6 inches. The walls of the compartments were made of screen mesh wire and were 4 1/2 inches high. The stimuli were fastened to cardboard and covered with plastic. A piece of stimulus cardboard was bent 10 inches from each end so that it conformed to the shape of the truncated pie-shaped compartment, covering all of the interior
walls.

There were six compartments and five stimuli. One compartment was utilized as an entrance compartment. When the animal left the entrance compartment, it was closed behind him so that he had access during the trial to five stimulus compartments and the central compartment.

A trial consisted of 10 minutes in the maze for 12 consecutive days for each animal. The locations of the stimuli were varied from day to day with each stimulus in each position during the first two blocks of 5 trials. They were rotated in the last two days at random.

The behavior of the animal was recorded on six of the channels of an Esterline-Angus recorder by marking where the animal was at all times during the trial by activating the appropriate event marker.

Figure 94 shows the total amount of time spent by each group in each of the available stimulus compartments. Those in the low range of complexities do not show a preference. Those in the higher range show some preference for the more complex stimuli. The group exposed to the full range show a definite preference for the more complex stimuli. Thus the range of stimuli available did have an effect. Preference was more clearly expressed with the wider range of stimuli.

Bias against repetition. Animals show a clear bias against repetition of an alternative. In two-choice alternative situations this produces a tendency to alternate choices in the absence of any factor, such as reward for one alternative, that disturbs the natural bias. This phenomenon has been discussed elsewhere by the more general term of action decrement.¹

With five choices available to the organism, it becomes possible to analyse the effects of action decrement beyond the first subsequent choice. In recording his data, Boykin registered the animal as occupying the central compartment only if it paused for a short period - about two seconds. About 36% of the choices were recorded in this central compartment. The general

FIGURE 94

THE EFFECT OF STIMULUS RANGE ON PREFERENCE

Mean times (in seconds) spent in each compartment by the three groups with choices of stimuli in different ranges of complexity.

pattern was for the animal to sit in the central compartment, inspect several stimulus compartments, and then choose one.

To analyse for action decrement, the choice of the central compartment (C) was taken as a base. The first choice from C was then noted. The next time the animal paused in C, his next choice was recorded as being the same or different from the previous choice. This was labeled as a first order tendency to repeat a choice. The next time he paused in C his first subsequent choice was again recorded and labeled as a repetition or a non-repetition in reference to the first choice after the first C. This was a second order repetition probability. This process was continued through the fifth order. The
analysis then moved to the next C and was begun again. If all six choices were the same, the animal would have repeated in all five orders. If the first five were all different, then the probability of repetition on the sixth choice, the fifth order, would be a .2 or the chance level.

Figure 95 shows the repetition probabilities through the 5th order. The probability of repetition in the first order (first chance to repeat) is below chance. Repetition probability in the second, third and fourth orders are above chance. In the fifth order it is again below chance.

Interpretation of these results in terms of the duration of action decrement is beyond the scope of this report. However, in the context of sequential analysis, it is clear that the effects of one choice endures through a considerable sequence of choices.

![Graph showing action decrement to the fifth order](image)

**FIGURE 95**

**ACTION DECREMENT TO THE FIFTH ORDER**

Repetition probabilities to the fifth order calculated from successive choices after leaving the central compartment of the circular maze. First order is for successive choices, second order for choices one choice removed, third order for two choices removed, etc.
Day-night cycle in rats. 1 An effort was made to determine whether preferences for stimuli would be affected by the day-night cycle in rats. Two groups of six animals each were stored in adjacent rooms and placed on a day-night cycle scheduled so that the light was on for one group and off for the other, and switching every 12 hours. Animals were then tested in mid-cycle so that one group was tested in the middle of the day cycle and the other in the middle of the night cycle. Twice during the experiment, independent judgments were made of the activity level of the animals when brought into another lighted room. On one test, the six night animals were all rated as more active than the day animals; and on the other occasion, there was an overlap of one animal in the distributions of ratings.

These animals were tested by placing them in the center of the circular maze and allowing them free access to three of the six compartments. These compartments were lined with checkered stimuli of 4, 25, or 144 elements per 4 in. by 4 in. section. They were exposed to these stimuli for 15 minutes per day for four days. No effect of day-night cycle on preference was noted.

In this study, there were also two days of preliminary exposure with all white stimuli in the compartments. In the six days, two preliminary and four tests, the two groups showed clear differences in the number of choices made as shown in Table 26.

<table>
<thead>
<tr>
<th>TABLE 26</th>
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</thead>
<tbody>
<tr>
<td>DAY-NIGHT CYCLE EFFECT ON NUMBER OF CHOICES</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Group</td>
</tr>
<tr>
<td>Day Tested</td>
</tr>
<tr>
<td>Night Tested</td>
</tr>
</tbody>
</table>

1 This study was done by Ronald Heyduk as a master's level research project, 1968-1969. It will result in a paper tentatively titled Effect of day-night cycle on preference for stimulus complexity in rats.
Frequency versus duration of response as a function of stimulus complexity. ¹ When a set of stimuli are available for choice in the sense that the organism can see them all and choose among them, it is difficult to separate the effects of complexity on the frequency of choice from the effects on duration of choice. The necessity of distinguishing the factors determining the termination of a response from those which govern the next choice has been pointed out elsewhere.²

The action decrement mechanism is clearly a mechanism for terminating a response. Stimulus complexity may be a factor in controlling the duration, with optimal stimulus levels producing the maximum duration, and stimuli either more or less than optimum producing shorter durations.

A test of this possibility was devised by Stephen Sales. He devised a box that consisted of a compartment that was about a foot in each dimension and which was totally dark when the lid was in place. On one side of the box there was a small hole through which a rat was able to stick his head far enough to break a photoelectric cell beam and to permit the animal to see what was in the adjacent compartment.

The adjacent compartment was arranged with a translucent panel positioned about 5 inches from the hole at floor level and slanted slightly toward the animal at the top. This panel was backlit. The photoelectric cell was used to record the behavior of the rat.

The panel was replaceable. Stimulus complexity was varied by constructing 9 such panels. Each consisted of a checkered pattern and they differed in the number of elements, 2, 4, 9, 16, 25, 64, 100, 196, and 256.

Nine groups of 15 rats each (total 135, 108 male and 27 female) were

¹This study was carried out by Stephen Sales and has been published. Sales, S. M. Stimulus complexity as a determinant of approach behavior and inspection time in the hooded rat. Canad. J. Psychol., Rev. Canad. Psychol., 1968, 22, 11-17.

each handled extensively and then introduced individually to the box. Ten seconds after introduction, the light was turned on in the adjacent compartment. Each animal was left in the box for a total of 8 minutes. Each animal was tested only once and with a single stimulus.

The photocell recorded the frequency of response through a counter, and the total duration of responding through a clock that accumulated the total amount of time the animal's head was in a position to break the photobeam.

Figure 96 shows the frequency of responding in the 9 groups thus self-exposed to the nine levels of stimulus complexity. There appears to be no orderly relationship between complexity and frequency. This result might be expected, since the animal could not see the stimulus until he responded.

FIGURE 96
FREQUENCY OF RESPONSE AS A FUNCTION OF STIMULUS COMPLEXITY

Mean responses in eight-minute periods for 9 groups of animals exposed to nine different levels of stimulus complexity.
Figure 97 shows the average duration of the responses, calculated by dividing the total response time by the frequency. Here there is a clear optimum with stimuli around 9 and 16 elements. Thus the complexity of the stimulus affected the duration of the response, with optimum complexity producing the longer responses, and either simpler or more complex stimuli producing responses of lesser durations.

Summary of animal studies of complexity and preference. The major finding of the animal studies of complexity and preference is that animals do tend to show preferences for stimuli of progressively increasing complexity with increased exposure in the choice situation. A correlated finding is that
when the animal could not see the stimulus until he made a response, stimulus complexity increased the duration of the response. This finding is interesting in a context in which it is important to distinguish between factors which affect the termination of a psychological event from those which affect the choice of the next event.

Analysis of sequences of responses permitted the scaling of disparate stimuli and confirmed the fact that the animals were indeed responding to the order of the stimuli along a complexity scale. It also permitted the determination of the effect of one choice through a long series of subsequent choices.

Animals were found to respond to the range of stimuli available as had been found in the human studies, and they were found to make a greater number of choices during the night phase of the day-night cycle.

An attempt to demonstrate the predicted effect of prior exposure to a stimulus on a complexity dimension on subsequent choices yielded clear but inexplicable results.
SECTION V
MAJOR RESULTS OF THE RESEARCH PROGRAM

The research reviewed in this report had two major objectives. (1) It was hoped that it would be possible to develop one or more methods of measuring arousal in an unrestrained animal. (2) If the first objective could be accomplished successfully, it was the plan to collect as much information as possible relating these measurements to arousal theory in as many aspects as possible.

Over the eight years that were supported by the grant, there have been 21 published papers, 56 unpublished papers, 14 completed doctoral dissertations, 9 dissertations in progress, and 2 honors dissertations.

The basic methodological objective was clearly met. The technique of measuring skin resistance in the rat developed by Stephen and Rachel Kaplan obviously measures an arousal-related aspect of the organism's state. The technique of measuring the output frequency of the weak electric fish employed by Dewsbury and Mortenson is likewise a fruitful methodology.

The concept of optimal arousal was not tested directly. There was some evidence from the electric fish that the frequency of output tended to vary around two frequencies, one representing an 'active' state and one representing an 'inactive' state. There is some merit to regarding these states as analogs of sleeping and waking in mammals, and some empirical evidence that the 'arousal' levels tracked in this manner are maintained within narrow limits. No information was obtained concerning the mechanisms operating to maintain the two optimal arousal levels.

If one accepts the correspondence between the dimension of stimulus complexity and arousal, and thus the equivalence of optimal complexity and optimal arousal, then considerable evidence was obtained concerning optimal complexity and arousal along complexity dimensions. Orderly relations were found between judged complexity and preference for visual materials in human
subjects. Depending on the stimulus set, preference might be for the simpler stimuli, for the more complex stimuli, or in one case for stimuli in the middle range. Human subjects who differed in amount of experience with graphic art differed in their judgments. The more experienced subjects judged the range to be more constricted than less experienced subjects, and there was minimal and insignificant evidence of preference for the more complex stimuli with greater experience. In contrast to the nearly inconclusive evidence with human subjects, rats do show a definite progression in preference for more complex stimuli with increased experience with the dimension.

Skin resistance in the rat shows individual differences, changes with age, and genetic differences. Whether any or all of these systematic relationships are differences in arousal remains in some question. In each case it is not certain the extent to which other factors such as weight and the effects of repeated experience can be excluded as alternative explanations.

Neither arousal as indexed by skin resistance in the rat or arousal as indexed by output frequency in the electric fish show any variation with supposed variation in appetitive drives. The output frequency of the fish does not change with increased time of food deprivation. The skin resistance of the rat does not change with time of food and water deprivation or in correspondence to the activity-related phases of the estrus cycle in the female rat. Arousal, as measured, and drive are not related variables.

There is evidence, however, of arousal increases associated with the application of stimuli ranging from moderate ones that induce orientation reactions to strong ones that might induce pain or fear. Rats sometimes respond to stimulus changes with increased arousal, and they respond to shock with profound increases. The electric fish respond to sounds and to objects placed in their tanks with increased arousal (frequency increase), and they also respond to mild shock.

Incentives produce arousal changes. The removal of shock is followed by a decrease in arousal in both the fish and rats. Rats show marked arousal reduction while consuming liquids, either water alone or water containing a sweet or nutritive material. The fish respond to the presence of food by an
arousal increase with a decrease following consumption.

When faced with an approach-approach conflict, there is some evidence that rats show a lower arousal level than when faced with an avoidance-avoidance conflict.

Taking all of the evidence together, it would seem a safe conclusion that arousal, as measured, varies with almost any factor which produces increases or decreases along a dimension ranging from boredom through alertness to a marked emotional state. Thus, with these measures, the arousal dimension and the drive dimension appear to be independent.

In the area of learning and performance, arousal level appears to affect performance (speed) more than accuracy. Otherwise, numerous correlations were found between arousal and aspects of learning. Two general conclusions could be risked on the basis of the evidence. (1) It is possible to condition arousal to a previously neutral stimulus. (2) In spite of this fact, arousal appears to be a product of the stage of learning or extinction rather than a causal factor. This conclusion arises from the fact that the arousal level can be changed in a learning problem by external factors without affecting the skeletal performance, and from the fact that the rate of change in indices of arousal (skin resistance and heart rate) is at least partially disassociated from the rate of change in the more traditional skeletal measures of learning. Thus arousal, as measured by these two physiological indices, appear to reflect the emotional state induced by the stage of learning rather than the motivation for the performance.
APPENDICES

Lists of published and unpublished papers supported by

HD 00904 and K6-MH-21, 868
Appendix A. List of published papers discussed in this report


Appendix B. List of unpublished studies discussed in this report

Boykin, A. W. The effects of level and range of complexity values on visual preferences in rats, 1969.


Dewsbury, D. A. Basal skin resistance level of rats in an avoidance learning situation, 1966.


Heyduk, R. Effect of day-night cycle on preference for stimulus complexity in rats, 1969.


Walker, E. L., and Williams, J. L. BRL during acquisition and extinction of a fixed ratio reinforcement schedule, 1967.


Williams, J. L. BRL conditioning in a conditioned suppression setting, 1968.

Williams, J. L. The goal gradient with shock used before and after maze running as an exaggerated paradigm of handling, 1968.


Appendix C. List of published studies discussed only in the previous report


Appendix D. List of unpublished studies discussed in the previous report

Ehrlich, N. J. Hypnotic control of "cross-over" effects in a recognition task, 1964.


Gadlin, H. Recall as a function of arousal and attention, 1963.


Gadlin, H., and Brown, M. Phonetic and semantic generalization following hypnotically induced arousal, 1964.


Tarte, R. D. The relationship between arousal and reaction times in a complex task, 1962.

Tarte, R. D. On the relationship between arousal and semantic satiation.

Tarte, R. D. On the relationship between arousal and semantic satiation.
   II. Free association of words, 1962.

Tarte, R. D. On the relationship between arousal and semantic satiation.
   III. Forced association of words, 1962.

Tarte, R. D. Conditioned arousal, nonsense syllable paired-associate learning as a function of interpolated interval, 1962.

Tarte, R. D. Memory storage as a function of arousal and time with interference and second training trials, 1964. (Later became a part of dissertation and publication by Walker and Tarte.)


Williams, J. L. BRL as an index of secondary reinforcement.

Williams, J. L., and Brandon, P. Progressive ratio and motivation.
Appendix E. List of supported publications not discussed in either report

Dewsbury, D.A. Changes in stimulus preference as a function of exposure in an extra-test situation. Psychon. Sci.,


Appendix F. List of Completed Doctoral Dissertations


Murofushi, Kiyoko "Experiments on temporary and semi-permanent memory traces." Supported by USPHS grant of Dr. Walker. Degree taken at Kyoto University, Japan. (1962).


Tarte, Robert D. "Effects of time of reactivation, or interference on trace consolidation in verbal learning." (1964).

Dewsbury, Donald Allen "Some correlates of electric organ discharge frequency in three species of electric fish." (1965).


Williams, Jon "The role of response contingency on the effects of punishment: Vol. I. A review of relevant theories and empirical findings; Vol. II. An experimental investigation of the changes in skeletal and autonomic responses" (1968).

Mortenson, F. Joseph "Determinants of the electric discharge rate in Gymnotus carapo, the banded knife fish." (1969).
Appendix G. List of Honors dissertations


Appendix H. List of current doctoral students with estimated time of completion

Arkes, Hal (1971)
Blatt, Ramon (1970)
Boykin, Wade (1972)
Frohman, Susan (1971)
Heyduk, Ronald (1972)
Higgins, Thomas (1970)
Pickett, Warren (1969)
Schell, Donna (1969)
Timberlake, William (1969)