SAFFORD Jr., Robert Reese, 1942-
VISUAL SPARE CAPACITY IN AUTOMOBILE DRIVING
AND ITS SENSITIVITY TO CARBOXYHEMOGLOBIN.

The Ohio State University, Ph.D., 1971
Engineering, industrial

University Microfilms, A XEROX Company, Ann Arbor, Michigan
VISUAL SPARE CAPACITY IN AUTOMOBILE DRIVING
AND ITS SENSITIVITY TO CARBOXYHEMOGLOBIN

DISSERTATION

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

By

Robert Reese Safford Jr. B.I.E., M.S.

The Ohio State University

Approved by

[Signature]
Adviser

Department of Industrial Engineering
PLEASE NOTE:

Some pages have indistinct print. Filmed as received.

University Microfilms, A Xerox Education Company
ACKNOWLEDGEMENTS

The research that has been reported here was designed to furnish information basic to understanding of the ability of the human operator to obtain the information necessary to operate a motor vehicle on the highway under various types of driving situations and under the influence of a degradant (Carbon Monoxide). This dissertation presents the development and results of a series of studies in which several subjects were studied while actually driving an automobile in order to determine if their spare visual capacity could be determined.

It is believed that this study, in which over 2,640 miles and over 148 hours of actual highway experimentation were logged, is one of the most extensive studies of its type yet conducted under actual highway conditions. A study of this magnitude is certainly not the work of just one person, and I would like at this time to thank a few of the people who helped make this study possible.

This research was conducted as part of a larger research project being conducted at The Ohio State University by the Department of Preventive Medicine of the College of Medicine and the Department of Industrial
Engineering of the College of Engineering. The research project of which this dissertation is a portion was sponsored by the Coordinating Research Council (Ohio State University Research Foundation project RF 314). The work presented in this dissertation was conducted by the Systems Research Group of the Department of Industrial Engineering but would not have been possible without the help and complete cooperation of the Environmental Health and Safety Group of the Department of Preventive Medicine.

As co-principal investigator on this research project, Dr. Thomas H. Rockwell provided the guidance which enabled the study to be conducted, and as my advisor, Dr. Rockwell furnished the aid and constructive criticism which has enabled the results to be presented in this form. The advice of Drs. Neuhardt, Smith, Weir, and Ernst was also appreciated.

A word of thanks is also deserved by many persons in the Systems Research Group who helped in various portions of this research. A partial list of these persons includes: Lois Graber, Irene Savage, Nan Still, Sharon Mays, Dennis Attwood, Gene Rackoff, Joan Case, Gail Lewis, Terri Case, and Connie Engle. Special thanks are also due to Robert Sousek whose help in almost every phase of the research was invaluable.

I would also like to thank the many persons whom
I had the pleasure to meet and work with from the Department of Preventive Medicine, especially Dr. Frank Weir, Ed Whitehead, Mukul Mehta, Doug Lofland, Marshall Bell, and Mrs. Leanord.

Thanks also to Mrs. Marianne Stockwell for the fine job done in typing the final copy of this dissertation.

And finally, a special word of thanks must also go to my wife, Marian, whose help and encouragement helped to make all of this possible.
VITA

February 19, 1942. . . . Born: Columbus, Ohio - U.S.A.

1961-1966. . . . . . . . Research Assistant, Systems Research Group, The Ohio State University, Columbus, Ohio

1964 . . . . . . . . . . B.I.E. (Bachelor of Industrial Engineering) The Ohio State University, Columbus, Ohio

1965 . . . . . . . . . . M.S.I.E. (Industrial Engineering) The Ohio State University, Columbus, Ohio

1966-Present . . . . . . Research Associate, Systems Research Group, The Ohio State University, Columbus, Ohio

MAJOR INTEREST


PUBLICATIONS


FIELDS OF STUDY

Major Field: Industrial Engineering

Studies in Human Factors Engineering: Professor Thomas H. Rockwell.


Studies in Operations Research: Professor Walter C. Giffin
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>VITA</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xv</td>
</tr>
</tbody>
</table>

CHAPTERS

1. INTRODUCTION AND SUMMARY OF EXPERIMENTS AND RESULTS                  | 1    |
| Introduction                                                          |      |
| Research Aims                                                         |      |
| Experiments                                                           |      |
| Conclusions Summary                                                  |      |
| Organization of Dissertation                                         |      |

2. DISCUSSION OF PROBLEM AND LITERATURE REVIEW                         | 12   |
| Discussion of Problem                                                 | 13   |
| Introduction                                                          |      |
| Role of Vision In Driving                                            |      |
| Proposed Conceptualization                                           |      |
| Usefulness of Proposed Conceptualization                             |      |
| in Highway Research                                                  |      |
| Past Experimentation Dealing With Vision and Driving                 | 20   |
| Introduction                                                          |      |
| Types of Eye Movement and Driving Performance Measures Most Likely to be Sensitive to Independent Variables in Driving Research |      |
| Hypothesized Effect of Stressors and Low Level Degradants on Eye-Movement In Driving |      |
| Visual Capabilities and Other Considerations                         | 27   |
| Introduction                                                          |      |
| Visual Channel Capacity                                              |      |
TABLE OF CONTENTS (Cont'd)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Channel Theory Versus Multiple Channel Theory</td>
<td></td>
</tr>
<tr>
<td>Deterioration of Visual Information</td>
<td></td>
</tr>
<tr>
<td>Caused by Simultaneous Inputs On Another Modality</td>
<td></td>
</tr>
<tr>
<td>Locus of Inference</td>
<td></td>
</tr>
<tr>
<td>3. SPARE CAPACITY, SPARE VISUAL CAPACITY AND RELATED RESEARCH..........</td>
<td>39</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Systems Research Group Pilot Study</td>
<td></td>
</tr>
<tr>
<td>Spare Capacity and Increased Task Difficulty</td>
<td></td>
</tr>
<tr>
<td>Measurement of Spare Capacity</td>
<td></td>
</tr>
<tr>
<td>Secondary Tasks and Driving</td>
<td></td>
</tr>
<tr>
<td>Measurement of Spare Visual Capacity</td>
<td></td>
</tr>
<tr>
<td>Via Visual Occlusion</td>
<td></td>
</tr>
<tr>
<td>Systems Research Group Pilot Experiment to Determine the Effects of</td>
<td></td>
</tr>
<tr>
<td>Learning in Visual Occlusion Studies</td>
<td></td>
</tr>
<tr>
<td>Experiment to Determine the Effect of Vehicle Speed on Visual Occlusion</td>
<td></td>
</tr>
<tr>
<td>Behavior (Voluntary)</td>
<td></td>
</tr>
<tr>
<td>4. MAJOR STUDY DESIGNED TO DETERMINE USEFULNESS OF VISUAL OCCLUSIONS TO</td>
<td>71</td>
</tr>
<tr>
<td>MEASURE SPARE VISUAL CAPACITY AND TO DETERMINE THE EFFECTS OF DEGRADANT ON THE SPARE CAPACITY</td>
<td></td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Independent Variables</td>
<td></td>
</tr>
<tr>
<td>Dependent Variables</td>
<td></td>
</tr>
<tr>
<td>Subjects</td>
<td></td>
</tr>
<tr>
<td>Results of the Main Series of Tests</td>
<td></td>
</tr>
<tr>
<td>Results Summary</td>
<td></td>
</tr>
<tr>
<td>5. ANALYSES OF BASELINE DATA</td>
<td>143</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
</tr>
<tr>
<td>Summary of Results</td>
<td></td>
</tr>
<tr>
<td>6. DETERMINATION OF EYE MOVEMENT FIXATION DISTRIBUTION CHARACTERISTICS</td>
<td>155</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Tests for Normality</td>
<td></td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (Cont'd)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Distributions</td>
<td></td>
</tr>
<tr>
<td>Effect of Eliminating Spare Visual Capacity</td>
<td></td>
</tr>
<tr>
<td>7. RELATIONSHIP OF LABORATORY TESTS TO MEASURES OF SPARE VISUAL CAPACITY</td>
<td>166</td>
</tr>
<tr>
<td>Relationship of Information Processing Ability (Channel Capacity) To Measures of Spare Visual Capacity</td>
<td>167</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Choice Reaction Time and Channel Capacity</td>
<td></td>
</tr>
<tr>
<td>Choice Reaction Time Task</td>
<td></td>
</tr>
<tr>
<td>Determination of Channel Capacity</td>
<td></td>
</tr>
<tr>
<td>Relation of Channel Capacity to Spare Visual Capacity</td>
<td></td>
</tr>
<tr>
<td>Discussion of Results.</td>
<td></td>
</tr>
<tr>
<td>Relationship of Time Estimation Ability To Spare Visual Capacity</td>
<td>178</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Time Estimation Experiment</td>
<td></td>
</tr>
<tr>
<td>8. EXPERIMENT TO DETERMINE USEFULNESS OF CLASSICAL TYPES OF LOADING TO MEASURE SPARE CAPACITY</td>
<td>185</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Independent Variables</td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
</tr>
<tr>
<td>Control Actuation Analysis</td>
<td></td>
</tr>
<tr>
<td>Velocity Analyses</td>
<td></td>
</tr>
<tr>
<td>Headway Analysis</td>
<td></td>
</tr>
<tr>
<td>Summary of Results</td>
<td></td>
</tr>
<tr>
<td>9. DISCUSSION OF RESULTS, CONCLUSIONS AND SUGGESTION FOR FUTURE RESEARCH</td>
<td>208</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Experiments</td>
<td></td>
</tr>
<tr>
<td>Research Results</td>
<td></td>
</tr>
<tr>
<td>Revision of Model of Spare Capacity</td>
<td></td>
</tr>
<tr>
<td>Effect of The Degradant on Risk Assumption</td>
<td></td>
</tr>
<tr>
<td>Comments on Results</td>
<td></td>
</tr>
<tr>
<td>Conclusions Summary and Suggestions</td>
<td></td>
</tr>
<tr>
<td>For Future Research</td>
<td></td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (Cont'd)

APPENDIX

<table>
<thead>
<tr>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Description of Research Equipment</td>
<td>230</td>
</tr>
<tr>
<td>B. Description of Data Reduction Techniques and Analyses Programs</td>
<td>239</td>
</tr>
<tr>
<td>C. Annotated Bibliography of References Related to Research To Determine</td>
<td>244</td>
</tr>
<tr>
<td>The Spare Visual Capacity of Automobile Drivers</td>
<td></td>
</tr>
<tr>
<td>D. Carbon Monoxide and Gassing Techniques Used In Highway Research Program</td>
<td>273</td>
</tr>
<tr>
<td>E. Annotated Data Tables and Figures</td>
<td>286</td>
</tr>
<tr>
<td>F. Information Theory</td>
<td>296</td>
</tr>
<tr>
<td>G. Analysis of Variance</td>
<td>300</td>
</tr>
</tbody>
</table>
BIBLIOGRAPHY                                                                | 306  |
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Data Summary of Pilot Study.</td>
<td>60</td>
</tr>
<tr>
<td>2.</td>
<td>ANOVA #1 (Occlusion Periods)</td>
<td>62</td>
</tr>
<tr>
<td>3.</td>
<td>ANOVA #2 (Open Periods).</td>
<td>63</td>
</tr>
<tr>
<td>4.</td>
<td>ANOVA #3 (Screened Open Periods)</td>
<td>64</td>
</tr>
<tr>
<td>5.</td>
<td>ANOVA #4 (Three Factor Analysis of Variance)</td>
<td>65</td>
</tr>
<tr>
<td>6.</td>
<td>Spare Capacity As A Function of Percent of Time That Subjects Kept Their Eyes Closed (Voluntarily Occluded Their Vision)</td>
<td>84</td>
</tr>
<tr>
<td>7.</td>
<td>Spare Capacity As A Function of The Percent Of Time That Subject Drivers Were Able To Close Their Eyes (Oclude Their Vision While Driving)</td>
<td>85</td>
</tr>
<tr>
<td>8.</td>
<td>Eye Movement Analysis Categories</td>
<td>89</td>
</tr>
<tr>
<td>9.</td>
<td>Mean Duration of &quot;Interlook Intervals&quot; Between Looks At Lead Car (Seconds).</td>
<td>91</td>
</tr>
<tr>
<td>10.</td>
<td>Mean Duration of &quot;Looks&quot; At Lead Car (Seconds).</td>
<td>92</td>
</tr>
<tr>
<td>11.</td>
<td>Mean Duration of &quot;Interlook Interval&quot; (Mean Duration of Occlusion Times) For Trials Involving Visual Occlusion (Time in Seconds)</td>
<td>94</td>
</tr>
<tr>
<td>12.</td>
<td>Variance of Duration of &quot;Interlook Interval&quot; (Variance of Duration of Occlusion Times) For Trials Involving Visual Occlusion.</td>
<td>95</td>
</tr>
<tr>
<td>13.</td>
<td>Mean of &quot;Open Duration&quot; (Seconds).</td>
<td>96</td>
</tr>
<tr>
<td>14.</td>
<td>Percentage of Time That The Mean Duration Time For &quot;Looks:&quot; At Different Objects Or Areas Greater Under CO Than Under Air.</td>
<td>99</td>
</tr>
<tr>
<td>Table</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>15.</td>
<td>Percentage of Time That The Variance of Duration Times of &quot;Looks&quot; At Different Objects and Areas Was Greater Under CO Than Under Air.</td>
<td>101</td>
</tr>
<tr>
<td>16.</td>
<td>Horizontal Range of Eye Fixations (In Degrees of Visual Angle)</td>
<td>108</td>
</tr>
<tr>
<td>17.</td>
<td>Vertical Range of Eye Fixations (In Degrees of Visual Angle)</td>
<td>108</td>
</tr>
<tr>
<td>18.</td>
<td>Number of Looks at The Lead Car.</td>
<td>111</td>
</tr>
<tr>
<td>19.</td>
<td>Number of Looks At Categories Other Than Lead Car</td>
<td>113</td>
</tr>
<tr>
<td>20.</td>
<td>Blink Rate Analysis (Rate = Average Per 3 Minute Period)</td>
<td>116</td>
</tr>
<tr>
<td>21.</td>
<td>Number of Occlusions</td>
<td>120</td>
</tr>
<tr>
<td>22.</td>
<td>Mean Duration of Occlusions</td>
<td>120</td>
</tr>
<tr>
<td>23.</td>
<td>% of Time In Occlusions</td>
<td>120</td>
</tr>
<tr>
<td>24.</td>
<td>Gas Pedal Reversals Summary</td>
<td>122</td>
</tr>
<tr>
<td>25.</td>
<td>Gas Pedal Reversals Summary For All Subjects Combined</td>
<td>123</td>
</tr>
<tr>
<td>26.</td>
<td>&quot;Gas Pedal Off&quot; Summary (Average Values Per 3 Minute Period)</td>
<td>126</td>
</tr>
<tr>
<td>27.</td>
<td>&quot;Brake Pedal On&quot; Summary (Average Values Per 3 Minute Period)</td>
<td>126</td>
</tr>
<tr>
<td>28.</td>
<td>Velocity Means</td>
<td>129</td>
</tr>
<tr>
<td>29.</td>
<td>Velocity Variances</td>
<td>130</td>
</tr>
<tr>
<td>30.</td>
<td>Velocity Means (Miles Per Hour)</td>
<td>133</td>
</tr>
<tr>
<td>31.</td>
<td>Velocity Variances (Miles Per Hour)</td>
<td>133</td>
</tr>
<tr>
<td>32.</td>
<td>Dependent Variable Correlation Matrix (Correlations Above Diagonal Are For &quot;Magnitudes&quot; of The Variables, Correlations Below The Diagonal Are For Magnitude of The Air Vs. CO Differences)</td>
<td>136</td>
</tr>
<tr>
<td>Table</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>33.</td>
<td>Summary of Results of Analyses Showing Significant Differences</td>
<td>140</td>
</tr>
<tr>
<td>34.</td>
<td>Blink Rate Per 3 Minute Period Obtained From Subject K During Baseline Data Collection and &quot;Air&quot; Rons</td>
<td>147</td>
</tr>
<tr>
<td>35.</td>
<td>Analysis of Gross Head Movements</td>
<td>150</td>
</tr>
<tr>
<td>36.</td>
<td>Number of Times Speedometer and Mirror Looked At In Baseline Series 1 Tests and Baseline Series 2 Tests</td>
<td>152</td>
</tr>
<tr>
<td>37.</td>
<td>Time Interval Production Mean</td>
<td>181</td>
</tr>
<tr>
<td>38.</td>
<td>Time Interval Production Variance</td>
<td>182</td>
</tr>
<tr>
<td>39.</td>
<td>Time Estimation Performance Measures</td>
<td>183</td>
</tr>
<tr>
<td>40.</td>
<td>Responses/Unit Time</td>
<td>197</td>
</tr>
<tr>
<td>41.</td>
<td>Percent Correct Responses</td>
<td>197</td>
</tr>
<tr>
<td>42.</td>
<td>Performance On Secondary Tasks</td>
<td>199</td>
</tr>
<tr>
<td>43.</td>
<td>Gas Pedal Analysis</td>
<td>200</td>
</tr>
<tr>
<td>44.</td>
<td>Brake Pedal Analysis</td>
<td>202</td>
</tr>
<tr>
<td>45.</td>
<td>Velocity Analysis</td>
<td>203</td>
</tr>
<tr>
<td>46.</td>
<td>Headway Analysis</td>
<td>205</td>
</tr>
<tr>
<td>47.</td>
<td>Mean Look Durations (Seconds)</td>
<td>221</td>
</tr>
<tr>
<td>48.</td>
<td>Speedometer Usage Observed For Subjects Participating in Main Experiment</td>
<td>288</td>
</tr>
<tr>
<td>49.</td>
<td>Rear Mirror Usage Observed For Subjects Participating In Main Experiment</td>
<td>289</td>
</tr>
<tr>
<td>50.</td>
<td>&quot;Gas Pedal Off&quot; - &quot;Brake Pedal On&quot; Summary</td>
<td>290</td>
</tr>
<tr>
<td>51.</td>
<td>&quot;Gas Pedal Off&quot; - &quot;Brake Pedal On&quot; Mean Summary</td>
<td>291</td>
</tr>
<tr>
<td>Table</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>52. Headway Means Observed For Subjects Participating In &quot;Main&quot; Experiment</td>
<td>292</td>
<td></td>
</tr>
<tr>
<td>53. Headway Variances Observed For Subjects Participating In &quot;Main Experiment&quot;</td>
<td>293</td>
<td></td>
</tr>
<tr>
<td>54. E.M.S. Table For Analysis of Variance</td>
<td>303</td>
<td></td>
</tr>
<tr>
<td>55. Analysis of Variance (For Data From Table) of Data Pertaining To The Number of Times Lead Car Was Looked At In Occlusion Trials</td>
<td>305</td>
<td></td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Schematic of Man-Machine System (Adapted from Birmingham and Taylor (1954))</td>
<td>14</td>
</tr>
<tr>
<td>2.</td>
<td>Effect of Loading on Performance of a Visual Task</td>
<td>16</td>
</tr>
<tr>
<td>3.</td>
<td>Hypothesized Hierarchy of Visual Behavior</td>
<td>18</td>
</tr>
<tr>
<td>4.</td>
<td>A Schematic Diagram of The Role of Vision in The Driving Task</td>
<td>28</td>
</tr>
<tr>
<td>5.</td>
<td>Sample Data From &quot;Learning&quot; Pilot Study</td>
<td>61</td>
</tr>
<tr>
<td>6.</td>
<td>Matrix of Independent Variables Considered In Main Experiment</td>
<td>74</td>
</tr>
<tr>
<td>7.</td>
<td>Perturbated Lead Car Velocity Profile Employed In Main Experiment</td>
<td>78</td>
</tr>
<tr>
<td>8.</td>
<td>Fixation Location Analysis For Subject K</td>
<td>104</td>
</tr>
<tr>
<td>9.</td>
<td>Fixation Location Analysis For Subject D</td>
<td>105</td>
</tr>
<tr>
<td>10.</td>
<td>Schematic of Diagram Used In &quot;Fixation Density&quot; Analyses</td>
<td>110</td>
</tr>
<tr>
<td>11.</td>
<td>Possible Shapes of The Weibull Distribution</td>
<td>160</td>
</tr>
<tr>
<td>12.</td>
<td>Cumulative Distribution of &quot;Looks&quot; Durations</td>
<td>163</td>
</tr>
<tr>
<td>13.</td>
<td>Information Vs. Reaction Time</td>
<td>174</td>
</tr>
<tr>
<td>14.</td>
<td>Matrix of Independent Variables</td>
<td>188</td>
</tr>
<tr>
<td>15.</td>
<td>Perturbated Lead Car Velocity Profile Employed In Experiments Involving Cognitive Loading</td>
<td>192</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>16.</td>
<td>Schematic Diagram of Drivers Visual Search and Scan and Spare Capacity Behavior</td>
<td>217</td>
</tr>
<tr>
<td>17.</td>
<td>Risk and Spare Capacity.</td>
<td>219</td>
</tr>
<tr>
<td>18.</td>
<td>Spare Capacity Versus Change In Open Time Due to CO.</td>
<td>224</td>
</tr>
<tr>
<td>19.</td>
<td>Spare Capacity Versus Change In Occlusion Times Due to CO.</td>
<td>225</td>
</tr>
<tr>
<td>20.</td>
<td>Chrysler T.V. Eye Movement System.</td>
<td>238</td>
</tr>
<tr>
<td>21.</td>
<td>Schematic of Elements of Data Collection System</td>
<td>241</td>
</tr>
<tr>
<td>22.</td>
<td>Subject COHb Levels.</td>
<td>284</td>
</tr>
<tr>
<td>23.</td>
<td>Sample Histograms of Look Durations - Subject K.</td>
<td>294</td>
</tr>
<tr>
<td>24.</td>
<td>Chi Square Goodness of Fit Test Employed In Chapter 6</td>
<td>295</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION AND SUMMARY OF EXPERIMENTS
AND RESULTS
CHAPTER 1

Introduction

It is generally accepted that vision is the most important input in driving. While information necessary for a driver may come from cues other than visual, and while auditory cues may indicate the presence and approximate location of stimuli of interest to a driver, vision is still necessary in order for a driver to orient his vehicle and operate satisfactorily on the highway.

A conceptualization of the driver's visual behavior is presented which suggests that a portion of his visual behavior in terms of visual sampling (e.g., viewing scenery, etc.) is not essential to the immediate control task and could be deleted without seriously affecting the "error-free" performance of the overall system. This is analogous to asserting that there exists a "spare capacity" in terms of visual sampling which the driver has available to him if the driving situation demands it.

Research Aims

Two major aims were associated with the research reported here. These included:

1. The determination of the spare visual capacity
of automobile drivers for selected driving situations, and

2. The determination of the effect of the degradant, carbon monoxide, on that spare capacity.

These research aims can also be expressed as the two major hypotheses investigated in this research. These hypotheses are presented below:

1. It is hypothesized that there exists a "spare capacity" in the automobile drivers' visual sampling ability which can be determined by empirical investigation for selected driving situations, and

2. It is further hypothesized that the presence of the degradant carbon monoxide in a sufficient quantity to produce 20% carboxyhemoglobin will reduce the spare capacity.

In addition to these two main hypotheses, it was also hypothesized that elevated carboxyhemoglobin levels would produce changes in the visual sampling behavior and the vehicular control behavior exhibited by the subject drivers.

Experiments

Toward these aims and hypotheses two series of experiments were designed. The first series of experiments incorporated a visual loading task (voluntary visual
occlusions) which required the driver to close his eyes whenever possible and to keep them closed for as long as possible. A complete list of the independent variables which were included in this study is presented below:

Independent Variables

A. Task Loading
   1. Open road driving at fifty miles per hour
   2. Car-following with the lead car maintaining a constant velocity of fifty miles per hour
   3. Car following with the lead car exhibiting a variable velocity profile with an average speed of fifty miles per hour

B. Visual Loading
   1. Normal or control—no additional task required
   2. Loading—imposed by requirement to engage in voluntary visual occlusion task

C. Degradant Level
   1. Normal or control—no degradant
   2. The degradant—carbon monoxide (CO) in a quantity sufficient to produce 20% carboxyhemoglobin (COHb).

Dependent variables of interest included:

1. Spare visual capacity as measured by the amount of time a driver was able to keep his eyes
closed during a task

2. Eye movement search and scan patterns
3. Vehicle velocity
4. Gas pedal position
5. Brake pedal activation, and
6. Headway between the subject's vehicle and lead vehicle.

Six subjects participated in this experiment. In addition one subject participated in several "baseline" replications of the test to enable determination of differences between day and night and to enable determination of any experimental artifacts due to experimental procedures.

A second series of experiment was designed which was very similar in nature to the first series of experiments with the exception that a cognitive loading task was utilized instead of a task requiring voluntary visual occlusions. One of the subjects who participated in the first series of experiments also participated in the second series of tests thus enabling a comparison of the two types of loading.

In addition to these experiments, conducted on the highway in instrumented vehicles in actual traffic, two types of laboratory tests were also conducted (choice reaction time tests and time estimation tests). These measures were related to the measure of the subjects spare visual capacity.
Research Results

The major results of these experiments are presented below:

1. The measure of visual spare capacity (i.e., the percentage of time that a driver was able to keep his eyes closed) was found to be sensitive to carbon monoxide and task difficulty. Both tended to cause decreases in the spare capacity.

2. Carbon monoxide tended to cause an increase in the "mean eye open" time in occlusion tasks.

3. Carbon monoxide tended to increase the mean "look" duration (i.e., the length of time the driver looked at an object or area in his field of view) for automobile drivers.

4. Variance of "look" times also tended to increase with CO.

5. Carbon monoxide tended to cause a lateral shift in visual fixation location (to the right lane marker or left center marker).

6. Carbon monoxide tended to cause an increase in the frequency of visual fixations on the lead car in car following which at the same time it caused a decrease in the frequency of fixations on objects or areas other than the lead car.
7. Blink rates which were measured in the experiments were found to reflect the stress associated with CO poisoning and task loading.

8. With respect to vehicular control, carbon monoxide tended to increase the velocity mean exhibited by the subject in situations where it was possible for the subject to elect his own velocity. This effect was particularly apparent when the subjects spare capacity was eliminated.

9. Carbon monoxide increased the velocity variance of the subjects vehicle in situations involving elected velocity.

10. Control actuation was also found to be sensitive to independent variables of interest. With respect to gas pedal reversals, task difficulty tended to increase the number of observed reversals while elevated carboxy-hemoglobin levels and the elimination of spare capacity resulted in a reduction in the number of gas pedal reversals.

11. Attempts to eliminate spare capacity via cognitive tasks yielded some results similar to that when capacity was eliminated via visual occlusion. These effects were not as apparent, however.
12. Attempts were made to relate laboratory measures to performance measures obtained on the roadway. It was found that information processing channel capacity as measured on a choice reaction time task was negatively correlated to spare visual capacity as measured by the percentage of time that a driver voluntarily occluded his vision. On the other hand, visual spare capacity was positively correlated with "zero-bit" simple reaction time.

14. Time estimation ability was also found to be negatively correlated with a driver's spare visual capacity.

Determination of Eye Fixation Time Distributions

In addition to the experiment and the analyses presented above, several investigations were made in order to obtain insights into the nature of the characteristics of eye fixation time distributions. In general it was found that the assumption of normality was not valid. The data suggested that a Weibull distribution or in some cases a negative exponential might be capable of fitting the data.
Conclusions Summary

With respect to some measures of performance, driving is essentially an "error-free" task. In terms of total system performance, complete failures, accidents or near accidents (e.g., running off the road or violently disrupting flow) seldom occur. A degradant such as CO does not usually manifest itself by a noticeable increase in such complete failures because the driver has a sufficient amount of spare capacity to compensate for his degraded performance. Rather, the effect of the degradant is to cause a reduction in the amount of spare capacity available for coping with other degradants or with unusual occurrences.

This research has demonstrated a method for determining the spare visual capability associated with certain types of driving and has demonstrated that a degradant such as CO detracts from the amount of spare capacity, while at the same time it begins to have an effect on the control behavior exhibited by the driver in achieving his "error-free" performance.

The laboratory tasks which indicate that information processing channel capacity correlates negatively with visual spare capacity suggest that a person's spare capacity might be capable of being predicted from laboratory tests and that spare capacity as measured by
voluntary visual occlusions might ultimately be related to measures of "total system" performance such as accident records.

Organization of Dissertation

This dissertation is arranged into four major segments composed of one or more chapters. To aid the reader a brief outline of the manner in which the material is organized is presented below:

1. Section 1: The first section is composed of chapters 2 and 3 and contains a discussion of the problem, literature reviews dealing primarily with vision and driving, visual spare capacity, and secondary tasks and driving. Past Systems Research Groups studies of vision and driving are summarized and two pilot studies conducted for and prior to the research reported here are presented.

2. Section 2: This section composed of Chapter 4 contains a description of the major study conducted for this dissertation. The results of that study are also presented in that chapter.

3. Section 3: This section composed of chapters 5, 6, 7, and 8 details some supplemental studies and analyses performed in addition
to the research described in Chapter 4. These supplemental studies and analyses included:

a. Chapter 5: An analyses of "baseline" data to determine the effects of experimental equipment and procedures on performance measures

b. Chapter 6: A determination of eye movement fixation distribution characteristics

c. Chapter 7: A determination of the relationship of laboratory tests to the measure of spare visual capacity.

d. Chapter 8: An investigation of the usefulness of classical types of loading for measuring spare capacity

4. Section 4: This section composed of Chapter 9 presents a discussion and summary of the results of the main experiment and of the supplemental studies and analyses.

In addition to these major segments of the report, several appendices are included containing additional material relevant to some portion of the research.
CHAPTER 2

DISCUSSION OF PROBLEM

AND

LITERATURE REVIEW
CHAPTER 2

DISCUSSION OF PROBLEM

Introduction

A simple schematic of a "man-machine system" (see Figure 1) depicts man as an element that continually monitors the "machine" and that continually furnishes inputs to the machine. Many complex models have been developed to describe the behavior of men and machines and their interaction, but all these models share the basic elements depicted in the schematic of Figure 1. Common, therefore, to these models and also to the actual "man-machine" systems is the interface between the two major elements of the system, namely, the man and the machine. This interface itself can be separated into two distinct parts. First, the interface between the "display" of the machine and the "sensor" of the man can be identified, and then, secondly, an interface between the "effector" of the man and the "control" of the machine can be separated out. The research that is being reported here deals primarily with phenomena observed in the former (i.e., the "display-sensor" interface) in automobile driving situations, and with the
associated behavior in the "effector-control" interface which is directly related to behavior observed in the display-sensor interface.

![Diagram of Man-Machine Interface](image)

FIGURE 1. --SCHEMATIC OF MAN-MACHINE SYSTEM (ADAPTED FROM BIRMINGHAM AND TAYLOR (1954))

Role of Vision In Driving

As Birmingham and Taylor (1958) point out, several of the human senses are capable of serving either singularly or jointly as the sensor in the "display-sensor" interface. In fact, however, vision and hearing are the ones utilized most often and of these two inputs, vision is the one employed most frequently. As Birmingham and Taylor also point out, "this is principally the result of the fact that only the sense of sight permits both the direct and accurate apprehension of geometrical space as it extends outward beyond the confines of the body."

Vision is also generally considered to be the most
important input in driving. While information about aspects of a driver's vehicle behavior may come from cues other than visual, and while auditory cues may indicate the presence and approximate location of stimuli interest to a driver, vision is still necessary in order for a driver to orient and operate satisfactorily on the highway.

Hartman (1970) asserts that man can assimilate 200 times more information per period of time via his visual system than via the next most important sensory input system (i.e., the auditory system). Hartman also maintains that the motorist assimilates more than 90% of the information that he needs when driving in traffic via the visual system.

Versace (1970) comments on the state of the art of research on several aspects of vision relative to driving. He also maintains that human performance on visual tasks in driving depends upon the degree of perceptual loading to which the driver is subjected. The effect of loading is illustrated in the diagram of Figure 2. As can be seen, loading can be used to distinguish differences in various visual tasks.

If the above arguments concerning the importance of vision are accepted, then it would seem logical to assert that vision must be considered in any research on aspects of driving. This consideration could be
manifested by direct measurement of the visual behavior or by measurement of behavior dependent upon the acquisition of visual information.

One approach to measuring behavior dependent upon vision would be to look at the "gross" measure of automobile accidents which might be related to visual failures or visual deficiencies. However, as Allen (1970) points out, "Analyses of accidents to determine the role played by measurable aspects of vision, such as visual acuity, color vision, and dark adaptation, have been disappointing. Allen further suggests that it is not necessarily a person's visual abilities, as such, that determines how he drives or his accident record but rather how he uses his vision to obtain information.
Proposed Conceptualization

Visual inputs to a driver are varied and complex. Visual behavior, likewise, is varied and complex. Any attempt to simply and adequately describe visual behavior is destined, at best, to meet with only partial success. One possible conceptualization of the visual behavior exhibit by the driver is given in the diagram of Figure 3, which attempts to establish a hierarchy of visual behavior. This hypothesized hierarchy suggests that in many driving situations (e.g., open road) the largest amount of observable visual behavior is devoted to obtaining information about stimuli not "essential" to the "immediate driving task of controlling the vehicle." This category would include license plate reading, staring at the hood ornament and fixations in which purely redundant information is obtained. The next higher and next most frequent type of visual behavior would be that devoted to obtaining information necessary for satisfactory performance in driving tasks such as lane position, maintenance and curve negotiation. The next higher type of visual behavior is exemplified in the sampling done by the driver in monitoring fixed obstacles such as poles, bridge abutments and moving obstacles such as lead or following vehicles. The highest level of visual behavior in this figure is that which the driver exhibits when he samples the environment for
"low probability" events such as a car approaching from the wrong way in his own lane.

FIGURE 3. --HYPOTHEZIZED HIERARCHY OF VISUAL BEHAVIOR

As was mentioned before, any attempt to completely and simply describe visual behavior is likely to be inadequate. The above conceptualization is presented, not in order to describe the entire area of visual information acquisition, but rather to point out that there are several types of visual behavior of varying degrees of importance that must be considered when vision is studied in relation to driving. That the hypothesized levels of visual behavior overlap due to the ability of the driver to obtain information via his peripheral vision is obvious. A driver, for example, might be engaged in viewing scenery and still be capable of monitoring for the occurrence of a low probability event of possible consequences to his driving performance. It is not reasonable to suppose, either, that the levels of visual behavior are non-varying. Driver differences
would be expected possibly due to differences in psycho-
physical capabilities. Differences within drivers could
result from the presence of degradants such as low levels
of alcohol or carbon monoxide. Differences in driver
visual behavior would also be expected with changes in
the visual environment of the driver. For example,
"nonessential" behavior such as viewing scenery can be
expected to decrease when no scenery is available to be
read.

Usefulness of Proposed Conceptualization in
Highway Research

The conceptualization just presented can be very
useful in formulating hypotheses to be tested in highway
research experiments. It does, for example, suggest that,
if the conceptualization is accurate, then a portion
of the drivers visual behavior in terms of visual
sampling (i.e., his sampling for the "non-essential"
items) could be deleted without seriously affecting the
systems performance. This appears analogous to asserting
that there exists a "spare capacity" in terms of visual
sampling, which the driver has available to him if the
driving situation demands.

The major theme of the research presented in
this report which is related to the hypotheses stated
earlier is the "Determination of the Spare Visual Capa-

city of Automobile Drivers in Selected Driving Situations and the Determination of the Effects of a Degradant on the Spare Capacity."

PAST EXPERIMENTATION DEALING WITH VISION AND DRIVING

Introduction

Much of the knowledge that we have about human vision has emanated from the work of those interested primarily in correcting or compensating for visual defects. Knowledge about the function of the normal or "corrected normal" eye is scarce by comparison. This lack of available information concerning driver visual behavior is partially due to the fact that very little equipment and few techniques have yet been developed to measure in an objective manner the visual behavior of persons in other than fixed laboratory systems. One exception to this is the "eye-movement camera" equipment developed by the Systems Research Group and described by Whalen, Rockwell, and Mourant (1968). The device described by these authors enables the accurate determination of the eye-movement behavior of automobile drivers and, consequently, information about the driver's visual sampling behavior to be determined. This eye-movement equipment is quite flexible and is capable of
being used in many types of driving situations. Several studies have already been conducted using this eye-movement apparatus. Some of these studies are commented on below. The major results of these studies are presented and an analysis of what these studies suggest concerning research into the determination of a driver's visual spare capacity and the effect of a degradant (COHb) on that spare capacity is also presented.

Whalen studied the eye-movement behavior of drivers operating an instrumented vehicle under conditions of open-road driving at two velocity levels, car following at two headway levels, passing situations and normal freeway traffic. Significant differences were found between conditions when spatial analyses were performed on the data (analyses of location of eye fixations) and also when temporal analyses were performed (analyses of eye fixation durations).

Zell (1969), using the aforementioned apparatus, studied driver eye movements as a function of driving experience. His results indicated:

1. Driver's spatial eye-movement patterns changed substantially as a function of experience, but that spatial differences between new and experienced drivers could be detected even after the new drivers had several months experience.
2. Differences in temporal aspects of eye movements between novice and experienced drivers were not apparent.

3. Experienced drivers tended to adjust their eye-movement patterns to driving conditions more than novice drivers did (i.e., experienced drivers tended to seek information at different distances in front of their vehicles at different speeds. Novice drivers tended to use a fixed forward reference regardless of speed.

4. Eye-movement patterns of new and experienced drivers were not noticeably different in car-following situations suggesting that the hazard of the lead car forced the subjects into performing in a similar manner.

In terms of the simple conceptualization presented earlier, it might be argued that Zell's results, which indicated that car following tended to homogenize the eye-movement patterns, also indicate that both sets of drivers tended to spend less time on the "non-essential" aspects of the visual environment and spent more time on sampling for possible changes introduced by the moving obstacle in front of them.

Kaluger (1969) studied driver eye-movement pat-
terns under conditions of prolonged driving and sleep deprivation. His findings also indicated that spatial differences in eye-movement patterns were most indicative of the differences in other experimental variables. He also found a "fatigue" effect in the duration of pursuit eye movements.

Rackoff (1960) compared the eye-movement patterns of drivers with accident and traffic records that resulted in their being classified as "high violators" with persons with no accidents or violations. Few differences in eye-movement patterns were found but those that were, tended to be of a spatial nature and included:

1. High violators spent more time foveally viewing stimuli "in the periphery" (i.e., on objects to the right or left of the roadway) than did non-violators.

2. High violators spent more time viewing "scenery" when driving on the freeway than did non-violators.

3. High violators spent a smaller percent of time looking at stop signs, but looked the same number of times at stop signs. (Violators did, however, look at stop lights when present more than non-violators)
These results might be interpreted as indicating that "high violators" spend a larger percent of their time on "non-essential" aspects of the visual environment present in driving.

In a study designed to determine the effects of low alcohol concentrations on driver eye movements, Belt (1969) found a significant increase in the amount of time drivers spent fixating in a $3^\circ \times 3^\circ$ area (measured in subtended visual angle in front of the experimental concentrations increased. This indicated a "spatial" narrowing which Belt hypothesized might be due to a blurring or blunting of the peripheral stimuli that forced the subject drivers to look only at the central vision area. Belt also observed that in some instances drivers were able to maintain "good lateral control" of their vehicles while exhibiting the narrowed eye fixation patterns, but that when subjects reverted to an eye-movement pattern typical of the "normal" driver their lateral control performance was degraded, indicating a decrement in his psychomotor capabilities. Belt was able to find no differences in "temporal" measures of eye-movement data that could be related to the various concentrations of alcohol. Some temporal differences were noticed when eye movements obtained during "car following" were compared with eye movements obtained during "open-road" driving.
Mourant (1971) found that novice drivers driving a vehicle at 70 miles per hour had approximately the same volume of pursuit eye movements as the subjects tested by Kaluger and Smith (1970). The experienced drivers tested by Mourant; however, did not make any pursuit eye movements. Novice drivers also tended to show an increase in the amount of horizontal and vertical eye movement activity.

Mourant also found that increased task difficulty in driving tended to reduce the blink rate for novice drivers.

Types of Eye Movement and Driving Performance Measures Most Likely to be Sensitive to Independent Variables in Driving Research

The above research studies would seem to indicate that the spatial (i.e., environmental) as well as temporal aspects of driver eye movements are likely to indicate differences in other experimental variables of interest. These results also indicate that stressors or degradants introduced into driving or other complex tasks are most likely to affect the manner in which a driver or operator samples his display of the environment for needed information before effects are noticed in the control movements exhibited by the driver. This sampling behavior might be characterized by a decrease in the number of fixations on "non-essential" features
of the environment as well as a narrowing of the visual fixations indicated by an increased density of fixations on the "essential items of information" presented to the driver.

Hypothesized Effect of Stressors and Low Level Degradants on Eye-Movement In Driving

Appendix D presents a discussion of the degradant carbon monoxide and briefly discusses how carbon monoxide might be expected to affect driving performance. Carbon monoxide at a level sufficient to produce 20% COHb was chosen as the degradant to be used in this research to determine the sensitivity of measures of spare capacity to a degradant.

Allen (1970) hypothesizes that carbon monoxide and other degradants act in part to destroy visual acuity, visual motor coordination, and perceptual alertness. He points out that any compensable visual anomaly becomes progressively less compensable under the influence of carbon monoxide or other degradants. This idea lends itself to the concept of a visual spare capacity. Allen also suggests that persons with measurable levels of carbon monoxide in their blood would have more asthenopia and more binocular vision and accommodative problems than persons not exposed to carbon monoxide. This suggests that fixation times for persons exposed to a degradant
might be increased. Carbon monoxide symptoms would be increased at higher elevations above sea level and would be aggravated by other degradants such as alcohol, darkness, and fatigue.

The manner in which CO or other degradants might affect vision in driving is suggested in the schematic diagram of Figure 4 (adapted from Allen).

**VISUAL CAPABILITIES AND OTHER CONSIDERATIONS**

**Introduction**

Any discussion concerning the spare capacity of a sensory mechanism must take into consideration what is known about the overall capacity of the sensory mechanism. Such discussions usually lead also to a consideration of "single channel" and "multiple channel" models of information processing. These topics will be briefly discussed below.

**Visual Channel Capacity**

Mowbray and Gebhard (1958) present a concise discussion of visual capabilities in terms of information acquisition. Some of their comments are incorporated in the discussion below which concerns itself with some of the aspects of visual information acquisition.
FIGURE 4. — A SCHEMATIC DIAGRAM OF THE ROLE OF VISION IN THE DRIVING TASK
The eye, like all sensory organs, is stimulated by energy. All visual sensations which the human perceives require a finite amount of energy to elicit them. At the other end of the "sensitivity spectrum" there exists an upper limit beyond which increased stimulation becomes physically unbearable or beyond which no further response is yielded. Energy capable of stimulating the eye is physical energy that occurs external to the eye. Normally two types of energy are associated with visual stimulation. These types include stimulation by some of the electromagnetic waves from an external source and stimulation by mechanical pressure occurring externally.

In terms of perceptual capabilities of the visual organ, the eye is sensitive to stimuli over an intensity range with a lower limit of 2.2 to $5.7 \times 10^{-10}$ ergs to an upper limit intensity roughly equivalent to the brightness of snow in the midday sun or about $10^9$ times the threshold intensity. In terms of relative intensity discrimination, the eye is capable with white light of about 570 discriminable intensity differences in a practical range. On the other hand, only 3 to 5 absolutely identifiable intensities are possible with white light by the human observer (relative discrimination implies a comparison and is the most common type of sensory judgment that humans make. Absolute discrimination is judgment in the absence of any reference and is extremely
difficult).

The eye is sensitive to wavelengths covering a
frequency range from 300 m$\mu$ to about 1500 m$\mu$. Within
the frequency spectrum the eye is capable of making about
128 relative frequency discriminations while about 12 or
13 hues can be absolutely determined.

Concepts derived from communications theory as
Mowbray and Gebhard point out have been applied to the
eye to determine its basic channel capacity. It has
been estimated that the eye is, theoretically, capable
of transmitting visual information at a rate of about
5 bits/second per nerve fiber or 3,440,000 bits/per
second. Useful rates of information transfer are of
course well below this theoretical maximum. Depending
on the method of encoding used, rates of about 2 to 25
bits per second might be expected. This same rate of
information assimilation holds true for all sensory
channels.

**Single Channel Theory Versus Multiple Channel Theory**

Discussions concerning the spare capacity of a
sensory channel and any attempt to measure the spare
capacity of a sensory channel must take into consider-
ation the interactions between the sensory channels.
Mowbray and Gebhart comment on these theories when they
state that: "for many years an argument has been debated about whether stimulation of one sensory modality has any effect either of a facilitory nature or of an inhibitory nature on the sensitivity of some other sensory modality." They point out that the body of literature concerning the controversy is vast and contradictory. The authors conclude that there seems to be little doubt that cross-stimulation of sensory modalities does occur considering the known loci of converging sensory pathways in the central nervous system. The results of sensory cross-stimulation are so minute, however, to be of very little, if any, practical value.

Deterioration of Visual Information Caused by Simultaneous Inputs on Another Modality

Generally speaking when a highly practiced motor performance is controlled by a sensory channel (e.g., vision), then that performance can be carried on adequately, with the simultaneous reception of information through another modality (e.g., audition). For example, most drivers can be expected to negotiate heavy traffic while carrying on a conversation with a passenger.

In terms of the "hypothesized hierarchy of visual behavior" presented earlier, "it might be hypothesized that the stimulation of sensory modalities other than vision simultaneous with the visual stimulation received within the two lowest categories (i.e., non-essential and
"own" vehicle placement)" would produce no noticeable degradation in the ability of the driver to control his vehicle. This may not be the case when non-visual inputs are made concurrent with the input of visual information relative to "obstacle avoidance" or "vigilance" since the response demanded by this type of stimuli may not qualify as "highly practiced."

Deterioration of overall performance can be expected when simultaneous inputs to more than one sensory modality are scanned or sequentially attended to. The deteriorations are usually noticed equally on the responses required by both inputs. Mowbray and Gebhart point out that the effect that is of greatest interest is that the amount of deterioration appears to be related to the type of material being used to stimulate the channels. When easy material is presented to one channel and difficult material is presented to another channel, the greatest amount of deterioration shows up with the easier material. This has important implications in driving and would suggest that decrement in performance due to attention to a competing non-visual stimuli might be reflected in the performance of tasks such as lane control and speed maintenance.

Another type of modality conflict occurs when one modality is being stimulated by meaningful material while the other is being stimulated by meaningless
excitations or noise that is a nuisance. For visual tasks requiring continuous performance over long periods of time. Mowbray and Gebhart assert that the presence of an intense noise as a competing stimulus tends to increase the failure in attention to the visual task and cause general, over-all, deteriorations of performance. This also has important implications in driving. On the other hand, comprehension of material is usually enhanced by the simultaneous presentation of identical material to different modalities. Responses to a visual input can be changed by the presence of other inputs—for example a tendency has been noted for observers to bias judgments about the location of sounds in the direction of an accompanying visual event—a good example of this is the dialogue in a drive-in movie. After accommodation the movie viewer tends to associate the sound with the mouth movements of those on the screen rather than with the metal box hanging on the window.

In general, when visual cues conflict with auditory cues in judgments of sound localization, the visual sense dominates the judgment. This phenomenon is observable in driving (e.g., a person driving next to another car with noisy engine valves often momentarily suspects that the noise is coming from his own automobile).

Visual cues can also conflict with non-auditory
labrynth senses. An example of this is the effect of angular acceleration and deceleration on vision and is referred to as the oculogyral illusion. This visual effect takes the form of apparent induced motion in a visual object that is fixed relative to the head of the observer. The observed motion following angular acceleration in a human centrifuge is in the direction of the turn and when the acceleration ceases no further motion is experienced.

Vision interacts with the stimulation of skin and muscles. For example in the perception of the upright, visual cues predominate over the non-visual cues to a striking degree, however, the non-visual cues do have some effect.

These comments about the role of vision as an informational channel and the interaction of vision with informational input channels have been presented to indicate just a few of the variables that need to be controlled or given consideration in any experiment designed to determine the role of vision in a complex task such as driving.

Some additional comments should be made about other work that has been done relative to the question of the single channel and multiple channel controversy. The fact that the human operator's central processing system is easily overloaded by simultaneously presented material
has led to the popular acceptance of the single-channel theory of information processing. Very simply stated the single channel theory states that while one signal is being processed all others are blocked.

Experiments designed to test single channel theory are difficult to conduct and difficult to interpret. This has resulted in the development of several alternative theories. One alternate theory suggests that the total capacity of the information processing system can be allocated to various tasks simultaneously making parallel processing possible as long as the total capacity is not exceeded. Other theories suggest a buffer into which incoming signals can be stored until they are capable of being handled.

All of these models include a "bottleneck" to information processing somewhere in the system. Therefore, even if a strict interpretation of single-channel theory is not accepted, it does at least point to the fact that there is a definite limit or restriction to the operator's information handling capacity.

Locus of Interference

An experiment designed to determine the spare capacity of a subject in performing a specified task, or any experiment incorporating a secondary task makes the implicit assumption that there exists a constant non-
varying capacity and that the primary and secondary tasks together utilize the entire capacity. As mentioned, this assumption implies a "bottleneck" to information processing somewhere in the system.

Visual occlusion has been suggested as a means for determining the visual spare capacity associated with a task. The ability of a subject to perform while occluding his vision is limited by his ability to recall information from his "short term memory." Sperling (1960) as discussed in Normann (1969) presents three possible models to describe short term memory processes for visually obtained information. These models also would seem to apply to describing a driver's behavior while engaged in visual occlusion. These models are discussed below.

1. The first model suggests that the information that is obtained visually is stored "visually" and that recall is possible as long as the visual image does not fade. This simple model is not adequate, however, to describe the behavior observed in most experiments involving short term memory because the visual image fades or decays long before the subject ceases to "remember" the stimulus.

2. A second alternative model suggests that the subject after obtaining the visual image
"rehearses" the image by vocally repeating or describing the stimulus. This model might be used to describe memory of certain simple stimuli but it is unable to be used to describe the recall of complex stimuli which if rehearsed would require a "rate" of rehearsal beyond the subjects ability.

3. A third possible model suggests that the visual stimulus presented to a subject is scanned and converted into a series of "motor instructions" which are stored in a "buffer memory." The program of motor instructions when executed by the rehearsal component, constitute rehearsal.

The important concept embodied in the "recognition buffer-memory" model is that the program of motor-instructions for a rehearsal can be set up in less time than the time to execute a rehearsal.

The third model suggested by Sperling seems best to describe the processes used by subjects in recalling tachistoscopically presented information from short term memory. The model is not, however, capable of describing how complex images are retained, and the ability of subjects to rehearse non-verbal material is also unknown. The idea, however, of describing human memory as a com-
plex chain of processes is more appealing than the more simple descriptions of models 1 and 2.

Sternberg (1967) suggests the theory of high speed scanning in memory. Sternberg's work which shows a linear relationship between response latency of recall with the number of stimuli in memory suggests that scanning and comparisons are made serially and not in parallel thus indicating that the "single channel" is located in the memory.
CHAPTER 3

SPARE CAPACITY, SPARE VISUAL CAPACITY
AND
RELATED RESEARCH
CHAPTER 3

Introduction

If visual information is the primary source of necessary information for a driver, then it can reasonably be asked if any of the drivers visual behavior can be considered unnecessary or unrelated to his driving task. On the other hand, studies in which driver visual behavior has been measured or observed indicate that drivers spend a large percentage of their time viewing "information sources" which at best can be considered marginally relevant to the driving task currently being preformed. The results of a small pilot study conducted by the Systems Research Group serve as an example of this observed behavior.

Systems Research Group Pilot Study

In this study a subject driver was required to drive one of the Systems Research Group's instrumented vehicle on the innerbelt (Interstate 71 and Interstate 70) in Columbus, Ohio, while wearing the eye-marker camera equipment. During this study the driver was told to maintain the speed of his vehicle as close as he could to fifty miles per hour at all times.
For the purposes of this study the innerbelt sections on which the subject drove were separated into three categories which were indicative of the traffic densities which were observed on the sections. Although no actual measurements of the densities were made, the three categories were considered to include "low density" traffic, "medium density" traffic, and "high density" traffic. In this small pilot study, low density traffic implied that no other vehicles were present near enough to the subject's vehicle to have an effect on his vehicle or close enough to require the subject to monitor their behavior. In medium density traffic, a few vehicles were present and were close enough to the subject's vehicle so that the subject could be expected to monitor their presence. In high density traffic, enough vehicles were present so that the subject driver was forced to "car follow" in "free-flowing traffic."

The driver was instructed that when he desired to look at the speedometer, he should do so by lowering his eyes while maintaining his head in a level position. This was necessary in order to maintain proper calibration of the eye-movement equipment throughout the testing. It was assumed, therefore, that whenever the "eyespot" on the film was out of the $20^\circ \times 20^\circ$ field of view of the camera that the driver was looking at his speedometer.
The rear view mirrors on the instrumented vehicle were arranged so that the subject driver was unable to use them in order to aid this assumption.

One analysis performed on the data obtained in this pilot study involved the determination of the percent of time that the subject driver spent fixating on the speedometer. The results of this small study were quite interesting. These results are presented below:

1. On the lightly traveled sections of the inner-belt the subject driver was able to spend approximately 80% of his time reading or monitoring the speedometer.

2. On the medium density sections of the inner-belt the amount of time that the driver was able to spend visually fixating away from the roadway (i.e., on the speedometer) was reduced to slightly more than 50%.

3. In the "heavy density" traffic where the subject driver was forced to "car follow" the time that the driver made available for the task of speedometer reading was reduced to 30%.

No attempt was made in this study to measure performance in terms of actual velocity control, lane position, or control movements. Also no attempt was made to study the "patterns" of the eye-movement fixations exhibited by
the driver while looking outside his vehicle.

In another pilot study conducted in the Systems Research Group, drivers were required to fixate foveally on objects to the "left" while following a lead car in a "car following" situation. This study indicated that the driver needed to spend only about 20% of his time fixating foveally on the lead car. Both of these pilot studies indicate that under normal driving situations, the automobile driver is able to spend at least a portion of the time fixating on objects not directly related to his immediate primary task of controlling the automobile adequately on the highway.

**Spare Capacity and Increased Task Difficulty**

Spare capacity has also been evident in other studies conducted by the Systems Research Group. In fatigue studies, for example, marked changes in objectively measured driving performance parameters were not apparent until after the subject had driven for an extraordinarily long time (for 24 hours in some cases).

In many of the car following studies conducted by the Systems Research Group, it has been necessary to force the subjects to drive at unnaturally short headways in order to emphasize differences in some other parameter of interest. For example, in the several rear lighting studies conducted by the Systems Research
Group, car following distances of 200 feet and vehicle speeds of 65 miles per hour were selected to emphasize differences between types of taillights with respect to measures associated with car following. This speed and distance combination is one that very few drivers would select voluntarily in open road driving.

The above examples are mentioned not in condemnation of current research techniques, but rather to point out that it is often necessary to study driving under extreme conditions in order to find performance differences between parameters of interest. This "necessity" points to the fact that under "normal" driving conditions, the automobile operator has a tremendous amount of spare capacity. This spare capacity would appear to be primarily spare sensory capacity although some spare motor capacity seems also to be present.

The presence of spare capacity under normal driving conditions does not mean that there aren't driving conditions and situations which tax the driver to or beyond his sensory or motor performance limits (although it might be argued that drivers are capable and do indeed for the most part, avoid most of those situations which are likely to tax them too heavily).
Measurement of Spare Capacity

Throughout this paper, mention has been made about the spare capacity of a sensory channel and in particular the spare visual capacity that is present in driving. Indeed, the stated purpose of the research being presented was to develop experimental methods to increase the sensitivity of driving performance measures and enable the qualification of the spare visual input of a driver.

It was suggested that the development of appropriate secondary tasks or of appropriate "loading" techniques would enable the research objectives to be realized.

Several examples of how "loading" has been used in Systems Research Group to emphasize the effects of experimental variables have already been mentioned. Another method that is often used to reduce the spare capacity in a task or to measure the spare capacity in a task, is the employment of a secondary or subsidiary task. Some of the work in this area has also been presented previously. This method assumes that if a subsidiary task is performed simultaneously with the primary task, then as the primary task becomes more difficult, the performance in the secondary task should suffer. The decrease in performance also then serves as a measure of the increased difficulty of the primary
task and also as a measure of the decrease in spare capacity due to the increase in primary task difficulty. (This assumes that the information handling capacity is limited and that the primary task and the secondary task together are sufficiently difficult to require utilization of all of the capacity).

One operational problem associated with the use of this method of subsidiary tasks is that of properly instructing the subjects to achieve the desired balance of attention to the elements of the overall task (i.e., in some instances it is desirable to have primary task performance remain constant while performance in the secondary task is allowed to increase or decrease, while in other cases just the opposite is true and while in some other situations performance on both the primary and secondary tasks is allowed to vary).

Knowles (1963) and others have developed "criteria" which secondary tasks should meet. These include:

1. **Non-interference**: The secondary task should not interfere with primary task performance. It is usually very difficult, however, to ensure non-interference.

2. **Simplicity**: The secondary task should require very little learning and base levels of performance should be indicative of inter-subject differences.
3. **Self-Pacing**: The loading task should be presented at a rate determined by the operator himself. Failure to do this will tend to affect primary task performance.

4. **Sensory Compatibility**: The secondary task should be selected so that it is different from the primary task. A secondary task which utilizes a different sensory modality than the primary task will help ensure non-interference.

Most of the experiments discussed in the literature make the implicit assumption that the primary task and the secondary task together use up the total capacity. This may not be the case. Drivers in an experimental situation might very well allow themselves a "safety factor" (i.e., the time allocated to the primary task might be much higher than is necessary. Changes in the actual amount of capacity used on the primary task might be reflected in changes in the unmeasured safety factor and not in the measured secondary task. The capacity thus indicated by the subject's performance on the extra task would thus be a measure of the subject's "subjective capacity." In order to measure the subject's true objective capacity it might be necessary for the subsidiary task to force the driver away from the primary
task. Appendix C to this thesis contains an annotated bibliography of some of the important works dealing with the use of secondary tasks in the measurement of human performance.

Secondary Tasks and Driving

The ability of the driver to perform adequately under "extreme" driving conditions, or to devote time to an additional task, other than controlling the vehicle, has been known for some time. Some of the major research work which has been performed using these facts is summarized below:

Secondary tasks of one kind or another have been used several times previously to measure aspects of driving performance. Brown, for example, (1961, 1962, 1966, 1967) has used different types of secondary tasks in various research projects. He maintains that one way of approaching the problems involved with measuring driving performance is to borrow concepts from information theory and think of the driver as a communications channel with a greater capacity for dealing with information than is usually required in driving. He also maintains that unless we have some way of measuring the driver's spare capacity, any investigation of variables which affect the difficulty of driving is unlikely to differentiate between "concentrated effort and relaxed,
overlearned skill." The results of some of his research are presented below:

Brown, Tickner, and Simmonds (c 1960) in a study designed to measure interference between concurrent tasks of driving and using a mobile telephone found that the requirement to engage in the secondary task increased the "risk taking" of subjects (i.e., while engaged in telephoning they attempted more driving maneuvers which by design they had no chance of successfully completing then they did when they weren't engaged in the secondary task. They also found a decrease in vehicle speed when telephoning had to be done concurrent with the driving task. Conversely, both the accuracy and speed of telephoning were adversely affected by having to drive concurrently. Interestingly enough, subjects whose vehicle speed decreased most due to the concurrent task requirement also showed the largest increases in "errors of judgment." The inference that the authors made from this result is that although the subjects drove slower than usual, in an attempt to compensate for the stress imposed by driving and telephoning concurrently, they did this only in order to maintain their accuracy on the secondary task, thus resulting in a degradation of their judgment of "risk situations." The authors also found that older subjects regardless of driving experience tended to give higher priority to the judgment aspects of
the task, thus neglecting the secondary task, than did the younger drivers. The authors also concluded from their data that driving "skill" was not, unlike judgmental ability, adversely affected by the secondary task performance.

In research reported by Brown and Poulton (1961), an attempt was made to measure the "spare mental capacity," using a secondary task. The subsidiary tasks that were employed in the research consisted of mental arithmetic tasks and selective attention type tasks. The results of their research indicated that the subsidiary tasks that they employed were "sensitive" enough to reveal the higher level of concentration required for driving in a "shopping area" compared to that required in a "residential" area. Differences in speed maintenance were also noted for these two types of driving. On the basis of these results, the authors conclude that the subsidiary task technique can be used effectively in field studies to measure the spare mental capacity of drivers. They also suggest that a measure of spare capacity would be useful not only in assessing the relative difficulty of driving in different kinds and levels of traffic but also for measuring the effect upon the driver of fatigue and small doses of alcohol or other degradants, "since a gradual reduction in spare
capacity is to be expected in these circumstances." They also claim that secondary tasks of the nature employed in their research did not adversely effect the primary task of driving the automobile.

In another experiment, Brown (1962) attempted to measure the effects of "fatigue" using a subsidiary task by studying drivers before and after an eight hour shift of driving. He unexpectedly found that "spare mental capacity," as measured by performance of the subsidiary task apparently increased after an eight hour spell of driving. He attributed this result to uncontrolled variation in the pretest activities but maintains that the idea of using a secondary task to measure driving performance is still a valid approach. This experiment also indicated that the type of subsidiary task which is used does not appear to matter very much, but that the relationship between "cause and effect" can more easily be observed in a subsidiary task which requires frequent responses.

In further experimentation along the same lines, Brown, Tickner, and Simmonds (1966) attempted to measure the effect of a subsidiary task (random generation of dates) in conjunction with prolonged driving. The main finding of their research was that prolonged driving had very little effect upon driving performance as measured
in their experiment and upon reserve capacity as measured on the subsidiary task of random generating (using "information" content measures).

In yet further experimentation, Brown, et al., (1967) attempted to measure the effects of "12 hour automobile driving" on performance of a subsidiary task of time-interval production. Performance on the subsidiary task was reliably more variable on days where driving was required than on other days, but subsidiary task performance was apparently unrelated to the duration of driving.

In summary it might be said that Brown's work has shown that secondary tasks can be utilized in driving research to measure the effects of certain variables. In general, however, the types of tasks employed by Brown fail to yield a quantified measure of the spare capacity available to the subject.

Measurement of Spare Visual Capacity via Visual Occlusion

One method of determining the spare visual capacity present in a driving task is to deprive a driver of a portion of his visual ability and to measure the result of that deprivation on his driving performance. Although not used extensively as a method of loading, several studies have been performed in which a driver's vision has been limited in one way or another. Some of these
studies are reviewed below:

Gordon (1960) reported experiments in which the driver of an automobile was required to guide the car while looking through a helmet and mask device containing a small aperture. By decreasing the visual field, the drivers were forced to obtain information in separate visual fixations. The authors felt that the use of the aperture method was more advantageous than use of an eye marker camera, because eye marker cameras do not show the contribution of peripheral vision, and, therefore, do not provide means for distinguishing essential from non-essential information. (Bhise's work would, however, suggest just the opposite.)

In these experiments, the shifts in fixations of the drivers' eyes emphasized the requirements of perceptual anticipation and vehicular alignment which force the driver to look "far" ahead to obtain a general idea of the conditions that he will have to meet while at the same time the driver must take a "close" look for alignment purposes.

Results obtained in this study indicate that drivers obtain both types of information by viewing the edges and centerline of the road.

Senders, et al. (1967), assume that a driver's attention is, in general, not continuously but only
intermittently directed to the road. Between observations, uncertainty about both the position of his own vehicle on the road and the possible presence of other vehicles or obstacles increases until it exceeds a threshold. At that moment the driver looks again at the road. The authors maintain that depriving a driver of part of his input artificially or naturally (in a snowstorm, etc.) can affect performance (e.g., cause "psychological" speed limits or other performance limits).

Another factor that might determine when a driver would look at the road is his estimate of the probability that some new object will enter the road or the probability that opposing traffic will deviate into the path of his vehicle between observations.

These "psychological limits" and subjective probability estimates might be a function of the level of stressors or degradants present in the task.

The authors state that a rather important notion which underlies their work is that drivers do tend to drive to a limit. They also suggest that the limit is determined by that point when the driver's information processing capacity either real or imagined is matched by the information generation rate of the road, either real or estimated. The drivers may be wrong in their estimates but they will tend to achieve this balance of input information rate and information processing rate.
Drivers will also accept different levels of risk and will drive to a limit such that the probability of an accident is no greater than, but approaches some upper threshold. The authors maintain that "subjective acceptable risk level" is a measurable characteristic of drivers and directly influences their behavior on the road. They tested their model using data collected with drivers who vision was occluded using a helmet with an opaque shield which could be raised or lowered over a driver's eyes.

Poulton's research (c 1952) gives some insights into the behavior of subjects during the periods of blackout of visual information. In this experiment, subjects were given glimpses of a tracking display of various lengths between constant length "blackout" periods. The authors concluded in their experiments, that subjects were clearly using speed cues, when they were available in order to anticipate target movement during the "blackout" period.

The research that was reviewed here, suggested that visual occlusions voluntarily undertaken by the driver might be used as a means of quantifying the driver's visual spare capacity.

Systems Research Group Pilot Experiment to Determine the Effect of Learning in Visual Occlusion Studies

The following experiment was conducted to determine
the effect of "learning" in visual occlusion studies. It was felt that this would be necessary before serious thought could be given to the use of visual occlusion in driving experiments.

Procedure

Two subjects were required to drive an instrumented vehicle on a lightly travelled section of Interstate highway while voluntarily closing their eyes as frequently and for as long a period as they deemed possible. Each subject was given five trials of 200 seconds each. Comparisons across trials were then made as described below to determine the effect of learning.

Subject Instructions

Prior to the beginning of the first trial, the subjects were read the following instructions:

I would like you to drive this automobile in the right hand lane of this highway at about 50 miles per hour. I would also like you to close your eyes whenever possible. That is, I would like you to keep your eyes shut as much as possible and when you do open your eyes to keep them open for as short a time as possible. The safety man seated next to you will be observing your behavior and that of the other traffic near this vehicle. He will alert you by stating the word "open" if he feels that you should open your eyes. If at any time you should feel that it is necessary to keep your eyes open for a long period of time, please let us know by stating the word "open." If that happens, please let us know when you are ready to resume the eye closing procedure by stating the words "closed." Are there any questions?
There were no questions prior to the start of testing, but it became clear after the start of the experiment that the subject wasn't performing as intended so the experiment was stopped and the subject was asked how he interpreted the instructions. His answer indicated that he assumed that he was to keep his eyes closed until he was told to open them or until he was sure that he was in imminent danger (e.g., running off the pavement). It was then explained to the subject that even though he was to use his eyes as little as possible, he was still expected to maintain control and lane placement and that the safety man's role was one of alerting him to unusual occurrences.

This lack of understanding on the part of the subject indicated the need to structure the instructions carefully in further tests in order to achieve the performance desired.

Subjects

Two subjects participated in this pilot study. For the first run, one of the subjects participated in the study as a driver of the experimental vehicle, while the second subject served as a "safety man" who rode next to the subject in the front seat. After experimentation was completed with the first subject, the roles of the subjects were reversed.
Data

The data that was collected in this pilot study and the analyses of that data is presented in the charts and graphs that follow. In addition to this formal analyses, the subjects were questioned about their thoughts concerning the testing procedure, after the experimentation. Their comments also presented below are informative and deserve consideration in the design of experiments utilizing visual deprivation or occlusion as a form of loading.

Subject Comments

After the experiment was completed, the subjects who participated in the tests were asked to comment on their performance and on the test itself. The comments solicited from the subjects were very interesting and are summarized below.

Both subjects indicated that they didn't worry during the performance of the experiment because they felt that the safety man would warn them of any danger. Both subjects felt that they learned the task quickly and that their performance "leveled off." One subject felt that he became "more efficient." He felt that as the task progressed, he opened his eyes more frequently but for shorter periods of time.

Neither subject claimed to have used the rear view
mirrors in the car, because they felt that the safety man would warn them of any danger approaching from the rear.

One subject stated that he quickly "gave up" trying to sense lateral movement of the vehicle and adopted the strategy of trying to hold the steering wheel steady.

One subject felt that his speed during the trials drifted up while the other subject felt that his speed tended to drift downward. Although records of the speeds were not kept, observations made by the experimenter indicated that the subjects were correct in their estimates. The subjects indicated that their strategy with respect to maintaining speed was to make discrete adjustment in the gas pedal position while their eyes were closed after determining during a "peek" that their velocity was drifting from the target velocity of 50 miles per hour.

(Note on Data):

On the tables presented in this report, "shut" is used to denote periods of visual occlusion and "open" indicates periods during which the subjects obtained visual information. "Screened opens" were periods of open road driving where no other vehicles or other obstacles were present to be looked at.


<table>
<thead>
<tr>
<th>Trial</th>
<th>Open</th>
<th>Shut</th>
<th>Screened</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>42.7</td>
<td>92.6</td>
<td>33.6</td>
</tr>
<tr>
<td>Trial 2</td>
<td>49.6</td>
<td>107.8</td>
<td>42.4</td>
</tr>
<tr>
<td>Trial 3</td>
<td>48.6</td>
<td>91.8</td>
<td>45.8</td>
</tr>
<tr>
<td>Trial 4</td>
<td>46.6</td>
<td>93.3</td>
<td>34.1</td>
</tr>
<tr>
<td>Trial 5</td>
<td>32.4</td>
<td>79.2</td>
<td>25.2</td>
</tr>
</tbody>
</table>

Note: $\bar{x}$ values are in 1/100 seconds

Note: $\sigma^2$ values are in (1/100 seconds)$^2$
FIGURE 5. --SAMPLE DATA FROM "LEARNING" PILOT STUDY
Several tests were performed on the data from this study and are presented below:

Analyses of Variance

**TABLE 2**

ANOVA #1 (OCCLUSION PERIODS)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares (SS)</th>
<th>Mean Square (MS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Subjects</td>
<td>1</td>
<td>748.23</td>
<td>748.13</td>
</tr>
<tr>
<td>Factor 2: Trials</td>
<td>4</td>
<td>137.65</td>
<td>34.41</td>
</tr>
<tr>
<td>Factor 1 2</td>
<td>4</td>
<td>386.93</td>
<td>96.73</td>
</tr>
</tbody>
</table>

1. To determine trial effects (at .05 level of significance)

\[ F = \frac{34.41}{96.73} = .355 \]

F critical = \( F_{1-\alpha} (4,4) = 6.39 \)

therefore, there is no significant difference between trials.

2. To determine subject effects (at .05 level of significance)

\[ F = \frac{748.23}{96.73} = 7.72 \]

F critical = \( F_{95} (1,4) = 7.71 \)

therefore, subjects are significantly different.
### TABLE 3
ANOVA #2 (OPEN PERIODS)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares (SS)</th>
<th>Mean Square (MS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1</td>
<td>1</td>
<td>1299.60</td>
<td>1299.60</td>
</tr>
<tr>
<td>Factor 2</td>
<td>4</td>
<td>66.79</td>
<td>16.70</td>
</tr>
<tr>
<td>Factor 1 2</td>
<td>4</td>
<td>288.81</td>
<td>72.20</td>
</tr>
</tbody>
</table>

1. To determine trial effects (at .05 level of significance)

\[
F = \frac{16.70}{72.20} = .231
\]

\[
F_{critical} = F_{1-\alpha(95)} (4,4) = 6.39
\]

therefore, there is no significant differences between trials.

2. To determine subject effects (at .05 level of significance)

\[
F = \frac{1299.60}{72.20} = 18.00
\]

\[
F_{critical} = F_{95} (1,4) = 7.71
\]

therefore, there is a significant difference between subjects.
TABLE 4
ANOVA #3 (SCREENED OPEN PERIODS)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares (SS)</th>
<th>Mean Square (MS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Subjects</td>
<td>1</td>
<td>1363.52</td>
<td>1363.52</td>
</tr>
<tr>
<td>Factor 2: Trials</td>
<td>4</td>
<td>205.31</td>
<td>51.33</td>
</tr>
<tr>
<td>Factor 1 2</td>
<td>4</td>
<td>86.51</td>
<td>21.63</td>
</tr>
</tbody>
</table>

1. To determine trial effects (at .05 level)
   \[ F = \frac{51.33}{21.63} = 2.38 \]
   \[ F \text{ critical } = F_{.95}^{(4,4)} = 6.39 \]
   therefore, there is no significant difference between trials.

2. To determine subject effects (at .05 level)
   \[ F = \frac{1363.5}{21.63} = 62.4 \]
   \[ F \text{ critical } = F_{.95}^{(1,4)} = 7.71 \]
   therefore, there is no significant difference between subjects.
### TABLE 5

**ANOVA #4**

*(THREE FACTOR ANALYSIS OF VARIANCE)*

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares (SS)</th>
<th>Mean Square (MS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Subjects</td>
<td>1</td>
<td>3355.34</td>
<td>3355.34</td>
</tr>
<tr>
<td>Factor 2: Trials</td>
<td>4</td>
<td>293.06</td>
<td>73.26</td>
</tr>
<tr>
<td>Factor 3: Dep. Variables</td>
<td>2</td>
<td>21027.40</td>
<td>10513.70</td>
</tr>
<tr>
<td>Factor 1 2</td>
<td>4</td>
<td>618.13</td>
<td>154.53</td>
</tr>
<tr>
<td>Factor 1 3</td>
<td>2</td>
<td>56.01</td>
<td>28.00</td>
</tr>
<tr>
<td>Factor 2 3</td>
<td>8</td>
<td>116.69</td>
<td>14.59</td>
</tr>
<tr>
<td>Factor 1 2 3</td>
<td>8</td>
<td>144.12</td>
<td>18.01</td>
</tr>
<tr>
<td>error--</td>
<td>0</td>
<td>0.</td>
<td>0.</td>
</tr>
</tbody>
</table>

In addition to performing the three two factor analysis of variance on the data from this pilot study, a three factor analysis of variance was also performed. The third factor considered each of the dependent variables previously considered separately as a level of a
common factor.

Although differences in this third factor would be expected, the inclusion of the factor in the analysis increases the power of the analysis with respect to testing for the effects of learning.

The results of the analysis are presented below:

1. To determine trial effects (at the .05 level)
   \[ F = \frac{73.26}{18.01} = 4.055 \]
   \[ F_{\text{critical}} = F_{.95}(4,8) = 3.84 \]
   therefore, there is a significant difference across trials.

2. To determine subject effects (at the .05 level)
   \[ F = \frac{3355.34}{18.01} = 187.00 \]
   \[ F_{\text{critical}} = F_{.95}(1,8) = 5.32 \]
   therefore, there is a significant difference across subjects.

3. To determine dependent variable difference (at the .05 level)
   \[ F = \frac{10513.70}{18.01} = 586.00 \]
   \[ F_{\text{critical}} = F_{.95}(2,8) = 4.46 \]
   therefore, there is a significant difference between the dependent variables.

4. To determine subject x trial interaction effects (at the .05 level)
\[ F = \frac{154.53}{1801} = 8.58 \]

\[ F \text{ critical} = 3.84 \]

therefore, there is a significant difference due to this interaction.

5. Tests for effects due to the other interactions were found to be non-significant.

Results

The major results accruing from this pilot study are presented below:

The subjective comments and, indeed, the data indicate that the subjects in a simple driving task of this nature (i.e., open road with no immediate traffic) feel rather confident in adopting a strategy that reduces their task to a level in which they sample only to determine errors in lane position and velocity maintenance. This suggests that it might be necessary to increase the percentage of time that "obstacles" are present (e.g., by car following) for the driver to visually sample.

This conclusion is further supported by the fact that the only condition in the two factor ANOVAs for which subject differences were found to be most significantly different was that in which "all peeks" were considered. This suggests that the differences were due to varying
fixations on obstacles.

Learning was indicated as being a significant factor in the three way analysis of variance performed on the data. This indicates that learning should be controlled or accounted for in future experiments.

**Experiment to Determine the Effect of Vehicle Speed on Visual Occlusion Behavior (Voluntary)**

An occlusion study similar to that described in the previous pilot study was conducted in which the driver of the experimental vehicle was required to drive while voluntarily closing his eyes as much as possible. In addition, the speed of the driver's vehicle was controlled at different levels. This study by Bhise (1971) studied the visual informational needs and the visual information acquisition processes. Bhise's approach was similar to that employed in the study above, in which the subject was requested to keep his eyes closed as much as possible during the experiment and to open his eyes for as short a time as possible when it was necessary to obtain information for vehicle control.

The primary aims in Bhise's study were to:

1. investigate the characteristics of eye movements during viewing time,

2. determine the effect of vehicle speed on visual information acquisition behavior, and
3. investigate the nature of levels of clarity in relation to preview time.

Bhise tested one subject who was asked to drive his vehicle in the middle lane of an unopened stretch of interstate highway which was three lanes wide at specified speeds. This subject was required to drive for one and one-half minutes at each of three speeds: 25 mph (run 1), 30 mph (run 2), and 35 mph (run 3).

Bhise’s data indicated that an increase in vehicle velocity was not associated with a decrease in time spent in voluntary visual occlusion. Bhise suggests that learning might have been confounded with velocity in his test because his increments in velocity were presented sequentially; i.e., 25 mph first, 30 mph second, and 35 mph third. Mean percent of time spent in occlusion for all runs combined for this test was not presented but was calculated from the data presented to be 90.19%.

Bhise found that no difference existed between the mean occlusion times for runs 1, 2 and 3. Differences in mean viewing times were noted when run 3 was compared via pairwise t tests with runs 1 and 2. Tests to determine the correlation between viewing and occlusion time showed that across all velocities the two measures were independent.

Bhise’s data also suggested that:
1. The mean number of fixations per look was less for run 3 (high velocity) as compared to the first two runs.

2. Fixations of less than 100 msec were found in runs 1 and 2.

3. The mean fixation duration of the first fixation in a look was statistically different and smaller than the second fixation.

Bhise concluded in his study that under the high level of stress demanded by the task of voluntary visual occlusion that the driver is forced to foveally attend to informational sources in his environment that he would normally attend to with his extra-foveal vision.
CHAPTER 4

MAJOR STUDY DESIGNED TO DETERMINE USEFULNESS OF VISUAL OCCLUSION TO MEASURE SPARE VISUAL CAPACITY AND TO DETERMINE THE EFFECTS OF DEGRADANT ON THE SPARE CAPACITY
Introduction

The experiment that is described here was conducted in order to determine the spare visual capacity of automobile drivers in selected driving situations and to determine the effects of the degradant (carbon monoxide) on that spare capacity.

A complete description of the aims of this experiment were presented earlier. In summary it might be said that the two major purposes of this series of tests were:

1. to determine the usefulness of a voluntary visual occlusion task in quantifying the spare capacity of drivers in selected driving situations, and

2. to determine how sensitive this measure of spare capacity would be to the effects of a degradant (carbon monoxide in quantities sufficient to produce 20% COHb).

The purpose of this chapter is to detail the experimental design employed to achieve the aforementioned aims and to present the results of the tests that were conducted.

Independent Variables

The following independent variables were included
in the experimental design employed in this series of tests:

A. Task Loading
1. open road driving—at fifty miles per hour
2. car following—with the lead car maintaining a constant velocity of fifty miles per hour
3. car following—with the lead car exhibiting a variable velocity profile with average velocity of fifty miles per hour

B. Visual Loading
1. normal or control—full unhindered vision
2. voluntary visual occlusion—subjects voluntarily closed their eyes whenever possible

C. Degradant Level
1. normal or control—no degradant
2. the degradant—carbon monoxide

These independent variables can be arrayed in a matrix as indicated in Figure 6. As can be seen, each subject utilized in this experimental design participated in six separate tests for each level of degradant employed. These tests are described in more detail below.

Trial 1: Open road driving (at fifty miles per hour, normal visual load).

In this segment of the experiment, the subject was given the following tape recorded instructions:

Please drive this car in your normal manner at about 50 miles per hour. Please keep to the right side of the road whenever possible. If you desire to pass anyone, please let us know and we will tell you when it is safe to do so. Are there any questions?
FIGURE 6. — MATRIX OF INDEPENDENT VARIABLES CONSIDERED IN MAIN EXPERIMENT.

Task Difficulty

<table>
<thead>
<tr>
<th>Car</th>
<th>Car</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following</td>
<td>Following</td>
</tr>
<tr>
<td>Variable</td>
<td>Constant</td>
</tr>
<tr>
<td>Velocity</td>
<td>Velocity</td>
</tr>
<tr>
<td></td>
<td>Open Road</td>
</tr>
</tbody>
</table>
Any questions that the subject had were answered as quickly and concisely as possible. After being given these instructions, the subject was allowed to drive the vehicle for a three minute period of time. After this period, the subject then proceeded to the next test.

**Trial 2: Open road driving (at fifty miles per hour, visual load via voluntary visual occlusion).**

Prior to running in this segment of the experiment, the subject driver was given the following tape recorded instructions:

Please drive this car in your normal manner at about 50 miles per hour, and keep to the right hand side of the road whenever possible.

During this part of the experiment we would like you, in addition to driving as we just described, to close your eyes whenever possible. That is, we would like you to keep your eyes shut as much as possible and when you open your eyes to keep them open for as short a time as possible. The "safety man" seated next to you will be observing your behavior and that of the other traffic near this vehicle. He will alert you by stating the word "open" if he feels that you should open your eyes. If at any time during this run you feel that you should open your eyes and keep them open, do not hesitate to do so.

Although we are asking you to keep your eyes closed as much as possible, we still expect you to maintain normal control of the vehicle and to keep the car in the right hand lane. The safety man's role will be that of alerting you to unusual occurrences that might develop. Are there any questions?

As in the first portion of the experiment, any questions were answered as concisely as possible. Also, as in the first run, the subject was allowed to drive the instru-
mented vehicle for a three minute period.

In this run, as in all other runs involving voluntary visual occlusion, the safety man seated next to the subject driver alerted the driver whenever he felt that there was the danger of a collision. The subject was not alerted when his performance deteriorated (e.g., driving off the roadway or across the center marker) if there was no immediate danger of a collision with a fixed object or other vehicle.

Trial 3: Car following (lead car velocity constant at fifty miles per hour, normal visual load).

Prior to the start of this run, the subject was given the following tape recorded instructions:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car but were unable to because of oncoming traffic in the left lane. Are there any questions?

Any questions that the subject had were answered as quickly as possible and the subject was then allowed to follow the lead vehicle, which maintained a constant velocity of fifty miles per hour, for a three minute period.

Trial 4: Car following (lead car velocity variable with a mean speed of fifty miles per hour, normal visual load).

In this segment of the research, the subject driver drove the instrumented vehicle after being given
the following tape recorded instructions:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car but were unable to because of oncoming traffic in the left lane. Are there any questions?

As in previous runs, any questions that the subject drivers had were answered as concisely as possible. The lead car in this run went through the velocity profile indicated in the diagram of Figure 7. This lead car program was decided on after an examination of the results of the work of Rockwell and Underwood (1964).

Trial 5: Car following (lead car velocity constant at fifty miles per hour, loading via voluntary visual occlusion).

The subject driver of the instrumented vehicle was given the following tape recorded instructions prior to the start of this run:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car, but were unable to do so because of oncoming traffic in the left lane.

The subject driver was then given the same instructions given previously requiring voluntary visual occlusions. In addition the subject driver was also told that:

During this run, the lead car will maintain approximately the same speed at all times. Are there any questions?

Trial 6: Car following (lead car velocity variable with a mean speed of fifty miles per hour), loading
FIGURE 7. --PERTURBED LEAD CAR VELOCITY PROFILE EMPLOYED IN MAIN EXPERIMENT
via voluntary visual occlusion.

In this segment of the research, the subject driver drove the instrumented vehicle after being given tape recorded instructions which were the same as those given for Trial #5 with the exception that at the end of the instructions the subject was told that:

During this run, the lead vehicle will upon occasion change speeds in a gradual manner. That is, it will slow down or speed up, but it will not do so suddenly. Are there any questions?

Again, as in all other tests, any questions that the subject driver had were answered as quickly and concisely as possible. The lead car in this run went through the same velocity profile used earlier and shown in the diagram of Figure 7.

A more complete description of the experimental procedures employed on the road and a description of the manner in which the carbon monoxide was administered and controlled is given in Appendix D of this report.

Dependent Variables

Measures of the following dependent variables were obtained during this series of experiments.

1. vehicle velocity - all trials
2. gas pedal position - all trials
3. brake pedal activation - all trials
4. TV picture of road, digital clock, subject's eye activity, and subject's foveal eye fix-
ation location - all trials

5. headway between subject vehicle and lead vehicle (from TV picture) - trials 3, 4, 5 and 6

This data was obtained using the equipment described in Appendix A to this report.

Subjects

Six subjects, all males between the ages of 21 and 30 years old were used. These subjects participated in all of the tests previously described under two separate levels of the degradant (nominally 0% COHb and 20% COHb). All of these subjects were non-smokers who volunteered for the tests. Each subject in this series of experiments and in all other road research reported in this document received a payment of $5.00 per hour for his services. These subjects will be referred to in this report as subjects K, Q, D, N, C and B. (A more complete description of these subjects and a description of the actual COHb levels achieved during the experiments is presented in Appendix D of this report)

In addition to the testing just described, two subjects were chosen for additional tests. Subject N was replicated in all tests under a level of "zero" COHb. Subject K participated in three baseline runs described below:
1. Baseline run 1 - all tests were performed but the subject did not wear the eye movement equipment and did not receive any gas of any type prior to or during road tests. No blood tests were taken from the subject in this run.

2. Baseline run 2 - all tests were performed but the subject was not subjected to any gassing prior to or during the run nor was the subject required to give any blood during the testing. The subject did wear the eye movement apparatus during this run.

3. Night baseline run - this run was essentially the same as baseline run 2 with the single exception that it was performed at night instead of during the day.

These baseline runs were chosen to enable insights into the effects of certain experimental procedures employed during the main series of test to be determined and to determine the effects on a driver's performance and his spare visual capacity of the procedures used in exposing him to carbon monoxide or air in the main series of tests. The results of these baseline experiments are presented in the next chapter.

Results of the Main Series of Tests

As was mentioned previously, several dependent
variables were considered in this series of tests. Each of these dependent variables will be discussed separately and then apparent relationships between the variables will be considered.

Spare Capacity Analysis

Of primary importance in this series of tests was the determination of the spare visual capacity of the subject drivers for the various types of driving situations considered in the experiments. Also of interest was the effect on this spare capacity of a degradant such as carbon monoxide.

As was stated earlier, the task of asking the subject to voluntarily occlude his vision was suggested as a means of allowing his spare visual capacity to be determined. As can be seen from the instructions for the various tests conducted voluntary visual occlusions were required in trials 2, 5 and 6 (open road driving, "constant" car following, and perturbated car following). One method for using the data obtained in these tests as a measure of spare capacity is to consider the percentage of time that a driver was able to keep his eyes closed during a particular run as the "spare capacity" available to the driver in that run.

One analysis that was performed on the data was to determine for each subject the percent of time during
a run that the driver kept his eyes open and the percent of time that he kept them closed. This analysis broken down by subject and trial is presented in Table 6. As can be seen from this table the subjects' abilities tend to differ greatly but each subject seems to be fairly stable (i.e., subject effects appear greater than trial effects). Task difficulty appears also to have an effect on spare capacity, but the effect of COHb is not immediately apparent, although as can be seen from the table, 9 out of 15 possible CO vs. air comparisons indicate that CO causes a reduction in the amount of spare capacity available to the subject.

If the data for each subject is combined it can be arrayed in a matrix as in Table 7. As can be seen in the data of this table the effects of task difficulty become apparent and a decrement in spare capacity due to COHb becomes apparent.

The data used to formulate the matrix of Table 7 was subjected to a three way analysis of variance. Because of the nature of the data used, the values were converted via an arcsine transformation prior to testing for significant differences. The transformation used was:

\[ f(x) = \text{arcsine} \sqrt{x} \]

This analysis failed to indicate that the differences due
TABLE 6

SPARE CAPACITY AS A FUNCTION OF PERCENT OF TIME THAT SUBJECTS KEPT THEIR EYES CLOSED (VOLUNTARILY OCCLUDED THEIR VISION)

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>Q</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75.4</td>
<td>83.4</td>
<td>49.4</td>
<td>57.5</td>
<td>15.4</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>86.1</td>
<td>62.6</td>
<td>58.3</td>
<td>42.3</td>
<td>61.3</td>
<td>58.7</td>
</tr>
<tr>
<td>Trial 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car Following</td>
<td>82.0</td>
<td>80.9</td>
<td>35.0</td>
<td>44.2</td>
<td>26.0</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>81.1</td>
<td>55.2</td>
<td>60.9</td>
<td>46.4</td>
<td>54.4</td>
<td>56.1</td>
</tr>
<tr>
<td>Trial 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perturbated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car Following</td>
<td>87.1</td>
<td>79.7</td>
<td>35.1</td>
<td>36.3</td>
<td>21.6</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>81.1</td>
<td>1.8</td>
<td>36.1</td>
<td>25.5</td>
<td>54.5</td>
<td>60.1</td>
</tr>
</tbody>
</table>

NA = Not Available
**TABLE 7**

SPARE CAPACITY AS A FUNCTION OF THE PERCENT OF TIME THAT SUBJECT DRIVERS WERE ABLE TO CLOSE THEIR EYES (OCCLUDE THEIR VISION) WHILE DRIVING

<table>
<thead>
<tr>
<th>Trial + Mode</th>
<th>Gas</th>
<th>Air</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. 2: Open Road</td>
<td></td>
<td>66.1</td>
<td>60.4</td>
</tr>
<tr>
<td>T. 5: Constant Car Following</td>
<td></td>
<td>62.7</td>
<td>56.6</td>
</tr>
<tr>
<td>T. 6: Variable Car Following</td>
<td></td>
<td>59.0</td>
<td>40.7</td>
</tr>
</tbody>
</table>
to trials, subjects or COHb level were significantly different. When an analysis of variance was applied to the measure of spare capacity (i.e., percent occlusion time) for data pooled across subjects it was found that effects due to trials were significant at the .25 level of significance while the decrement due to CO was also significant at the same level.

This analysis indicates that voluntary visual occlusion tasks can yield a measure of visual spare capacity that is sensitive to levels of task difficulty and which is sensitive to the effects of COHb at a 20% level.

Perhaps the most significant aspect of this analysis is that it indicates that under perturbated lead car driving conditions a driver's spare capacity is reduced by one-third. This is even more significant if we consider that most urban freeway driving where a driver is likely to be exposed to high ambient concentrations of CO is similar to the perturbated lead car condition employed in this experiment.

Eye Movement Data Analysis

As was mentioned previously, the subjects who participated in the research described in this chapter all wore the Systems Research Group's Eye Marker Camera equipment. This equipment which is described in detail
in the appendices enables the determination of the point in front of the driver on which the driver is foveally fixating at any point in time. Several analyses were performed on the data collected with the eye movement camera system to determine the sensitivity of the data to task difficulty, loading and carbon monoxide. One analysis to determine an overall measure of spare capacity was presented previously. Other analyses are presented below.

Eye Marker Data Reduction

The eye movement data obtained in this series of experiments was collected using the Systems Research Group's television eye marker system. This data collection system yields a magnetic tape which can be "played back" using a television tape recorder and the data can then be displayed on a television monitor. The nature of the data reduction procedure has been detailed in the appendices. Some specific comments about the data reduction procedures employed for the research reported in this chapter will be outlined here.

The data obtained in each trial for each subject at each COHb level was examined and the following types of information were obtained.

1. Eye spot fixation location and "look" duration: TV tapes obtained in the experiment
were examined and each separate "look" at an object or area in the scene and its duration was recorded. For purposes of this research the duration of a "look" was defined as the period of time beginning with the appearance of the eye spot on an object or area of interest and ending with the disappearance of the eye spot from that same object or area. A "look," therefore, consisted of one or more visual fixations on an object or an area.

2. Other eye behavior: In addition to the aforementioned data obtained from analyzing the "scene and eyespot" image displayed on the TV monitor, several items of information were obtained by looking at the image of the eye also displayed on the TV monitor. These items of information included "looks" at the rear view mirror and speedometer and the frequency and duration of blinks.

All data reduction was done utilizing the digital clock which was normally set to read time in increments of 50 milliseconds.

A list of the objects and areas considered in the data reduction and analysis of the eye movement data is presented in Table 8.
<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>Right lane marker</td>
</tr>
<tr>
<td>S</td>
<td>Straight ahead</td>
</tr>
<tr>
<td>C</td>
<td>Eyes closed</td>
</tr>
<tr>
<td>SK</td>
<td>Sky</td>
</tr>
<tr>
<td>SR</td>
<td>Scenery right</td>
</tr>
<tr>
<td>LC</td>
<td>Lead car (car in right lane)</td>
</tr>
<tr>
<td>TC</td>
<td>Other car (any vehicle except lead vehicle)</td>
</tr>
<tr>
<td>CM</td>
<td>Center marker</td>
</tr>
<tr>
<td>RS</td>
<td>Road sign</td>
</tr>
<tr>
<td>SS</td>
<td>Scenery straight</td>
</tr>
<tr>
<td>SL</td>
<td>Scenery left</td>
</tr>
<tr>
<td>B</td>
<td>Bridge</td>
</tr>
<tr>
<td>RL</td>
<td>Right lane</td>
</tr>
<tr>
<td>LL</td>
<td>Left lane</td>
</tr>
<tr>
<td>OV</td>
<td>Out of View</td>
</tr>
<tr>
<td>BL</td>
<td>Blink</td>
</tr>
<tr>
<td>RM</td>
<td>Rear Mirror</td>
</tr>
<tr>
<td>SP</td>
<td>Speedometer</td>
</tr>
</tbody>
</table>
The data obtained in this manner was submitted to several analyses which are described below.

Interlook Interval Analysis (for Looks at Lead Car)

This research has suggested that spare capacity as measured by the length of time that a driver was able to deprive himself of vision and visual information is sensitive to the effects of a degradant such as CO (in quantities to produce a 20% level of COHb).

Another measure of visual deprivation is the length of time that a driver spends looking at objects other than the lead vehicle in "close" car following situations. The mean duration of these "interlook intervals" was computed for all subjects from the data obtained in trial 4 (perturbated car-following with normal vision). These means are presented in Table 9. As can be seen no apparent differences can be identified due to COHb.

If the length of the interval between the interlook intervals at the lead car is examined (i.e., the length of the look at the lead car), as is done in Table 10 it can be seen that differences due to trials or task difficulty and differences due to subjects can be readily identified. Differences due to COHb are, however, not apparent.
TABLE 9

MEAN DURATION OF "INTERLOOK INTERVALS" BETWEEN LOOKS AT LEAD CAR (SECONDS)

TRIAL 4 DATA

PERTURBATED CAR FOLLOWING NORMAL VISION

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gas</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air</td>
<td>0.868</td>
<td>9.136</td>
<td>3.219</td>
<td>1.403</td>
<td>0.578</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>1.124</td>
<td>1.495</td>
<td>2.207</td>
<td>2.033</td>
<td>0.817</td>
</tr>
<tr>
<td>Trial</td>
<td>Gas</td>
<td>Subject</td>
<td>K</td>
<td>D</td>
<td>N</td>
<td>B</td>
</tr>
<tr>
<td>-------</td>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>T. 3</td>
<td>Constant</td>
<td>Car Following</td>
<td>Normal Vision</td>
<td>6.475</td>
<td>5.079</td>
<td>0.361</td>
</tr>
<tr>
<td></td>
<td>Perturbated</td>
<td>Normal Vision</td>
<td>2.517</td>
<td>2.029</td>
<td>0.437</td>
<td>1.135</td>
</tr>
<tr>
<td>T. 5</td>
<td>Constant</td>
<td>Occlusion</td>
<td>0.395</td>
<td>0.200</td>
<td>0.427</td>
<td>0.545</td>
</tr>
<tr>
<td></td>
<td>Perturbated</td>
<td>Occlusion</td>
<td>0.194</td>
<td>0.350</td>
<td>0.552</td>
<td>1.385</td>
</tr>
</tbody>
</table>
An analysis of variance on the data contained in Table 10 indicates that differences due to trials were significant at the .001 level of significance while differences due to the subjects were significant at the .005 level.

Occlusion Time and Open Time Analysis

An analysis similar to the one just presented can be done on the data obtained in occlusion trials. The mean and variance of the duration of occlusions and open periods can be calculated as was done for Table 11, 12 and 13. Open periods can be considered a "look" at the entire environment while occlusions might be considered an interlook interval in which no visual information is obtained from the environment in front of the driver.

Analyses of variances were performed on the data contained in these tables. These analyses indicated:

1. Differences in the mean duration of occlusion time due to subjects and trials were significant at the .0005 level.

2. Differences in the variances of the duration of occlusion times were not statistically significant.

3. Differences in the length of time of the "open" periods were significantly higher for CO
TABLE 11

MEAN DURATION OF "INTERLOOK INTERVAL"
(MEAN DURATION OF OCCLUSION TIMES)
FOR TRIALS INVOLVING VISUAL OCCLUSION
(TIME IN SECONDS)

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Road</td>
<td>4.240</td>
<td>3.312</td>
<td>2.975</td>
<td>3.833</td>
<td>2.398</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant Car Following</td>
<td>3.127</td>
<td>3.064</td>
<td>2.041</td>
<td>3.246</td>
<td>2.368</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perturbated Car Following</td>
<td>2.628</td>
<td>2.603</td>
<td>1.284</td>
<td>2.354</td>
<td>1.852</td>
</tr>
<tr>
<td>Subject</td>
<td>K</td>
<td>D</td>
<td>N</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>---------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
</tr>
<tr>
<td>Trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Head</td>
<td>4.172</td>
<td>1.155</td>
<td>1.937</td>
<td>4.472</td>
<td>1.367</td>
</tr>
<tr>
<td>Trial 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.799</td>
<td>0.789</td>
<td>0.792</td>
<td>1.183</td>
<td>0.876</td>
</tr>
<tr>
<td>Car Following</td>
<td>0.972</td>
<td>0.560</td>
<td>0.269</td>
<td>1.345</td>
<td>1.036</td>
</tr>
<tr>
<td>Subject</td>
<td>K</td>
<td>D</td>
<td>N</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>1.22</td>
<td>0.63</td>
<td>2.33</td>
<td>2.76</td>
<td>0.39</td>
</tr>
<tr>
<td>Constant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>0.68</td>
<td>0.73</td>
<td>3.69</td>
<td>4.40</td>
<td>0.54</td>
</tr>
<tr>
<td>Following</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.39</td>
<td>0.66</td>
<td>2.38</td>
<td>3.88</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>4.05</td>
<td>4.48</td>
<td>1.69</td>
<td>1.61</td>
<td></td>
</tr>
</tbody>
</table>
conditions than for air conditions at a .25 level of significance.

A non-parametric test (binomial test) was applied to the data contained in Table 13 to see if the fact that 12 out of the 15 COHb-Air comparisons indicated that COHb produced longer mean open times. This test indicated that air and CO differences were significant at the .0005 level of significance. (Note: application of the binomial test in this manner implies that separate comparisons across trials for the same subject are independent. If this assumption is not valid then the test can still be applied for the data pooled across trials if this is done for the data in Table 13 the difference due to CO presence is still found to be significant at a .25 level of significance (3 out of 5)).

Means and Variances of "Look" Durations

As was mentioned previously the duration of time that a subject spent looking at an object was determined for each trial and for each level of degradant.

Means and variances of these durations were also computed. The mean duration of looks at each category of eye movements was compared across CO levels for each individual subject and each individual trial and the percentage of these comparisons indicating that COHb produced longer mean look times than air was computed.
This data is summarized in the matrix of Table 14. As can be seen from the table, 62% of these percentages (indicating the percentage of "COHb mean look durations" greater than "air mean look durations") were greater then 50%. In only 20.8% of the cases were these percentages less than 50%. This indicates that under COHb, subjects tend to spend more time per look obtaining information from the objects and areas in their environment.

The following analyses was performed in order to determine if the results just presented concerning the mean look durations could be considered statistically significant. If the null hypothesis that there is no effect due to the presence of carbon monoxide is assumed, then the probability that the number of mean look durations for an individual subject and an individual trial will be either greater or less than 50% under COHb conditions than under air conditions is $^\frac{1}{2}$ (if instances where ties are ignored). As mentioned previously, however, in only 20.8% of the cases (6 out of 29) were the percentage of COHb mean look duration times greater than air mean look duration times less than 50%. If the null hypothesis is true, then the aforementioned result would be expected less than 1% of the time (as determined via a non-parametric Binomial test). The previous
<table>
<thead>
<tr>
<th>Trial</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80%</td>
<td>70%</td>
<td>100%</td>
<td>29%</td>
<td>75%</td>
</tr>
<tr>
<td>2</td>
<td>0%</td>
<td>50%</td>
<td>100%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>3</td>
<td>100%</td>
<td>67%</td>
<td>--</td>
<td>45%</td>
<td>57%</td>
</tr>
<tr>
<td>4</td>
<td>0%</td>
<td>60%</td>
<td>50%</td>
<td>40%</td>
<td>67%</td>
</tr>
<tr>
<td>5</td>
<td>100%</td>
<td>83%</td>
<td>67%</td>
<td>50%</td>
<td>86%</td>
</tr>
<tr>
<td>6</td>
<td>67%</td>
<td>67%</td>
<td>100%</td>
<td>40%</td>
<td>67%</td>
</tr>
</tbody>
</table>
analysis may be considered, therefore, statistically significant at the .01 level of significance. This trend applies to all objects and areas which the subject looked at (with the exception of blinks, speedometer looks, out of view, and rear mirror usage which were analyzed separately).

A similar analysis was performed on the variances of the "look" duration times. Table 15 contains values which represent for a given subject and a given trial the percentage of time that the variance of the duration times of "looks" at different objects and areas were greater under CO than under air. As can be seen from the table, 48.3% of the values are over 50% while only 24.5% of the values are less than 50%. This indicates that the variability of "look" times under COHb for all categories (except blinks, out of view, speedometer and rear mirror) tends to be greater than it is under air.

An analysis was performed on the data contained in the matrix of Table 15 similar to that performed on the data of Table 14. This analysis indicated that the probability of obtaining 24.5% of the values less than 50% was less than 5%. Therefore, the results may be considered significant at the .05 level of significance. (Note: these two analyses also consider that the measures obtained across trials for the same subject are
TABLE 15
PERCENTAGE OF TIME THAT THE VARIANCE OF THE DURATION TIMES OF "LOOKS" AT DIFFERENT OBJECTS AND AREAS WAS GREATER UNDER CO THAN UNDER AIR

<table>
<thead>
<tr>
<th>Trial</th>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>50%</td>
<td>72%</td>
<td>100%</td>
<td>50%</td>
<td>67%</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0%</td>
<td>100%</td>
<td>100%</td>
<td>50%</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>0%</td>
<td>60%</td>
<td>--</td>
<td>75%</td>
<td>60%</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>67%</td>
<td>67%</td>
<td>0%</td>
<td>50%</td>
<td>0%</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>100%</td>
<td>100%</td>
<td>50%</td>
<td>14%</td>
<td>100%</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>100%</td>
<td>100%</td>
<td>50%</td>
<td>50%</td>
<td>0%</td>
</tr>
</tbody>
</table>
independent. If this assumption of independence is not made the binomial test can still be applied by calculating a "mean percentage" for each subject from the data contained in Tables 14 and 15. If this is done for the data contained in Table 14 it will be seen that 4 of the 5 resulting percentages indicate an increase in look duration under CO. This result is significant at the .05 level of significance. A similar pooling of data for the data in Table 15 indicates that two of the mean percentages are greater than 50%, two are less than 50%, while one is equal to 50%. This does not indicate any significant difference due to the presence of CO.)

These two measures tend to distinguish a difference between performance under CO and performance under air. Differences due to task difficulty and level of loading are not apparent with these measures.

Histogram Analysis

Fixation locations with respect to the horizon and the focus of expansion (the point on the horizon where the right and left sides of the road appear to meet) were obtained for two subjects (subject K and subject D) for their performance on trials 1 and 2 (open road trials) at both levels of the degradant. Frequency histograms for both the vertical and horizontal
fixation locations are presented in Figures 8 and 9. As can be seen in Figure 8, subject K’s fixation distribution for trial 1 shifts slightly upward and definitely to the left on the day during which he was administered CO before driving compared to his performance after having been administered air. It can also be noticed that there is a definite spread in the range of the fixation distributions on the CO day perhaps indicating a loss of peripheral vision capabilities.

Performance data for trial 2 where the subjects spare visual capacity was eliminated via voluntary visual occlusions is also presented in Figure 8. As can be seen from the figure, CO tends to produce a shift away from the “normal” horizontal fixation location. In this case the subject showed a shift to the right. The subject’s mean eye fixation location also showed a definite shift downward in this trial.

Figure 9 indicates that COHb presence is reflected by a horizontal shift to the right in the mean eye fixation position for both trials 1 and 2 exhibited by subject D. As with subject K the range of fixation locations indicates that in non-loaded situations CO tends to produce an increase in the horizontal dispersion of eye movements.

Considering these two figures together it seems
FIGURE 8. FIXATION LOCATION ANALYSIS FOR SUBJECT K
FIGURE 9. --FIXATION LOCATION ANALYSIS FOR SUBJECT D
to indicate that carbon monoxide will tend to cause a horizontal shift either to the right or left in the subject's eye fixation location. This might be indicative of a need to obtain lateral placement indication and velocity cues from foveal fixations on the right or left lane marker under CO because of loss of peripheral vision. The data for these subjects was re-examined and it was found in fact that on trial one under air subject K spent 2.62% of his time obtaining information from the left side of the road while under CO he spent 14.49% of the time in that area. During trial 2, on the other hand, this subject looked at the right lane marker 3.45% of the time under air as opposed to 12.67% of the time under CO. Similarly in trial 1 under air, subject D spent 4.46% of his time foveally fixating on the right lane marker while under air he spent 13.17% of his time on the right lane marker. In trial 2, subject D spent only 1.96% of his time on the right lane marker compared to 9.99% of the time under COHb.

These analyses seem to indicate therefore, that the horizontal shifts in eye fixation locations produced by COHb are shifts made by the subject for obtaining lane position and vehicle velocity information. These shifts might also be taken as indicators of a decrement in peripheral vision abilities due to COHb.
Activity Analysis

Reference was made to an apparent increase in the range of fixation locations under COHb in the last analysis. Mourant (1971) found that the range of vertical and horizontal eye fixations was a measure of activity that enabled differences between novice and experienced drivers to be determined. A similar analysis was performed for the data obtained from subjects K and D in this study. This data is presented in Table 16 and Table 17. This data indicates that COHb appears to cause a slight increase in horizontal activity and a slight decrease in vertical activity. If, however, the data for trial 2 is considered separately, it appears that the elimination of spare capacity tends to cause a decrease in both the horizontal and vertical range of activity. This might indicate under the loading associated with the occlusion task a narrowing of attention which isn't apparent under normal vision conditions where foveal fixations in the periphery are made to obtain information that would be obtained with peripheral vision when COHb was not present.

Fixation Density Analysis

Another type of analysis was performed in order to determine how the subject allocated his fixations. This analysis was concerned with determining which
### TABLE 16

**HORIZONTAL RANGE OF EYE FIXATIONS**
*(IN DEGREES OF VISUAL ANGLE)*

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>Air</td>
<td>CO</td>
</tr>
<tr>
<td>Trial</td>
<td>Air</td>
<td>CO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Normal Vision</th>
<th>7</th>
<th>16</th>
<th>7</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 2</td>
<td>Occlusions</td>
<td>15</td>
<td>12</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

### TABLE 17

**VERTICAL RANGE OF EYE FIXATIONS**
*(IN DEGREES OF VISUAL ANGLE)*

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>Air</td>
<td>CO</td>
</tr>
<tr>
<td>Trial</td>
<td>Air</td>
<td>CO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Normal Vision</th>
<th>4</th>
<th>6</th>
<th>9</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 2</td>
<td>Occlusions</td>
<td>11</td>
<td>5</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>
objects and areas in the scene in front of the driver received the most attention in terms of the percentage of time and the number of fixations. For purposes of this analysis certain categories of objects and areas were combined as shown in the diagram of Figure 10. As can be seen from this figure, the categories for sky and bridge (SK+B) were combined as were those for lead car, straight ahead and scenery straight (LC, OC, S, SS). Another category included right lane marker, left lane, right lane and center marker (RLM, LL, RL, CM). Road signs and scenery right (RS, SR) categories were combined while the category scenery left was retained. Data reduction categories of rear mirror (RM), out of view (OV), speedometer (SP), close (C) and blink (BL) were also kept separately.

After forming these new categories, the number of times that a subject driver fixated in one of them and the percentage of time that he spent fixating in them was determined.

This method of analysis proved particularly useful in distinguishing differences in visual search and scan patterns during car following due to the presence of carbon monoxide and loading.

Table 18 presents data for the number of visual fixations made on the lead car in trials 4 and 6.
FIGURE 10

SCHEMATIC OF DIAGRAM USED IN "FIXATION DENSITY" ANALYSES

SK + B

1c+oc
s+ss

SL

RLM, LL, RL, CM

RS + SR

(notation in figure taken from Table 8, page 89)
<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial</td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
</tr>
<tr>
<td>T. 4 - Perturbated Car Following Normal Vision</td>
<td>73</td>
<td>56</td>
<td>66</td>
<td>68</td>
<td>98</td>
</tr>
<tr>
<td>T. 6 - Perturbated Car Following Occlusions</td>
<td>30</td>
<td>68</td>
<td>57</td>
<td>56</td>
<td>67</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>103</td>
<td>124</td>
<td>123</td>
<td>124</td>
<td>165</td>
</tr>
</tbody>
</table>
for each subject at both levels of the degradant. Table 19 presents data for the number of visual fixations made in all of the other categories surrounding the category containing "lead car." Trials 4 and 6 required the subject to follow the lead car which went through a variable velocity profile. In trial 4 the subject used "normal" vision while in trial 6 his vision was occluded whenever he felt it was possible.

As can be seen from these tables CO causes the driver to look at the lead car more often to obtain information about its position. This is particularly evident in the data on trial 6 where the subject's spare visual capacity was eliminated. CO also has the effect of reducing the number of looks that are made on other categories and areas away from the lead car. Again this is particularly apparent when the excess visual capacity is eliminated.

The data included in Table 18 was subjected to a three factor analysis of variance, and the differences due to the three main variables of interest were all found to be statistically significant. Differences due to the trial and to the subjects were both significantly different at the .05 level of significance, while differences between levels of COHb were significant at the .1 level of significance.
## TABLE 19

NUMBER OF LOOKS AT CATEGORIES OTHER THAN LEAD CAR

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trial</strong></td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
</tr>
<tr>
<td>T. 4 - Perturbated Car Following Normal Vision</td>
<td>23</td>
<td>38</td>
<td>53</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>T. 6 - Perturbated Car Following Occlusion</td>
<td>38</td>
<td>1</td>
<td>70</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>61</td>
<td>39</td>
<td>123</td>
<td>28</td>
<td>8</td>
</tr>
</tbody>
</table>
The data of Table 19 was also subjected to a similar analysis which indicated that differences due to the subjects were significant at the .1 level of significance while COHb differences were significant only at the .25 level. Differences due to the task difficulty were not found to be statistically significant. Interactions involving the presence or absence of COHb (i.e., the trial by "environment" and the subject by "environment" interaction) were significant at the .25 level of significance.

This analysis indicates a need for increased foveal concentration on the lead car due to the presence of CO.

It should be stated that despite the usefulness of this data summary technique in pointing out differences in car-following trials due to CO, differences in other categories were not apparent.

Blink Analysis

Eyeblink rates have been found by researchers to be related to the stress associated with a task. Poulton and Gregory (1952) found that blink rate varied inversely with the difficulty of a tracking task (i.e., increased difficulty in the tracking resulted in a decreased blink rate). Mourant (1971) found also that increased task difficulty in driving tended to reduce
the blink rate for novice drivers.

As mentioned previously, eyeblinks were recorded and analyzed in this research study. Two measures related to blinking were obtained. These included:

1. The average blink rate (expressed as the average number per three minute period - the normal length of the trials in this research
2. The percentage of time that the subject spent blinking.

For purposes of analysis the data from trials 2, 5 and 6 was deleted since these trials required the subject to engage in voluntary visual occlusions. This task undoubtedly would have some effect on the blink rate although the exact nature of this effect is not known.

Deleting trials 2, 5 and 6 and considering only the blink rate (percentage values correlate very closely to the rate) results in the matrix of Table 20. As can be seen from the data included in Table 20 the blink rate analysis reveals differences between subjects, task difficulty and carbon monoxide. Increasing task difficulty results in a reduced blink rate, particularly when COHb is included in each task. Carbon monoxide also reduces blink rate when analyzed across trials.

A three factor analyses of variance was performed on the data pertaining to blink rates. Differences due
### TABLE 20

**BLINK RATE ANALYSIS**  
(*RATE = AVERAGE PER 3 MINUTE PERIOD*)

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Road</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>32</td>
<td>85</td>
<td>91</td>
<td>71</td>
</tr>
<tr>
<td>T. 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant Car Following</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>24</td>
<td>61</td>
<td>52</td>
<td>*</td>
</tr>
<tr>
<td>T. 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Car Following</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>40</td>
<td>36</td>
<td>34</td>
<td>76</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>51</td>
<td>96</td>
<td>182</td>
<td>177</td>
<td>220</td>
</tr>
</tbody>
</table>

* Average Value Computed for Analysis Purposes
to carbon monoxide were found to be statistically significant at the .005 level of significance. Differences due to subjects were also significant at the .0005 level of significance while trial differences were barely significant at the .25 level. Trial by subject interactions and subject by COHb level interactions were both found to be significant at the .01 level of significance.

These blink rates are as mentioned primarily indicators of stress and by themselves do not indicate performance decrement. They are, however, useful for comparing different conditions which a driver might be subjected to.

**Speedometer Usage Analysis**

Another analysis that was performed on the data obtained in these studies was to determine for each subject, trial, and level of degradant the number of times that the speedometer was looked at and the percentage of time that was spent looking at the speedometer. This data is presented in Appendix E. Differences between subjects were noticed in the data and it was particularly interesting to note that subject K, a very "experienced research subject" used the speedometer very little. No apparent differences were noticed due to the level of the degradant, but it seemed apparent that the loading imposed by the secondary task (visual occlusion) and the
load imposed in car following tended to reduce the amount of speedometer usage.

Mirror Usage Analysis

An analysis similar to that performed to determine speedometer usage was performed to determine mirror usage. For each subject, trial and level of degradant, the number of times that either rear view mirror was looked at and the percentage of time that was spent looking at the mirrors was determined. This data is also presented in Appendix E. As with speedometer usage, differences between subjects can be noticed in the data and again it was interesting to note that subject K, the "experienced research subject," used the rear view mirrors very little. Again as with speedometer usage no apparent differences were noticed due to the level of the degradant. For the one subject who did use the mirrors frequently, loading due to an increase in task difficulty tended to make him use the mirrors more frequently.

Learning and Eye Movements

Eye movement behavior is a very highly learned type of behavior. The tests reported here did not instruct the driver about what he was to sample and thus eye movement patterns are considered normal. Several of
the tests conducted did, however, require the subject to engage in a task of visual occlusion while driving. This hopefully "new" task might be suspected of being capable of being affected by learning. Graphs of the eye movement behavior (i.e., length of open and closed periods) were obtained for all trials involving visual occlusion. These graphs were examined and no evidence of learning was apparent for any subjects in any trial. One subject's data (subject C) was selected for a more objective and thorough analysis for the effects of learning. Tables 21, 22, and 23 illustrate various measures of performance in the occlusion task for trials involving occlusion. This data obtained for subject C's first day of experimentation (a day on which he was exposed to carbon monoxide) was divided into two segments, the first half and the second half. As can be seen from the data, no consistent learning effects seem to be present.

Control Actuation Analysis

In addition to the aforementioned analyses of eye movement data, analyses of data relating to vehicular control were also made from the recordings made with the oscillograph recorder mounted in the instrumented vehicle.

Two control related variables which were considered
TABLE 21
NUMBER OF OCCLUSIONS

<table>
<thead>
<tr>
<th>Segment of Trial</th>
<th>Trial</th>
<th>T2</th>
<th>T5 Constant Car Follow</th>
<th>T6 Perturbated Car Follow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Half</td>
<td>Open Road</td>
<td>14</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>2nd Half</td>
<td></td>
<td>12</td>
<td>15</td>
<td>22</td>
</tr>
</tbody>
</table>

TABLE 22
MEAN DURATION OF OCCLUSIONS

<table>
<thead>
<tr>
<th>Segment of Trial</th>
<th>Trial</th>
<th>T2</th>
<th>T5 Constant Car Follow</th>
<th>T6 Perturbated Car Follow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Half</td>
<td>Open Road</td>
<td>4.079</td>
<td>3.933</td>
<td>2.784</td>
</tr>
<tr>
<td>2nd Half</td>
<td></td>
<td>4.212</td>
<td>3.600</td>
<td>2.359</td>
</tr>
</tbody>
</table>

TABLE 23
% OF TIME IN OCCLUSION

<table>
<thead>
<tr>
<th>Segment of Trial</th>
<th>Trial</th>
<th>T2</th>
<th>T5 Constant Car Follow</th>
<th>T6 Perturbated Car Follow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Half</td>
<td>Open Road</td>
<td>60.68</td>
<td>51.98</td>
<td>56.11</td>
</tr>
<tr>
<td>2nd Half</td>
<td></td>
<td>56.61</td>
<td>60.33</td>
<td>63.92</td>
</tr>
</tbody>
</table>
in this series of experiments were the gas pedal actuation behavior and the brake pedal actuation behavior of the subject driver. More specifically, it was hypothesized that the number and duration of brake applications and the number and duration of gas pedal releases (periods of time in which the driver took his foot off the gas) as well as the number of gas pedal reversals would be related to task difficulty, secondary task loading and differences in the level of the degradant.

With respect to control movements, the number of gas pedal reversals (as measured by the number of times that the slope of the gas pedal trace changed sign) exhibited by the subjects in each of the trials was obtained. This data is summarized for each subject in Table 24. Table 25 summarizes this data for subjects combined with each other. As can be seen from the data, particularly the data contained in Table 25, the measure of gas pedal reversals seems to be a measure that is sensitive to task difficulty, loading, and the presence of CO. As indicated in the data, increasing task difficulty tends to increase the number of gas pedal reversals. This is to be expected, however, since the more difficult tasks required more control movements. Loading the driver by requiring him to engage in a voluntary visual occlusion task results in a lowering of
### Table 24

**Gas Pedal Reversals Summary**

<table>
<thead>
<tr>
<th>Subject</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trial</strong></td>
<td><strong>Air</strong></td>
<td><strong>CO</strong></td>
<td><strong>Air</strong></td>
<td><strong>CO</strong></td>
</tr>
<tr>
<td>Trial 1:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Road - Normal Vision</td>
<td>4</td>
<td>8</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Trial 2:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Road - Occluded Vision</td>
<td>6</td>
<td>2</td>
<td>23</td>
<td>12</td>
</tr>
<tr>
<td>Trial 3:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant Car Following</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Vision</td>
<td>87</td>
<td>47</td>
<td>68</td>
<td>83</td>
</tr>
<tr>
<td>Trial 4:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perturbed Car Following</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Vision</td>
<td>48</td>
<td>--</td>
<td>58</td>
<td>64</td>
</tr>
<tr>
<td>Trial 5:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant Car Following</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occluded Vision</td>
<td>42</td>
<td>29</td>
<td>36</td>
<td>38</td>
</tr>
<tr>
<td>Trial 6:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perturbed Car Following</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occluded Vision</td>
<td>40</td>
<td>16</td>
<td>48</td>
<td>38</td>
</tr>
</tbody>
</table>

Values are the Number of Reversals Per 3 Minute Period
TABLE 25
GAS PEDAL REVERSALS SUMMARY FOR ALL SUBJECTS COMBINED
(REVERSALS PER 3 MINUTE PERIOD)

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th></th>
<th>CO</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal Vision</td>
<td>Occluded Vision</td>
<td>Normal Vision</td>
<td>Occluded Vision</td>
</tr>
<tr>
<td>Open Road</td>
<td>16.8</td>
<td>12.7</td>
<td>21.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Constant Car</td>
<td>65.6</td>
<td>38.2</td>
<td>57.5</td>
<td>26.8</td>
</tr>
<tr>
<td>Following</td>
<td>65.7</td>
<td>44.0</td>
<td>64.0</td>
<td>39.2</td>
</tr>
<tr>
<td>Perturbated Car</td>
<td>148.1</td>
<td>84.9</td>
<td>143.0</td>
<td>73.5</td>
</tr>
<tr>
<td>Column Total</td>
<td>233.0</td>
<td></td>
<td>216.5</td>
<td></td>
</tr>
<tr>
<td>Combined Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the number of gas pedal reversals. The presence of carbon monoxide (20% COHb) also results in a decrease in the number of gas pedal reversals. The effects of carbon monoxide are particularly evident when comparisons for COHb effects are made across trials involving load.

These results indicate that both loading and carbon monoxide result in a decrease in the amount of control activity exhibited by the driver.

The data contained in Table 25 was subjected to a three factor analysis of variance test. The results of that test indicate that gas pedal reversals are significantly different for the two COHb levels at the .025 level of significance. Trials and the presence or absence of spare capacity produced differences significant at the .005 level of significance. One interaction, the trial by "loading" interaction was found to be significant at the .05 level of significance. The other two interactions, trial by COHb and COHb by loading, were barely significant at the .25 level of significance.

Another measure of control activity that was considered in this research was the number of times that a driver took his foot off the gas pedal and the number of times that a subject placed his foot on the brake pedal. This data is summarized for each individual subject in Appendix E. As can be seen from the table,
very little activity of this nature is exhibited by the subjects in trials 1 and 2 (open road driving with and without visual occlusion). The data for trials 3, 4, 5 and 6 is combined across subjects in Tables 26 and 27.

As can be seen in Table 26 the measure of the number of times that a driver takes his foot off the gas pedal appears to be sensitive to task difficulty, loading and COHb. As with the measure of gas pedal reversals, task difficulty increases the number of such control actions while the stress imposed with the loading associated with an elimination of spare capacity and COHb results in a reduction in the quantity of such control movements.

Table 27 indicates that the measure of brake pedal activations can be used as indicators of task difficulty and as an indicator of stress associated with the elimination of spare capacity. CO effects are apparent in the perturbated car following condition but are not as evident in the constant car following condition possibly due to the very small number of control movements of this nature made in constant speed car following.

In addition to the number of control movements exhibited by the subject drivers in this experiment, the length or duration of these control movements was also
### TABLE 26
"GAS PEDAL OFF" SUMMARY  
(AVERAGE VALUES PER 3 MINUTE PERIOD)

<table>
<thead>
<tr>
<th>Gas + Mode</th>
<th>Air</th>
<th>COHb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal Vision</td>
<td>Occluded Vision</td>
</tr>
<tr>
<td>Trial</td>
<td>Normal Vision</td>
<td>Occluded Vision</td>
</tr>
<tr>
<td>Constant Car Following</td>
<td>10.2</td>
<td>7.0</td>
</tr>
<tr>
<td>Perturbated Car Following</td>
<td>14.6</td>
<td>9.6</td>
</tr>
</tbody>
</table>

### TABLE 27
"BRAKE PEDAL ON" SUMMARY  
(AVERAGE VALUES PER 3 MINUTE PERIOD)

<table>
<thead>
<tr>
<th>Gas + Mode</th>
<th>Air</th>
<th>COHb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal Vision</td>
<td>Occluded Vision</td>
</tr>
<tr>
<td>Trial</td>
<td>Normal Vision</td>
<td>Occluded Vision</td>
</tr>
<tr>
<td>Constant Car Following</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Perturbated Car Following</td>
<td>4.8</td>
<td>3.9</td>
</tr>
</tbody>
</table>
measured. This data for individual subjects is presented in Appendix E. Although differences in this data could be seen between subjects, and between levels of task difficulty, the data does not indicate any apparent differences due to loading or to COHb.

Velocity Analyses

The velocity of the instrumented vehicle being driven by the subject in this series of tests was measured and recorded using the equipment described in the appendix. This data was subsequently reduced with samples taken at every one second interval for all trials and levels of degradants.

Velocity means and variances for tests 3, 4, 5 and 6, all of which involve car-following, are primarily dependent upon the speed profile of the lead vehicle. Since the lead vehicle maintained the same velocity profile across levels of degradant for each test, we would not expect to find much difference between velocity measures in these tests. In fact, no apparent differences were noticed in velocity means and variances for these tests. On the other hand, test 1 and 2 involved open road driving and here the speed was determined solely by the subject who was instructed to "drive in your normal manner at about 50 miles per hour" (test 2 also incorporated the additional requirement to engage
in voluntary occlusions whenever possible). Table 28 presents the velocity means for all subjects for trials 1 and 2. As can be seen, this data indicates that subjects tend to drive slightly faster under the effects of CO then they do under air. This difference is apparent for both levels of loading. Loading also has an effect on performance inasmuch as it tends to reduce the speed slightly.

Velocity variances were also obtained and are presented in the matrix of Table 29. As can be seen from the data presented in the table, a 20% carbony-hemoglobin level tends to increase the velocity variance that the subject exhibits. This increase holds for both levels of loading. The loading task on the other hand tends to decrease the velocity variance slightly.

A three factor analyses of variance was performed on the data contained in the matrix of Table 28. This analyses failed to show significance at the .05 level in the differences due to any of the main factors (subjects, CO level or amount of spare capacity). This failure is perhaps due to the sample size which is relatively small.

The differences in velocity variances due to the loading associated with the elimination of spare capacity were found to be significantly different at the .10 level of significance when tested via a three factor
TABLE 28
VELOCITY MEANS

<table>
<thead>
<tr>
<th>Gas+ Mode</th>
<th></th>
<th>Air</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1: Open Road</td>
<td>Trial 2: Open Road</td>
<td></td>
</tr>
<tr>
<td>Subj</td>
<td>Normal Vision</td>
<td>Occluded Vision</td>
<td>Normal Vision</td>
</tr>
<tr>
<td>D</td>
<td>50.59</td>
<td>49.99</td>
<td>55.68</td>
</tr>
<tr>
<td>N**</td>
<td>54.50</td>
<td>53.91</td>
<td>52.61</td>
</tr>
<tr>
<td>B</td>
<td>50.34</td>
<td>43.82</td>
<td>51.94</td>
</tr>
<tr>
<td>C</td>
<td>50.81</td>
<td>50.59</td>
<td>48.49</td>
</tr>
<tr>
<td>Column Mean</td>
<td>51.31</td>
<td>49.57</td>
<td>52.18</td>
</tr>
<tr>
<td>&quot;Combined&quot; Mean</td>
<td>50.44</td>
<td></td>
<td>51.33</td>
</tr>
</tbody>
</table>

* Only Partial Data Obtained For Subjects Q and K.

** Data For Subject N Under "Air" Represents the Average of Two Replications.
### TABLE 29

**VELOCITY VARIANCES**

<table>
<thead>
<tr>
<th>Gas + Mode</th>
<th>Subject</th>
<th>Air Trial 1: Open Road Normal Vision</th>
<th>Air Trial 2: Open Road Occluded Vision</th>
<th>CO Trial 1: Open Road Normal Vision</th>
<th>CO Trial 2: Open Road Occluded Vision</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>3.958</td>
<td>3.187</td>
<td>8.992</td>
<td>3.989</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3.028</td>
<td>3.285</td>
<td>2.776</td>
<td>2.809</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1.339</td>
<td>2.818</td>
<td>3.943</td>
<td>5.524</td>
</tr>
<tr>
<td></td>
<td><strong>Column Mean</strong></td>
<td><strong>4.261</strong></td>
<td><strong>3.344</strong></td>
<td><strong>5.538</strong></td>
<td><strong>3.419</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Combined Mean</strong></td>
<td><strong>3.802</strong></td>
<td></td>
<td><strong>4.479</strong></td>
<td><strong>130</strong></td>
</tr>
</tbody>
</table>
analyses of variance. This same test, however, failed to show significance in the differences found due to COHb levels or trials.

Headway Analysis

From the television tapes collected during the experimentation measurements were made of the image size of the lead car during car following trials. From these measurements the headway or distance of the lead car driven by the subject was computed for every one second interval. Means and variances were then computed for each of the car following trials for each subject and each level of degradant. This data is presented in Appendix E. A three way analysis of variance performed on this data failed to distinguish any statistically significant differences due to the level of degradant (COHb). Differences due to subjects and trials were, however, significant at the .05 level of significance. (It should be pointed out that the errors associated with determining headway from the image size of a vehicle on a TV screen tend to mask small differences such as might be expected due to levels of COHb.)

Learning and Control Movements

In order to check for the possibility of learning, the data for one subject (subject C) was chosen and portions of that data were analyzed for possible changes
due to learning. More specifically the velocity data for trials 1 and 2 (non car following trials) was chosen and means and variances were calculated for the data for the first half of the trial and for the second half of the trial (Table 30 and 31). If learning was a factor in the subjects performance we would expect that second half performance would improve. This improvement might be expressed by a decreased velocity variance. As can be seen from the Table 31, however, the velocity variance indicates a slight increase not indicative of learning.

The gas pedal reversals exhibited by subject C in these trials were also examined. This examination indicated that in the first half of trial 1, six reversals were made while in the second half of the same trial, eleven reversals were made. In the trial 2, however, only 2 reversals were made in the first half of the trial as opposed to 5 for the second half. If learning were present it might be reflected in a reduction of the gas pedal reversals as the driver became more adept at maintaining his desired velocity. The data does not, however, indicate that this is the case.

Dependent Variable Correlation

The analysis described in this section was performed in order to determine how the various dependent
### TABLE 30

**VELOCITY MEANS**

(MILES PER HOUR)

<table>
<thead>
<tr>
<th>Trial Segment of Trial</th>
<th>T1: Open Road Normal Vision</th>
<th>T2: Open Road Occluded Vision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Half</td>
<td>47.48</td>
<td>48.61</td>
</tr>
<tr>
<td>2nd Half</td>
<td>49.52</td>
<td>48.78</td>
</tr>
</tbody>
</table>

### TABLE 31

**VELOCITY VARIANCES**

(MILES PER HOUR)$^2$

<table>
<thead>
<tr>
<th>Trial Segment of Trial</th>
<th>T1: Open Road Normal Vision</th>
<th>T2: Open Road Occluded Vision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Half</td>
<td>1.36</td>
<td>3.52</td>
</tr>
<tr>
<td>2nd Half</td>
<td>4.36</td>
<td>7.27</td>
</tr>
</tbody>
</table>
variables previously considered separately might be related to each other. The six dependent variables which were found to be most sensitive to differences in the three major independent variables (COHb level, subjects, tasks) were selected for this analysis. These dependent variables included:

1. visual spare capacity in tasks involving occlusion
2. mean duration of "open" times in occlusion tasks
3. number of looks at lead car in car following tasks involving visual occlusion
4. blink rates for tasks not involving visual occlusion
5. gas pedal reversals for all tasks
6. velocity variance for all open road tasks.

Two types of measures were obtained for each of these independent variables for each subject who participated in the testing. These measures included the average magnitude of the dependent variable across all trials considered in the experiments and the average magnitude of the difference in the dependent variable due to the presence of COHb across all "pairs" of trials considered.

Pairwise linear regressions were then computed for each possible pair of these dependent variables and for both types of measures of performance across subjects.
The correlation coefficients associated with the linear regressions were also computed. These correlation coefficients which indicate the extent to which the various dependent variables are related are presented in the matrix of Table 32. The correlation coefficients associated with the pairwise regressions of the magnitude of the values of the dependent variables are presented in the cells above the diagonal of the matrix. The correlation coefficients of the regressions of the values indicating the magnitude of the differences between CO and air are presented in the cells below the main diagonal of the matrix.

Several interesting relationships are apparent from the values presented in the matrix. Some of these relationships are presented below.

As can be seen from the matrix several of the dependent variables seem to be related. With respect to the actual magnitude of the dependent variables the following pairs of dependent variables produced high correlations (above .700):

1. Mean duration of "open" times and number of looks at lead car
2. Mean duration of "open" times and blink rates
3. Number of looks at the lead car and gas pedal reversals
<table>
<thead>
<tr>
<th>Dep. Variable</th>
<th>Visual Spare Capacity</th>
<th>Mean Duration of &quot;Open&quot; Times</th>
<th>Number of Looks at Lead Car</th>
<th>Blink Rate</th>
<th>Gas Pedal Reversals</th>
<th>Velocity Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Spare Capacity</td>
<td></td>
<td>-.579</td>
<td>-.149</td>
<td>-.805*</td>
<td>.653</td>
<td>-.092</td>
</tr>
<tr>
<td>Mean Duration of &quot;Open&quot; Times</td>
<td>.944*</td>
<td></td>
<td>.776</td>
<td>.849*</td>
<td>.118</td>
<td>.439</td>
</tr>
<tr>
<td>Number of Looks At Lead Car</td>
<td>.903*</td>
<td>.748</td>
<td></td>
<td>.592</td>
<td>.817</td>
<td>.169</td>
</tr>
<tr>
<td>Blink Rate</td>
<td>.604</td>
<td>.202</td>
<td>.261</td>
<td></td>
<td>.404</td>
<td>.753</td>
</tr>
<tr>
<td>Gas Pedal Reversals</td>
<td>-.461</td>
<td>-.001</td>
<td>-.425</td>
<td>-.956*</td>
<td></td>
<td>.441</td>
</tr>
<tr>
<td>Velocity Variance</td>
<td>-.976*</td>
<td>-.873</td>
<td>-.976*</td>
<td>-.662</td>
<td>.442</td>
<td></td>
</tr>
</tbody>
</table>
4. Blink rate and velocity variance
5. Blink rate and spare visual capacity
   (negatively related).

It is interesting to note that all of these high correlations are for pairs of variables including at least one measure of visual performance. This would seem to indicate that subject differences with respect to one visual parameter might be reflected in another visual parameter or in a performance measure such as velocity variance or gas pedal reversals.

Of even more interest are the high correlations that are observed below the main diagonal of the matrix. These high correlations were obtained in comparisons of the following pairs of dependent variables:

1. Visual spare capacity and mean duration of "open" times
2. Visual spare capacity and the number of looks at the lead car
3. Visual spare capacity and velocity variance (negatively correlated)
4. Number of looks at the lead car and mean duration of "open" times
5. Mean duration of "open" times and velocity variance
6. Number of looks at the lead car and velocity variance
7. Blink rate and gas pedal reversals (negative correlation)

Again it is interesting to note that all of these pairs of variables include one or more measures of visual performance. These positive correlations tend to indicate a degradant such as COHb which affects one visual parameter will simultaneously affect another visual parameter. The high correlations between changes in visual spare capacity and the mean duration of "open" times and the number of looks at the lead car indicate that the decrease in spare capacity due to the presence of COHb reflects an increase in the time necessary to obtain the information necessary for adequate driving performance.

The high negative correlation between blink rates and gas pedal reversals is interesting because it suggests that if both are measures of stress associated with a task then it is not sufficient to consider only one measure of stress in assessing a task. That is, different individuals may react to stress in differing ways.

The negative correlations obtained when velocity variance differences due to COHb were compared to decrements in other dependent variables suggests that compensatory mechanisms are operating. That is an increase in the time spent obtaining information
enables a driver to compensate for decreased ability in maintaining velocity.

Results Summary

Several significant results were presented in this chapter. Table 33 summarizes the results for which statistical significance was evident. These results are commented on below.

With respect to the measure of visual spare capacity (i.e., the percentage of time that a driver was able to keep his eyes closed), it was found that carbon monoxide and task difficulty both tended to cause decreases in the spare capacity.

Other eye movement performance measures were also found to be sensitive to COHb level, task difficulty and loading (due to elimination of spare capacity) as detailed below.

1. Carbon monoxide tended to cause an increase in the "mean open" time for occlusion tasks
2. Carbon monoxide tended to increase the mean "look" duration for automobile drivers
3. Variance of look times also tended to increase with CO
4. Carbon monoxide tended to cause a lateral shift in fixation location (to the right lane marker or left center marker)
### TABLE 33

**SUMMARY OF RESULTS OF ANALYSES SHOWING SIGNIFICANT DIFFERENCES**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Significant Difference Due To</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trials</td>
</tr>
<tr>
<td>1. Spare Visual Capacity</td>
<td>.25</td>
</tr>
<tr>
<td>2. Interlook Interval (Looks at Lead Car)</td>
<td>NS</td>
</tr>
<tr>
<td>3. Length of Look at Lead Car</td>
<td>.001</td>
</tr>
<tr>
<td>4. Mean Duration of Occlusion Periods</td>
<td>.0005</td>
</tr>
<tr>
<td>5. Variance of Occlusion Duration</td>
<td>NS</td>
</tr>
<tr>
<td>6. Mean Duration of Open Road</td>
<td>-</td>
</tr>
<tr>
<td>7. Mean of Look Duration</td>
<td>-</td>
</tr>
<tr>
<td>8. Variance of Look Duration</td>
<td>-</td>
</tr>
<tr>
<td>9. Number of Looks at Lead Car</td>
<td>.05</td>
</tr>
<tr>
<td>10. Number of Looks Not at Lead Car</td>
<td>NS</td>
</tr>
<tr>
<td>11. Blink Rate Analysis</td>
<td>.25</td>
</tr>
<tr>
<td>12. Gas Pedal Reversal Rate</td>
<td>-</td>
</tr>
<tr>
<td>13. Velocity Variance</td>
<td>NS</td>
</tr>
<tr>
<td>14. Headway Means</td>
<td>.05</td>
</tr>
<tr>
<td>15. Headway Variances</td>
<td>.05</td>
</tr>
</tbody>
</table>

*NS = Not Significant (<.25)*

* = Not Tested

* Assuming Independence Across Trials for Individual Subjects
5. Carbon monoxide tended to cause an increase in frequency of fixation on the lead car in car-following while at the same time it caused a decrease in the frequency of fixations on objects or areas other than the lead car.

6. Speedometer usage was found to decrease during trials where spare visual capacity was eliminated but mirror usage tended to increase slightly with loading.

7. Blink rates measured using the Systems Research Group eye marker camera system were found to reflect the stress associated with CO poisoning and task loading.

Several measures of vehicular control performances were also found to be sensitive to the effects of carbon monoxide, the amount of spare capacity, and task difficulty. These effects are summarized below.

1. Carbon monoxide tends to increase the mean velocity in elected velocity driving trials. This effect was particularly apparent when spare visual capacity was diminished.

2. Carbon monoxide also tended to increase velocity variance when the subject was able to elect his velocity.
3. Gas pedal reversals were found to be effected by task difficulty, COHb, and elimination of spare capacity. Task difficulty tended to increase the number of reversals, while COHb and the elimination of spare capacity tended to decrease the number of reversals.

4. The number of "gas pedal releases" and the number of brake pedal actuations also tended to increase with an increase in task difficulty and decrease with CO presence and loading.

Several interesting correlations were also noted between the individual dependent variables which were considered in the experiment.

Despite these differences noted here, the subject drivers were able to drive in an essentially "error free" manner. That is, they exhibited no gross failures and experienced no accidents or near accidents. The changes in performance which were noted above indicate, therefore, that the driver had to exert more effort and use a portion of his spare capacity to achieve this error free performance. Despite the "error-free" performance some decrements in performance were still noted such as an increase in velocity variance and less sensitive control movement activity.
CHAPTER 5

ANALYSES OF BASELINE DATA
Introduction

As mentioned in the previous chapter, one subject, (subject K) was tested on several baseline experiments on the highways in addition to the standard tests conducted after "gassing" with either air or CO. These baseline tests are described below:

1. Baseline series 1 (no eye marker equipment worn, no gassing procedures employed)--This series of tests was essentially the same as the series described in the previous chapter with the exception that the subject was not exposed to any gassing procedures (see Appendix D) prior to driving and the subject did not wear the eye marker camera gear while driving.

2. Baseline series 2 (eye marker equipment worn, no gassing procedures employed)--This series was identical with baseline series 1 with the exception that the subject driver wore the Systems Research Groups eye movement camera equipment.

3. Night Baseline tests (eye marker equipment worn, no gassing procedures employed)--This series of tests was identical with baseline
series 2 except that it was conducted at night (approximately 2 hours after sunset).

These tests were designed to enable some insights to be gained concerning possible experimental artifacts contained in the data due to the research equipment and experimental procedures employed. From these baseline tests several kinds of comparisons were possible as explained below:

Comparison of data obtained in baseline series 1 (no eye marker equipment, no gassing procedures) with the data obtained in baseline series 2 (no gassing procedures) enabled the determination of the effects of wearing the eye marker equipment.

Comparison of data obtained in baseline series 2 (no gassing procedure) with the data obtained at night (no gassing procedures) enabled the effects of night driving to be determined.

Differences between the data obtained in baseline 2 (no gassing procedures) testing and the data obtained on the day that air was administered to subject K can be taken as indicative of the effects due to the gassing procedures that were employed during the testing.

Results

Blink Rate Analysis

Gregory and Poulton (1952) and Mourant (1971)
have found that one measure of performance that is useful in determining the amount of stress associated with a task is the blink rate exhibited by the subject while performing the task. Blink rates were obtained in the baseline data by analyzing the television tapes. The blink rates for the baseline series of tests and the blink rates for subject K's performance under it are presented in the matrix of Table 34.

As can be seen from the data, the largest number of blinks tend to occur in the tests associated with baseline series 1. The effect of wearing the helmet is to reduce the blink rate slightly (indicative of some stress). An analysis of the blink rate data obtained during nighttime tests indicates a further reduction when compared to the baseline 2 series of tests. Blink rates are at their lowest for subject K on the day when he had been exposed to the procedure associated with the gassing preparation.

This analyses would seem to indicate that on the days that the subject was being tested to determine the effects of the degradant he was under more stress then on any of the "baseline days." The least stressful situation appears to occur, not too surprisingly, when the subject is able to drive unincumbered by any research equipment and without participating in any pretest preparation or tasks.
<table>
<thead>
<tr>
<th>Trial</th>
<th>Day</th>
<th>Baseline 4 No Helmet No Gas</th>
<th>Baseline 2 Helmet No Gas</th>
<th>Air Ron Helmet Gas: Air</th>
<th>Night Baseline Helmet No Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>Open Road</td>
<td>NA</td>
<td>36.0</td>
<td>NA</td>
<td>37.0</td>
</tr>
<tr>
<td>Trial 3</td>
<td>Constant Car Following</td>
<td>43.2</td>
<td>38.4</td>
<td>16.8</td>
<td>30.0</td>
</tr>
<tr>
<td>Trial 4</td>
<td>Perturbated Car Following</td>
<td>55.2</td>
<td>36.0</td>
<td>20.4</td>
<td>28.8</td>
</tr>
</tbody>
</table>

NA = Not Available
Head Movement Analysis

One criticism that occasionally is voiced concerning the use of eye movement recording equipment is that the equipment inhibits head movements and the data thus obtained is not representative of the data that would be obtained without the equipment.

The Systems Research Groups eye marker recording equipment (described in Appendix A) is a unique system inasmuch as the drivers head is not fixed in any one position and is free to turn in any direction. It can also be argued that in certain experiments (for example, in research designed to test for the effects of a low level degradant) the presence of the equipment in all trials does not influence the results. Nonetheless it seems reasonable to suspect that the quantity and magnitude of head movements might be altered by the use of eye movement measuring equipment regardless of how flexible it is. A comparison of the data obtained in the test of "baseline series 1" and "baseline series 2," enables a determination of the differences in head movements due to the helmet to be obtained.

As is mentioned in Appendix A, one of the television cameras in the instrument vehicle is aimed at a small mirror mounted on the A pillar of the automobile which reflects an image of the drivers left eye. This image is lost if the driver moves his eye position with
respect to the car (by moving his head) up or down about 2 inches or backwards or forwards about two inches. The image is also lost if the driver rotates his head to the right more than about 45°.

One measure of head movements is, therefore, the percentage of time that the image of the drivers eye is out of view. While wearing the helmet of the Systems Research Groups eye movement recording system, the image of the drivers eye virtually never leaves the mirror. This is not always true, however, when the eye movement helmet is not worn. Table 35 contains the percentage of time for each test in baseline series 1 that the image of the subjects eyeball was out of view of the television camera. Table 35 also contains an indication of the number of times that the subjects eye disappeared from view.

As can be seen from the table, head movements sufficiently large to cause the eye image to go out of view were noticed in those trials where the subjects spare visual capacity was not deleted.

Subjective observations made by the experimenter suggested that the head movements which caused the eye image to move sufficiently far so as to be lost from the view of the camera were not the kind of head movements that would be made for purposes of information seeking (e.g., turning the head to look for merging traffic
TABLE 35

ANALYSIS OF GROSS HEAD MOVEMENTS

| Trial | Measure | Baseline 1 | | Air Run: E.M. Helmet Worn Gas Administered Air |
|-------|---------|------------|------------|
|       |         | No E.M. Helmet No Gas | | |
| T.1   | Open Road No Load | 11 | 9.23 | 0 | 0.0 |
| T.2   | Open Road Visual Occlusion | 0 | 0.0 | 0 | 0.0 |
| T.3   | Car Following Constant Speed - No Load | 6 | 1.95 | 0 | 0.0 |
| T.4   | Car Following Variable Speed - No Load | 7 | 8.77 | 0 | 0.0 |
| T.5   | Car Following Constant Speed Visual Occlusion | 0 | 0.0 | 0 | 0.0 |
| T.6   | Car Following Variable Speed Visual Occlusion | 0 | 0.0 | 0 | 0.0 |
or traffic in the other lane), but rather were head movements associated with "body movements" (e.g., slouching in the seat, shifting to the side or bending the back forwards). This plus the fact that no gross head movements were noticed when spare capacity was eliminated suggests that in driving situation similar to those employed in this series of experiments, that gross head movements are not made for purposes of obtaining "essential" information.

The presence of the eye marker helmet does seem to have a slightly inhibitory effect on the number of times that the subject samples the speedometer and the mirror in open-road "normal vision" driving. Table 36 presents the data obtained relative to the speedometer and mirror usage in the "baseline series 1" and the "baseline series 2" trials. As can be seen from the data, when the mirror or speedometer are sampled by the subject (which occurs infrequently) they are sampled more without the helmet.

Attempts were made to see if any of the other performance measures collected during the baseline tests could be used to reflect differences due to the parameters of the tests. Specifically subject K's spare capacity measure, velocity means, and variances, vehicular control actuation (i.e., gas pedal reversals, brake pedal applications and gas pedal releases), and headway
<table>
<thead>
<tr>
<th>Trial</th>
<th>Measure</th>
<th>Speedometer Usage (Number)</th>
<th>Mirror Usage (Number)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline 1</td>
<td>Baseline 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Gas</td>
<td>No Gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Helmet</td>
<td>Helmet</td>
</tr>
<tr>
<td>T.1 Open Road</td>
<td></td>
<td>34</td>
<td>12</td>
</tr>
<tr>
<td>No Load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.2 Open Road</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Visual Occlusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.3 Car Following</td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Constant Speed - No Load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.4 Car Following</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Variable Speed - No Load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.5 Car Following</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Constant Speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Occlusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.6 Car Following</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Variable Speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Occlusion</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
were examined for his baseline 1 trials (no helmet and no gas) and for the baseline 2 trials (helmet and no gas) to see if any differences could be found which would indicate an effect of wearing the eye marker helmet. Analyses of these measures failed to distinguish any differences due to the presence of the eye marker helmet.

Effect of Subject Preparation

With the exception of the decrease in blink rates (indicative of mild stress) no differences in performance measures were apparent when data from the "baseline series 2" tests were compared with the data obtained on the day during which subject K was given the gas air.

Day Versus Night Comparisons

Mention has already been made of the effect of night driving on blink rate. Blink rates tend to decrease with the stress associated with nighttime driving. No other differences in performance measures were, however, apparent when data from the "baseline series 2" tests were compared with the data obtained in the "night baseline" tests.

Summary of Results

The analyses presented in this chapter indicate that some subject stress can be expected from the experimental procedures and equipment employed in this research.
The presence of the eye marker camera was found to have a slightly inhibitory effect on driver head movements, but in general, the head movements that are inhibited are not movements made for purpose of seeking information.
CHAPTER 6

DETERMINATION OF EYE MOVEMENT FIXATION

DISTRIBUTION CHARACTERISTICS
CHAPTER 6

Introduction

One of the major measures of performance considered in this research has been the manner in which a driver visually samples from his environment to obtain the information necessary to perform his task in an "error-free" manner. Measures of visual sampling were obtained for subjects with "normal" vision and for the same subjects when their spare visual capacity had been eliminated by voluntary visual occlusion.

Several differences in visual sampling behavior were found across levels of independent variables of interest. For example it was found that a majority of the "mean times for look durations" were greater under COHb than under air.

In no case, however, were parametric statistical tests requiring the assumption of normality used to compare individual distributions of eye "looks" with other distributions, because it was felt that these distributions were not normal in nature.

The purpose of this chapter is to determine if this assumption of non-normality is true and if it is true to determine if some other distribution can be
found which can be used to describe the data.

**Tests for Normality**

Histograms of look durations were plotted for several subjects for selected trials and for looks at selected objects or categories. These selections were made in the following manner: Data for the five subjects for whom eye movement had been recorded on both days of experimentation involving CO and air were selected (Subjects K, Q, N, B, and C). Data for the day on which air had been used as a gas was selected and histograms of look durations were prepared for "looks" at the "object or category receiving the highest number of looks" in trials 1, 2, 4, and 6. These trials were chosen because they represented the widest possible ranges of the independent variables of task difficulty and loading due to the elimination of spare capacity. The choice of the object or category receiving the largest number of looks was made in order to insure a large sample for each histogram. In the "open road" trials (trials 1 and 2), the category normally receiving the most looks was the category, "straight ahead," while in the car-following trials the category receiving the largest number of looks was not too surprisingly the category "lead car." Samples of these histograms are presented in the figures in Appendix E. For purposes of checking
on the assumption of normality, the distribution exhibiting characteristics most like those of a normal distribution was chosen (subject K, trial 6) and a comparison was made via a Chi square goodness of fit test between the data contained in the histogram with the theoretical values obtained from a normal distribution with the same mean and variance as the sample distribution. The results of this test (see Appendix E) indicated that the hypothesis that the sample data was distributed normally was rejected at the .10 level of significance.

The results of this test indicate that comparisons of eye movement "look" duration distributions via tests requiring the assumption of normality are not valid.

Other Distributions

Another possible distribution which can be fit to eye fixation data, is the Weibull Distribution. The cumulative distribution function for the Weibull Distribution is given by the formula:

\[ F(x) = 1 - e^{-\frac{(x-\gamma)}{\alpha}} \]

where:
\[ \alpha, \beta > 0 \]
\[ x > \gamma \]

and

The probability density function is given by the formula:

\[ f(x) = \frac{\beta}{\alpha} (x-\gamma)^{\beta-1} e^{-\frac{(x-\gamma)}{\alpha}} \]
where again:
\[ \alpha, \beta > 0 \]
and
\[ x > \gamma \]

The parameter \( \gamma \) is a location parameter which is equal to the minimum possible value of the random variable. If \( \gamma \) can be taken to be equal to zero, which it can be with eye-movement data since it is not possible to have a "look" of a duration less than "zero seconds," then these formulas reduce to:

\[
F(x) = 1 - e^{-\frac{x}{\alpha}} \quad \text{and} \quad f(x) = \frac{\beta}{\alpha} (x)^{\beta-1} e^{-\frac{(x)^\beta}{\alpha}}
\]

where again:
\[ \alpha, \beta > 0 \]

The range of shapes that the graph of the Weibull density can take is very broad and depends primarily on the parameter \( \beta \) which is often referred to as the "shape" parameter. If \( \beta < 1 \) then a curve is obtained with asymptotes to both axes. If \( \beta = 1 \) then the density function is identical to the density function for a "negative exponential" distribution. If \( \beta < 3.25 \) then the curve obtained is a curve which is skewed to the right. If \( \beta = 3.25 \) then the density of the Weibull distribution is very "similar" to the normal density function. Finally, if \( \beta \) is greater than 3.25 a symmetric bell shaped curve is obtained with a "peak" greater
FIGURE 11. POSSIBLE SHAPES OF THE WEIBULL DISTRIBUTION
than the peak for the "normal" curve. A sample of the shapes of these curves is given in Figure 11.

Estimates of the parameters $\alpha$ and $\beta$ of the Weibull distribution are somewhat difficult to obtain. An analytical method for obtaining estimates of these parameters involves the iterative solution of a set of equations as described below.

The analytic method first requires an estimate of $\beta$. An easy way to obtain an estimate of $\beta$ is to graph the density function from the data hypothesized to be from a Weibull distribution and make an "eyeball" estimate $\hat{\beta}$, from the shape of the curve. Then compute an estimate of $\alpha$, $\hat{\alpha}$, from the formula:

$$\hat{\alpha} = \frac{\sum x_i \beta_1}{N}$$

After this is obtained compute:

$$\hat{\beta}_2 = \frac{1}{\frac{1}{\hat{\alpha}} \sum x_i \beta_1 \ln x_i - \sum \ln x_i}$$

Then compare $\hat{\beta}_1$, with $\hat{\beta}_2$. If the two estimates are very close then the iterative procedure may be stopped and the last estimates of $\alpha$ and $\beta$ may be taken as the values of the parameters. If $\hat{\beta}_1 \neq \hat{\beta}_2$ then it is necessary to calculate an

$$\hat{\alpha}_2 = \frac{\sum x_i \beta_2}{N}$$
and use this value to calculate $\hat{\beta}_3$ in the same manner as $\hat{\beta}_2$ was calculated. This iterative process continues until the estimates of $\beta$ converge to some value. This iterative process is most easily handled by a computer.

The shape of many of the frequency histograms in Appendix E suggests that the data used to obtain the curve might be distributed negative exponentially. If this was the case then $\lambda = 1$. One method for determining whether or not the data could be fit to a negative exponential is to plot the cumulative distribution of the sample data on semi logarithmic paper. If the graph thus obtained is a straight line or approximately straight, it is an indication that the negative exponential is a "good fit." If a straight line is obtained the slope of the line is related to the parameter $\lambda$ of the negative exponential distribution.

The cumulative distributions curves of the histograms in Appendix E were plotted on semi-log paper as is also illustrated in Figure 12. As can be seen from the graphs and the shapes of the samples given in Fig. 12 the curves seemed to be composed of two intersecting straight lines indicating that the process used to generate the curves is perhaps some combination of two negative exponential distributions.
FIGURE 12. --CUMULATIVE DISTRIBUTION OF "LOOK" DURATIONS
Effect of Eliminating Spare Visual Capacity

The effect of the elimination of the visual spare capacity can be seen in the histograms and in the cumulative distribution plots of Appendix E and Figure 12. As mentioned previously, trials 1 and 4 for each subject, "open road" driving and "perturbated" car following respectively, were conducted with the subject at full visual capacity. Trials 2 and 6 on the other hand, were open road driving and perturbated car following with visual spare capacity reduced or eliminated. As can be seen in the histograms, the effect of the deletion of spare capacity is a truncation of the distribution. The cumulative distribution plots indicate that this truncation does not alter the general shape of the overall distribution (i.e., a combination of negative exponential distribution) but rather alters the parameters associated with the distribution.

An interesting exception to this last generalization can be seen in the cumulative distribution plot for subject K, trial 6. This subject on that trial kept his eyes closed about 76% of the time. The effect of the deletion of that much spare capacity was reflected in an almost complete truncation or elimination of one component of the combination of negative exponentials. This suggests that the two different negative exponential
components might reflect differences in the "importance" of the "looks" made by the subject. That is, the first negative exponential distribution (the one with the steepest slope) might describe the "look" durations associated with the obtaining of "essential" information while the second negative exponential distribution (the one with the less steep slope) might, describe the durations associated with looks at "non-essential" items in the environment.

This data also suggests that if spare capacity is eliminated, then eye movement fixation duration data might be capable of being described by a single negative exponential distribution. If this were possible, then by using a suitable transformation of the data, tests requiring the assumption of normality might be employed in some cases for comparing distributions. The fact that the process used to generate the curves might be considered to be a single negative exponential suggests that independence exists between the length of time that a driver will continue to look at an object or area and the length of time that he has already spent looking at the object or area.
CHAPTER 7

RELATIONSHIP OF LABORATORY TESTS TO MEASURES OF SPARE VISUAL CAPACITY
CHAPTER 7

RELATIONSHIP OF INFORMATION PROCESSING ABILITY (CHANNEL CAPACITY) TO MEASURES OF SPARE VISUAL CAPACITY

Introduction

A central theme of the research discussed in this report is the relationship between spare visual capacity and driving performance. The findings of experiments, which indicate that autonomic activity might be related to channel capacity and driving performance measures, suggests that the procedures employed by Krenek (1970), and others ought to be considered to determine what implications they have on the research reported here.

The determination of a "stability rank" of autonomic activity, similar to that used by Krenek, for the subjects employed in this experiment was unfortunately not possible. Even if it were possible, the direct comparison of individuals with the same stability rank across groups of subjects for whom the ranks were calculated independently, would not be possible because of the nature of the statistics employed. Instead, it was decided that the determination of the "channel capacity" of the subjects employed in this research would be
made using a choice reaction time task and that this measure of performance capability would be related to differences in other dependent variables of interest.

**Choice Reaction Time and Channel Capacity**

Krenek summarizes the use of the concepts of "information theory" to determine the "channel capacity" of a subject performing a choice reaction time experiment. The concept of "information" can be used to determine the "channel capacity," of a subject performing a choice reaction time type of experiment. How that is possible is summarized below and in the discussion of Appendix F.

The use of the concept of information theory suggests that the amount of information transmitted per response, as well as the information transmission rate, are useful measures for comparing the "relative difficulty" of similar experiments.

As Krenek (1970) points out, Hicks (1964) suggests that since information is a logarithmic function of the number of alternatives, that a linear equation should be sufficient to relate reaction time to the amount of information transmitted. If this is accepted, then the reciprocal of the slope of the linear function represents the average rate of information transmission in bits per second.
his assumption of linearity appears to be valid for choice reaction time experiments incorporating up to four bits of information (Fitts and Posner, 1967). This type of choice reaction time experiment has been chosen for use in this research and is explained below:

Choice Reaction Time Task

The choice reaction time task chosen for use in this experiment was one similar to that employed by Krenek. This task was conducted using the teletypewriter input to a Digital Electronics Corporation PDP8-L Computer. The subject sat at the keyboard and the computer generated a stimulus from its storage which was presented to the subject on the output of the typewriter. The subject responded by pressing the appropriate key on the keyboard. The computer then calculated the time between the presentation of the stimulus and the subject's response. In the event that the subject depressed the wrong key on the keyboard, the typewriter printed out the word WRONG.

Each of the subjects who participated in the road research, described previously, was required to perform choice reaction time tasks using the PDP8-L digital computer. Each of the subjects performed these tasks on days when no other tests were administered (i.e., days on which no gas, either air or CO, was given to them) and
the data obtained, therefore, can be considered "baseline" data.

Each subject performed choice reaction tasks incorporating different levels of response uncertainty (i.e., either 0, 1, 2, or 3 bits of information). The instructions for these various tasks are given below:

**Instruction for "Zero bit" Choice Reaction task:**

In this experiment, we would like you to respond to the stimulus presented on the teletype by pressing the appropriate button on the keyboard as quickly as possible. During this portion of the experiment the numeral 4 will appear and you should respond by pressing the key corresponding to that numeral. After responding, please rest your hand at the bottom of the keyboard below the spacer bar. Are there any questions?

**Instructions for "One bit" Choice Reaction Task:**

In this experiment we would like you to respond to the stimulus presented on the teletype by pressing the appropriate button on the keyboard as quickly as possible. During this portion of the experiment the numeral 5 or 6 will appear and you should respond by pressing the key corresponding to the numeral that does appear. After responding, please rest your hand at the bottom of the keyboard below the spacer bar. Are there any questions?

**Instructions for "Two bit" Choice Reaction Task:**

In this experiment we would like you to respond to the stimulus presented on the teletype by pressing the appropriate button on the keyboard as quickly as possible. During this portion of the experiment the numeral 2, 3, 4, or 5 will appear and you should respond by pressing the key corresponding to the numeral that does appear. After responding, please rest your hand on the bottom of the keyboard below the spacer bar. Are there any questions?
Instructions for "Three bit" Choice Reaction Task:

In this experiment we would like you to respond to the stimulus presented on the teletype by pressing the appropriate button on the keyboard as quickly as possible. During this portion of the experiment the numeral 1, 2, 3, 4, 5, 6, 7, or 8 will appear and you should respond by pressing the key corresponding to the numeral that does appear. After responding, please rest your hand at the bottom of the keyboard below the spacer bar. Are there any questions?

Any questions that the subjects had were answered as concisely as possible.

Each task consisted of the presentation of sixteen stimuli and each subject performed each of the tasks two times.

Determination of Channel Capacity

The data obtained in the experiments above was used to form a linear equation for each subject in the following manner. These equations were of the form

\[ y = A + Bx \]

where:

- \( x \) = the number of bits of information contained in the task
- \( y \) = reaction time in 100ths of a second
- \( A \) = the intercept of the regression equation (equivalent to the "0 bit" reaction time
- \( B \) = the slope of the regression line (inverse of the channel capacity)

A correlation coefficient of the form

\[ r = \frac{1}{N} \sum \frac{xy}{\sigma x \times \sigma y} \]
where

\[ r = \text{the correlation coefficient} \]
\[ N = \text{number of trials of each choice reaction time task} \]
\[ x = \text{number of bits of information contained in each task} \]
\[ y = \text{reaction time} \]
\[ \bar{x} = \text{mean of } x \]
\[ \bar{y} = \text{mean of } y \]
\[ \sigma_x = \text{standard deviation of } x \]
\[ \sigma_y = \text{standard deviation of } y \]

These equations are presented below with the correlation coefficients.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Equation</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>( Y = 60.73 + 4.86x )</td>
<td>.8189</td>
</tr>
<tr>
<td>Q</td>
<td>( Y = 52.82 + 4.97x )</td>
<td>.9679</td>
</tr>
<tr>
<td>D</td>
<td>( Y = 53.73 + 6.93x )</td>
<td>.9919</td>
</tr>
<tr>
<td>K</td>
<td>( Y = 47.31 + 7.71x )</td>
<td>.9879</td>
</tr>
<tr>
<td>N</td>
<td>( Y = 50.55 + 9.15x )</td>
<td>.9656</td>
</tr>
<tr>
<td>C</td>
<td>( Y = 46.70 + 10.65x )</td>
<td>.9987</td>
</tr>
</tbody>
</table>

These equations can be used to determine the subjects information processing channel capacity. These channel capacities are:
Subjects		Channel capacity (bits/seconds)
B		21.4
Q		20.1
D		14.5
K		13.0
N		10.9
C		9.4

These equations can also be shown as in Figure 13.

Relation of Channel Capacity to Spare Visual Capacity

One of the primary measures of visual spare capacity mentioned earlier is the amount of time that a driver will elect to spend voluntarily occluding his vision. The previous chapter presented a description of a series of tests in which drivers were instructed to drive while voluntarily occluding their vision as much as possible.

If channel capacity is related to spare visual capacity then we might hypothesize that a subject's information processing ability expressed in terms of his channel capacity in bits per second, might be related to the amount of time that a driver is able to keep his eyes closed while driving. If the data from the driving experiments is combined so that the mean "eyes closed" time for each subject's is calculated for all visual occlusion runs, then the following measure of "visual
FIGURE 13. — INFORMATION VS REACTION TIME
"spare capacity" is achieved.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Visual spare capacity</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>81.4%</td>
<td>2</td>
</tr>
<tr>
<td>N</td>
<td>61.3%</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>57.5%</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>44.4%</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>42.6%</td>
<td>5</td>
</tr>
<tr>
<td>Q</td>
<td>21.0%</td>
<td>6</td>
</tr>
</tbody>
</table>

The correlation coefficient associated with the linear regression of these two measures (i.e., visual spare capacity and information processing channel capacity) was calculated to be $r = -0.663$. This indicates that there is a negative correlation between the channel capacity defined in "information theory" and the ability or willingness to deprive oneself of information while driving.

This correlation can be considered significantly different from zero at a significance level of .10.

The failure of this particular hypothesis, that channel capacity can be positively related to visual spare capacity, tends to confirm the following statement made by Fitts and Posner (1967):

The concept of channel capacity as employed in information theory should not be confused with concepts regarding man's capacities and limitations. Man does have a limited capacity
for many tasks. Some of man's capacities can be discussed in terms of the amount or rate of information transmission. However, there is not a single human channel capacity for all tasks and codes. It is not possible to predict on purely rational grounds the limits to the rate at which human beings process information. Instead, the limitations on many different aspects of processing must be analyzed from empirical studies.

Krenek's work also suggested that a high correlation might exist between autonomic activity and basic reaction time ("0-bit" reaction time). Similarly, he found a relationship between autonomic levels and measures of driving performance. This work suggests that "0-bit" reaction time might be related to spare visual capacity.

A rank order analysis was performed on the data and it was found that a rank correlation of .543 could be calculated when ranks spare visual capacity were compared to simple reaction time ranks. This positive ranking indicates that persons with short reaction times tend to have a larger spare capacity. This rank correlation though positive was not significant at the .05 level of significance.

These two correlations suggest that the inverse of the slope of a subject's linear equation for information processing is related to the intercept of the equation by negative correlation. In fact it was found that a negative correlation \( r = - .784 \) resulted when
the measure of basic reaction time was compared to the measure of channel capacity. This indicates that persons with fast simple reaction times are likely to be the "slower" information processors.

This negative correlation can be considered significant at the .05 level of significance.

Discussion of Results

In this chapter the hypothesis that "information processing channel capacity" could be related to visual spare capacity was explored. If this hypothesis had been substantiated and strong correlations had been found between spare visual capacity and "channel capacity," it would have suggested that the same high order central nervous system functions, which affect information processing ability, also determine a subject's visual sampling behavior. An analyses of the data showed, however, that "channel capacity" and visual spare capacity are negatively correlated. This, coupled with the fact that positive correlations were found between short reaction times and high spare capacity, indicates that visual sampling and the need for visual sampling appears to be positively related to the ability of the subject to respond to the information requiring a single choice.

The negative correlation between spare capacity and channel capacity is interesting in view of the
work by Fergensen (1971) who matched seventeen subjects on the basis of their driving experience and then divided them into four groups according to their accident and traffic violation records. Subjects were then tested to determine this information processing channel capacity. Subjects with high accident records processed information at a significantly lower rate than non-accident subjects. Subjects with "high" violations but no accidents had the highest channel capacities.

This would suggest that persons with the highest spare capacity or perhaps persons willing to give up a greater portion of their spare capacity might be the persons with the poorer accident records.

RELATIONSHIP OF TIME ESTIMATION ABILITY TO SPARE VISUAL CAPACITY

Introduction

The previous analyses indicated that visual capacity might be more related to simple reaction time than to processes requiring higher order processing. Another hypothesis which is suggested by the work of Krenek (1970), is that ability to produce time intervals might also be related to spare visual capacity as measured by the amount of time spent in voluntary visual occlusion while driving.
Time Estimation Experiment

Three of the subjects who participated in the driving research, described previously (subjects N, Q, and D), also performed time estimation tasks in the laboratory under the influence of carbon monoxide. Each subject was required to estimate two second, four second and eight second intervals after being given the following instructions.

Instructions for Two Second Time Estimation Task

"This portion of the experiment is designed to test your ability to estimate time intervals.

Your (first) task will be to estimate two second time intervals. At the tone, begin to estimate a two second interval. When you feel that two seconds have elapsed, press your right hand pushbutton and begin to estimate the next two second interval.

Continue this task until you hear another tone in your earphones. At that time please remove your earphones for further instructions.

It is important that you attempt to judge the two second interval without counting. If you are wearing a watch, please do not use it. Is this clear?

Please put on your earphones and be prepared to begin estimating at the sound of the tone."

The subject was then allowed to estimate approximately twenty, two second time intervals. The earphones that the subject wore furnished him with a constant level "white" noise in order to mask any external cues that
the subject might have used to aid him in his time estimation.

After performing this task, the subject was then given similar instructions for eight second time estimations and four second time estimation tasks.

The data that was obtained in this experiment is summarized in Tables 37 and 38. Using the data presented in the tables, three measures of performance in the time estimation tasks were calculated. These included:

1. the average absolute mean deviation from the target time being estimated,
2. the average standard deviation of estimate, and
3. the average variance of the time estimate.

These measures are presented in the matrix of Table 39.

Non-parametric rank correlations were performed with each of these three measures in an attempt to see if they could be related to spare visual capacity. In each case, high levels of spare capacity were compared with low levels of mean error or mean deviation. This analyses yielded negative rank correlations of -.500 for all three comparisons. Because of the small sample size employed, however, these values were not statistically different from zero at a significance level of .05.

Although these correlations were not significant, they are interesting because they are all negative. This
<table>
<thead>
<tr>
<th>Test</th>
<th>Subject</th>
<th>Subject</th>
<th>Subject</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>Q</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>2 Second Production</td>
<td>$\bar{x} = 2.26$</td>
<td>$\bar{x} = 1.896$</td>
<td>$\bar{x} = 2.287$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$d = .26$</td>
<td>$d = -104$</td>
<td>$d = .287$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N = .26$</td>
<td>$N = 25$</td>
<td>$N = .21$</td>
<td></td>
</tr>
<tr>
<td>4 Second Production</td>
<td>$\bar{x} = 5.41$</td>
<td>$\bar{x} = 4.81$</td>
<td>$\bar{x} = 3.516$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$d = 1.41$</td>
<td>$d = -81$</td>
<td>$d = -484$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N = 18$</td>
<td>$N = 20$</td>
<td>$N = 26$</td>
<td></td>
</tr>
<tr>
<td>8 Second Production</td>
<td>$\bar{x} = 6.808$</td>
<td>$\bar{x} = 8.30$</td>
<td>$\bar{x} = 7.48$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$d = 1.192$</td>
<td>$d = .30$</td>
<td>$d = .520$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N = 26$</td>
<td>$N = 20$</td>
<td>$N = 25$</td>
<td></td>
</tr>
</tbody>
</table>

($\bar{x}$ and $d$ are in seconds)
### TABLE 38

**TIME INTERVAL PRODUCTION VARIANCE**

<table>
<thead>
<tr>
<th>Test</th>
<th>Subject D</th>
<th>Subject Q</th>
<th>Subject N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2 Second</strong></td>
<td>S = .242</td>
<td>S = .271</td>
<td>S = .266</td>
</tr>
<tr>
<td>Production</td>
<td>S² = .059</td>
<td>S² = .077</td>
<td>S² = .071</td>
</tr>
<tr>
<td>N = 26</td>
<td></td>
<td>N = 25</td>
<td>N = 21</td>
</tr>
<tr>
<td><strong>4 Second</strong></td>
<td>S = .488</td>
<td>S = .500</td>
<td>S = .355</td>
</tr>
<tr>
<td>Production</td>
<td>S² = .238</td>
<td>S² = .250</td>
<td>S² = .126</td>
</tr>
<tr>
<td>N = 18</td>
<td></td>
<td>N = 20</td>
<td>N = 26</td>
</tr>
<tr>
<td><strong>8 Second</strong></td>
<td>S = .751</td>
<td>S = .981</td>
<td>S = 1.19</td>
</tr>
<tr>
<td>Production</td>
<td>S² = .564</td>
<td>S² = .961</td>
<td>S² = 1.41</td>
</tr>
<tr>
<td>N = 24</td>
<td></td>
<td>N = 20</td>
<td>N = 25</td>
</tr>
</tbody>
</table>

*(s is in seconds)*

*(s² is in seconds²)*
### TABLE 39
TIME ESTIMATION PERFORMANCE MEASURES

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean Absolute Error</th>
<th>Mean S</th>
<th>Mean S²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject D</td>
<td>2.862</td>
<td>.494</td>
<td>.287</td>
</tr>
<tr>
<td>Subject Q</td>
<td>1.214</td>
<td>.584</td>
<td>.429</td>
</tr>
<tr>
<td>Subject N</td>
<td>1.291</td>
<td>.604</td>
<td>.536</td>
</tr>
</tbody>
</table>

*errors are in seconds*

*(s² are in seconds²)*
suggests that an inverse relation exists between ability to produce time intervals from some "internal mechanism" and the ability to voluntarily occlude vision while driving.

Discussion

The results of this investigation into the time estimation ability of subjects coupled with the analyses of their channel capacities and the attempt to relate both these measures to visual spare capacity furnishes further evidence that the amount of spare capacity that is available in the driving situation is not easily related to measures of ability requiring higher levels of mental activity.
CHAPTER 8

EXPERIMENT TO DETERMINE USEFULNESS OF
CLASSICAL TYPES OF LOADING TO
MEASURE SPARE CAPACITY
CHAPTER 8

Introduction

The previous chapters described a series of tests which were designed and conducted for the purpose of determining the spare visual capacity of an automobile driver and for determining the effect of the degradant CO on that capacity.

The series of tests reported in this chapter were designed for a similar purpose. As can be seen from the descriptions given below, tests 1 through 6 are similar in form to those employed previously with the exception of the fact that cognitive loading tasks were introduced to replace the loading task of voluntary visual occlusion. These tests are described in detail below.

Independent Variables

The following independent variables were included in the experimental design:

A. Task Loading

1. Open road driving—at fifty miles per hour,
2. Car following—lead car at a constant velocity of fifty miles per hour,
3. Car following—lead car exhibiting a variable velocity profile with an average speed of fifty miles per hour.

B. Cognitive Loading

1. Normal or control--no additional task required,
2. Secondary task--subject instructed to perform one of the secondary tasks described below.

C Degradant Level

1. Normal or control--no degradant,
2. Degradant--carbon monoxide

These independent variables can be arrayed in a matrix as indicated in Figure 14. As can be seen from the figure, the subject utilized in this experimental design participated in six separate tests for each level of degradant employed. In addition, the subject was replicated fully in tests 1-4 at each of the two levels of degradant. The subject selected for this experiment was one of the subjects (subject K) who participated in the experiments described earlier.

The tests of this series are described in more detail below.

Test 1: Open road driving at fifty miles per hour, no load.

In this segment of the experiment, the subject was read the following instructions:

Please drive this car in your normal manner at about 50 miles per hour. Please keep to the
FIGURE 14. -- MATRIX OF INDEPENDENT VARIABLES
right hand side of the road whenever possible. Are there any questions?

Any question that the subject had were answered as quickly and concisely as possible. After being given these instructions, the subject was allowed to drive the vehicle for a four minute period of time. After this test, the subject proceeded to the next test.

Test 2: Open road driving at fifty miles per hour, load via secondary task.

Prior to driving in this segment of the experiment, the subject driver was given the following instructions:

Please drive this car in your normal manner at about fifty miles per hour. Please keep to the right hand side of the road whenever possible. During this part of the experiment, we would like you in addition to driving as we have just described, to perform the following task as much as possible.

The subject was then told to perform one of the following secondary tasks:

Task 1:

Using the mirror mounted on the front roof pillar of the car, please read the first three numbers on the digital clock into the microphone. Then read the speed to the nearest mile, e.g., 53, 68, 64, etc., from the speedometer into the microphone. Then mentally add the two numbers together and read the sum into the microphone. After doing this, please start the task again as quickly as possible. Are there any questions?

Task 2:

Using the mirror mounted on the front roof pillar of the car, please read the first three numbers on the digital clock into the micro-
phone. Then mentally divide that number by two and read the answer into the microphone. After doing this, please start the task again as quickly as possible. Are there any questions?

Task 1 was used as a secondary task during the first replication of the series of tests. It was observed, however, that the subject kept the vehicle speed as close as he could to fifty miles per hour in order to simplify the secondary task. Task 2 was adopted for the second replication of the series of tests in order to avoid this problem.

As in the first portion of the experiment, any questions were answered as concisely as possible. After being read the instructions, the subject was allowed to drive the instrumented vehicle for a six minute period.

In this run as in all other runs of this series of experiments as well as the first series of experiments, the safety man seated next to the subject driver was prepared to alert the driver or take over control of the vehicle whenever he felt there was a danger of a collision. The subject was not alerted when his performance deteriorated and there was no immediate danger of a collision with a fixed object or another vehicle (e.g., when the subject drove off the road or crossed the center marker).
Test 3: Car-following (lead car velocity constant at fifty miles per hour), normal visual load.

Prior to the start of this run, the subject was read the following instructions:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car but were unable to because of oncoming traffic in the left lane. Are there any questions?

Any questions that the subject had were answered as quickly as possible and the subject was then allowed to follow the lead vehicle, which maintained a constant velocity of fifty miles per hour, for a four minute period.

Test 4: Car-following (lead car velocity variable with a mean speed of fifty miles per hour), normal visual load.

In this segment of the research, the subject drove the instrumented vehicle after being given the following instructions:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car but were unable to because of oncoming traffic in the left lane. Are there any questions?

As in previous runs any questions that the subject drivers had were answered as concisely as possible. The lead car in this test went through the velocity profile indicated in the diagram of Figure 15. As can be seen,
FIGURE 15. — PERTURBATED LEAD CAR VELOCITY PROFILE EMPLOYED IN EXPERIMENTS INVOLVING COGNITIVE LOADING
this lead car program was similar to that employed in tests reported earlier.

**Test 5:** Car-following (lead car velocity constant at fifty miles per hour), leading via secondary task.

The subject driver of the instrumented vehicle was read the following instructions prior to the start of this run:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car but were unable to because of oncoming traffic in the left lane.

During this part of the experiment, we would like you, in addition to driving as we have just described, to perform the following task as much as possible.

The subject was then asked to perform one of the two secondary tasks detailed in the description of test 2.

Any questions that the subject had were answered as concisely as possible and the subject was then allowed to follow the lead vehicle which maintained a constant velocity of fifty miles per hour for a three minute period.

**Test 6:** Car-following (lead car velocity variable with a mean speed of fifty miles per hour), leading via secondary task.

In this segment of the research, the subject
driver drove the instrumented vehicle after being given the following instructions:

Please drive this car behind the lead car as if you were on a two-lane highway attempting to pass the lead car but were unable to because of oncoming traffic in the left lane.

During this part of the experiment, we would like you, in addition to driving as we have just described, to perform the following task as much as possible.

Again, as in tests 2 and 4, the subject was requested to perform one of the secondary tasks mentioned earlier. Also, as in all other tests, any questions that the subject driver had were answered as quickly as possible. The lead car in this run went through the same velocity profile used earlier and shown in the diagram of Figure 15.

**Dependent Variables**

The following dependent variables were obtained during this series of tests:

1. Vehicle velocity—all tests
2. Gas pedal position—all tests
3. Brake pedal activation—all tests
4. TV picture of road, digital clock, and subjects' eye—tests 1 and 2
5. Headway between subject vehicle and lead vehicle—tests 3 - 6
This data was obtained using the equipment described in the Appendices to this report.

Results

As was mentioned previously, several dependent variables were considered in this series of tests. Each of these dependent variables will be discussed separately below and then the apparent relationships between the variables will be considered.

Secondary Task Analysis

Of primary importance in this series of tests is the determination of the usefulness of cognitive tasks such as those employed as secondary tasks in these experiments for measuring spare capacity. Also of interest is the sensitivity of those tasks to the effects of a degradant such as CO on that capacity.

As was mentioned previously, two separate secondary tasks were employed in these experiments. Task 1 required the subject driver to read a digital clock and his speedometer and mentally add the two together and then read the sum into a microphone. This task was used by subject K as a secondary task in tests 2, 5 and 6 on two days. On the first day, subject K participated in the tests after being administered CO in the manner described in the appendix. On the second day, subject K
repeated an identical experimental regime with the exception that air was used instead of CO for gassing purposes.

Two measures of performance were obtained for the secondary task performance. These included:

1. mean number of responses per unit time, and
2. % correct.

These results are presented in Tables 40 and 41.

As can be seen from the tables, the performance measure "number of responses per unit time" seems to be sufficiently sensitive to distinguish between levels of task difficulty. This measure appears particularly sensitive to the difference between variable velocity car-following and the other two driving tasks (open road driving and constant velocity car-following). Comparisons of this performance measure between gassing conditions (CO and air) are somewhat contradictory. Secondary task performance is degraded by CO on tests 2 and 5, but is somewhat slightly improved with CO on test 6.

As can be seen from Table 41, the performance measure "percent correct responses" also appears sensitive to level of task difficulty. In particular, this measure is sensitive to the difficulty incorporated in test 6 (variable velocity car-following). This particular
### TABLE 40
RESPONSES/UNIT TIME

<table>
<thead>
<tr>
<th>Test</th>
<th>Gas</th>
<th>Air</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 2</td>
<td>Open Road</td>
<td>13.0/Min.</td>
<td>10.00/Min.</td>
</tr>
<tr>
<td>Test 5</td>
<td>Constant Car Following</td>
<td>10.0/Min.</td>
<td>9.67/Min.</td>
</tr>
<tr>
<td>Test 6</td>
<td>Variable Car Following</td>
<td>5.0/Min.</td>
<td>6.2/Min.</td>
</tr>
</tbody>
</table>

### TABLE 41
PERCENT CORRECT RESPONSES

<table>
<thead>
<tr>
<th>Test</th>
<th>Gas</th>
<th>Air</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 2</td>
<td>Open Road</td>
<td>94.87%</td>
<td>90.00%</td>
</tr>
<tr>
<td>Test 5</td>
<td>Constant Car Following</td>
<td>86.67%</td>
<td>93.10%</td>
</tr>
<tr>
<td>Test 6</td>
<td>Variable Car Following</td>
<td>80.00%</td>
<td>83.87%</td>
</tr>
</tbody>
</table>
measure does not, however, appear to be too sensitive to the effects of the degradant COHb.

Secondary task 2, which was described earlier, required the subject to read a digital clock and then mentally divide the reading by two. This task was performed on the third and fourth days of experimentation in this series of experiments by subject K on test 2 only. On the third day subject K had been exposed to air while on the fourth day the subject was exposed to CO.

As with task 1, two measures were obtained from the data for evaluating performance on the secondary task. These included:

1. mean number of responses per unit time,

2. percent correct responses.

These measures are reported in Table 42 for trial 2 (open road driving). As can be seen from Table 42, performance on secondary task 2 does not seem to decline during open road driving under COHb as does performance secondary task 1.

Control Actuation Analyses

Two other dependent variables which were considered in this series of experiments were the gas pedal actuation behavior and the brake pedal actuation behavior of the subject driver. More specifically, it was hypothe-
sized that the number and duration of brake applications and the number and duration of "gas pedal releases" (periods of time in which the driver took his foot off the gas) could be related to task difficulty, secondary task loading and differences in the level of the degradant.

TABLE 42

PERFORMANCE ON SECONDARY TASK 2

<table>
<thead>
<tr>
<th>Measure</th>
<th>Gas</th>
<th>Air</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Number of Responses Per Unit Time</td>
<td></td>
<td>8.57/min.</td>
<td>9.15/min.</td>
</tr>
<tr>
<td>Percent Correct Responses</td>
<td></td>
<td>95.0%</td>
<td>94.36%</td>
</tr>
</tbody>
</table>

With respect to gas pedal actuation, the number of times that a subject removed his foot from the gas pedal was computed for each of the test conducted under each level of degradant. In addition, the duration of each gas pedal release was measured and a mean and variance of the gas pedal release time was calculated for each trial and each level of CO. This data is presented in Table 43.

A similar analyses was performed for the brake pedal actuations and this data is contained in the
# Table 43

GAS PEDAL ANALYSIS

<table>
<thead>
<tr>
<th>Test</th>
<th>Air</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 0</td>
<td>N = 2</td>
</tr>
<tr>
<td></td>
<td>$\bar{X}^2 = 0$</td>
<td>$\bar{X}^2 = 2.407$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 0$</td>
<td>$s^2 = 1.155$</td>
</tr>
<tr>
<td>Test 2</td>
<td>N = 0</td>
<td>N = 0</td>
</tr>
<tr>
<td></td>
<td>$\bar{X}^2 = 0$</td>
<td>$\bar{X}^2 = 0$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 0$</td>
<td>$s^2 = 0$</td>
</tr>
<tr>
<td>Test 3</td>
<td>N = 2</td>
<td>N = 0</td>
</tr>
<tr>
<td></td>
<td>$\bar{X}^2 = 1.330$</td>
<td>$\bar{X}^2 = 0$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = .018$</td>
<td>$s^2 = 0$</td>
</tr>
<tr>
<td>Test 4</td>
<td>N = 26</td>
<td>N = 17</td>
</tr>
<tr>
<td></td>
<td>$\bar{X}^2 = 3.094$</td>
<td>$\bar{X}^2 = 4.509$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 10.997$</td>
<td>$s^2 = 19.433$</td>
</tr>
<tr>
<td>Test 5</td>
<td>N = 2</td>
<td>N = 1</td>
</tr>
<tr>
<td></td>
<td>$\bar{X}^2 = 1.187$</td>
<td>$\bar{X}^2 = .760$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = .041$</td>
<td>$s^2 = 0$</td>
</tr>
<tr>
<td>Test 6</td>
<td>N = 17</td>
<td>N = 22</td>
</tr>
<tr>
<td></td>
<td>$\bar{X}^2 = 4.968$</td>
<td>$\bar{X}^2 = 3.990$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 20.297$</td>
<td>$s^2 = 9.728$</td>
</tr>
</tbody>
</table>

Note: $\bar{X}$ units are in seconds  
$s^2$ units are in seconds$^2$
matrix of Table 44.

As can be seen from the tables, these measures are sensitive to differences in the levels of task difficulty, but do not appear to reflect differences due to loading or due to the level of degradant employed.

**Velocity Analyses**

The velocity of the instrumented vehicle being driven by the subject in this series of tests was measured and recorded. This data was subsequently reduced by sampling at every one second interval for all trials and levels of degradant. The results of this analyses are presented in Table 45.

Velocity means and variances for tests 3, 4, 5 and 6, all of which involve car-following, are primarily dependent upon the speed profile of the lead vehicle. Since the lead vehicle maintains the same profile across levels of degradant for each test, we would not expect to find much difference between velocity measures in these tests. The data presented in Table 45 reflects this. On the other hand, tests 1 and 2 involve open road driving and here the speed is determined solely by the subject driver who was instructed to "drive in his normal manner at about 50 miles per hour." The table indicates that the variance of the vehicle velocity under subject CO exposure is greater for both tests 1 and 2.
### TABLE 44

**BRAKE PEDAL ANALYSES**

<table>
<thead>
<tr>
<th>Test</th>
<th>Air</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>$N = 0$</td>
<td>$N = 0$</td>
</tr>
<tr>
<td></td>
<td>$\bar{X} = 0$</td>
<td>$\bar{X} = 0$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 0$</td>
<td>$s^2 = 0$</td>
</tr>
<tr>
<td>Test 2</td>
<td>$N = 0$</td>
<td>$N = 0$</td>
</tr>
<tr>
<td></td>
<td>$\bar{X} = 0$</td>
<td>$\bar{X} = 0$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 0$</td>
<td>$s^2 = 0$</td>
</tr>
<tr>
<td>Test 3</td>
<td>$N = 0$</td>
<td>$N = 0$</td>
</tr>
<tr>
<td></td>
<td>$\bar{X} = 0$</td>
<td>$\bar{X} = 0$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 0$</td>
<td>$s^2 = 0$</td>
</tr>
<tr>
<td>Test 4</td>
<td>$N = 8$</td>
<td>$N = 6$</td>
</tr>
<tr>
<td></td>
<td>$\bar{X} = 2.719$</td>
<td>$\bar{X} = 3.275$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 2.818$</td>
<td>$s^2 = 2.656$</td>
</tr>
<tr>
<td>Test 5</td>
<td>$N = 0$</td>
<td>$N = 0$</td>
</tr>
<tr>
<td></td>
<td>$\bar{X} = 0$</td>
<td>$\bar{X} = 0$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 0$</td>
<td>$s^2 = 0$</td>
</tr>
<tr>
<td>Test 6</td>
<td>$N = 7$</td>
<td>$N = 10$</td>
</tr>
<tr>
<td></td>
<td>$\bar{X} = 4.790$</td>
<td>$\bar{X} = 2.223$</td>
</tr>
<tr>
<td></td>
<td>$s^2 = 3.649$</td>
<td>$s^2 = 2.180$</td>
</tr>
</tbody>
</table>

**Note:**

- $\bar{X}$ units are in seconds
- $s^2$ units are in (seconds)$^2$
**TABLE 45**

**VELOCITY ANALYSIS**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Gas</th>
<th>Mean (Air)</th>
<th>Variance (Air)</th>
<th>Mean (CO)</th>
<th>Variance (CO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Air</td>
<td>50.5060</td>
<td>1.2306</td>
<td>50.8868</td>
<td>1.5261</td>
</tr>
<tr>
<td>Test 2</td>
<td>Air</td>
<td>50.7514</td>
<td>0.8112</td>
<td>50.6476</td>
<td>1.3704</td>
</tr>
<tr>
<td>Test 3</td>
<td>Air</td>
<td>54.6061</td>
<td>0.7684</td>
<td>54.4236</td>
<td>0.7236</td>
</tr>
<tr>
<td>Test 4</td>
<td>Air</td>
<td>54.8071</td>
<td>60.0795</td>
<td>54.4707</td>
<td>63.0618</td>
</tr>
<tr>
<td>Test 5</td>
<td>Air</td>
<td>53.9138</td>
<td>0.6021</td>
<td>54.9308</td>
<td>1.6603</td>
</tr>
<tr>
<td>Test 6</td>
<td>Air</td>
<td>54.6525</td>
<td>63.0146</td>
<td>55.0115</td>
<td>53.1039</td>
</tr>
</tbody>
</table>
than it is when the subject was exposed to air. It also appears that the velocity variance is reduced in test 2 for both levels of degradant as opposed to test 1. As mentioned previously, this appears to be due to the fact that the subject, while performing secondary task 1, attempted to maintain the vehicle speed as close as possible to 50 miles per hour in order to minimize task difficulty. Despite this effort, however, to minimize the velocity variance, it appears that the measure is sensitive to CO presence for this subject.

**Headway Analysis**

The headway between the instrumented vehicle and the lead vehicle was obtained in tests involving car-following. This headway data was sampled every second and headway means and variances were calculated for every test and degradant. This headway data is presented in Table 46. As can be seen from the data, headway means appear particularly sensitive to the effects of the load imposed by the secondary task (comparison of tests 3 and 4 with tests 5 and 6). Comparisons across levels of degradant and levels of task difficulty failed to show any differences.

**Summary of Results**

The purpose of the the experiments reported in
### Table 46

**Headway Analysis**

<table>
<thead>
<tr>
<th>Trial</th>
<th>CO</th>
<th>Air</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
</tr>
<tr>
<td>Test 3</td>
<td></td>
<td>68.8306</td>
<td>50.0771</td>
</tr>
<tr>
<td>Test 4</td>
<td></td>
<td>60.5336</td>
<td>217.0118</td>
</tr>
<tr>
<td>Test 5</td>
<td></td>
<td>72.9264</td>
<td>29.1608</td>
</tr>
<tr>
<td>Test 6</td>
<td></td>
<td>101.2481</td>
<td>1638.9788</td>
</tr>
</tbody>
</table>
this chapter were to determine whether or not cognitive secondary tasks might be useful for measuring spare capacity and whether or not performance on these secondary tasks might be sensitive to the presence of carbon monoxide. At the same time performance measures were obtained from the secondary tasks. Measures of vehicular control and vehicle behavior were also obtained. The results of the analyses performed on the data obtained in this supplemental study indicate that:

1. Cognitive secondary tasks appear sensitive to the effects of task difficulty but not to the effects of COHb.

2. Control actuation behavior also reflects difficulty due to tasks but does not indicate the presence of COHb.

3. Velocity variance appears slightly higher in tasks involving elected velocity under COHb compared to the same tasks under air, but the differences would be small in terms of their effect on system performance (i.e., the variances are low even under COHb).

4. Headway means reflected the difficulty due to the loading imposed by the secondary task in car following situations. Differences in
this measure due to COHb, however, were not apparent.

In summary it might be said that cognitive secondary tasks such as those employed here appear useful for distinguishing differences due to task difficulty but do not readily distinguish differences due to a degradant such as 20% COHb for an individual subject.
CHAPTER 9

DISCUSSION OF RESULTS, CONCLUSIONS AND SUGGESTION FOR FUTURE RESEARCH
CHAPTER 9

Introduction

The research reported in this document was designed by considering a conceptualization of a drivers visual behavior which suggested that a portion of his visual behavior in terms of his visual sampling was unnecessary and could be deleted without seriously affecting his driving performance and without altering substantially the "error free" nature of the overall system. This conceptualization implied that there existed a "spare capacity" in terms of visual sampling which the driver had available to him for compensatory use if the driving situation demanded it.

More specifically two major aims were associated with the research reported here. These included:

1. The determination of the spare visual capacity of automobile drivers for selected driving situations, and

2. The determination of the effect of a degradant (carbon monoxide) on that spare capacity.
Experiments

Several series of studies have been reported in the previous chapters which were designed to achieve these research aims. These experiments had as their primary independent variables: task loading, secondary task loading to deprive the subject of his spare visual capacity, and the presence or absence of carbon monoxide. In addition to these experiments several "baseline" experiments were conducted to enable determination of differences between day time and night time performance and to enable determination of artifacts due to the experimental procedures employed in the research.

In addition to these experiments, conducted on the highway, laboratory tests were also conducted to relate spare visual capacity to measures of information processing channel capacity and time estimation abilities.

Research Results

The previous chapters have detailed the analyses performed on the data collected in these experiments. The results of these analyses and discussions of their meanings have also been presented previously. The major findings of this research are, however, reiterated in this chapter.
Visual Spare Capacity

Visual spare capacity as measured by the percent of time that a driver was able to keep his eyes closed was found to be a measure of spare capacity that was sensitive to differences in task difficulty and sensitive to differences in CO. Spare capacities as high as 87.1% were identified for certain subjects under certain driving conditions. Spare capacities were also found to be different for different subjects. (A more thorough discussion of the research results relating to spare capacity is presented later in the chapter.)

Visual Search and Scan Patterns

Mean duration of "looks" (the length of time that a driver fixated continuously on an object or area) tended to increase with the presence of the degradant. This indicates that the drivers were forced to spend more time obtaining information from an object or area in the scene when they fixated on it after being exposed to a level of carbon monoxide sufficient to produce 20% COHb.

Variance of "looks" also tended to increase with carbon monoxide.

Carbon monoxide tended to increase the number of looks that were made at the lead car in "perturbated lead car" trials and to decrease the number of "looks"
made at objects and areas. This indicates that the driver was forced to compensate for his decreased ability under CO and utilize more of his time obtaining information about the lead car. This in effect indicates that CO forces the driver to utilize a portion of his spare capacity.

An analyses of the fixation locations for two of the subjects indicated that with normal vision the drivers horizontal fixation location tended to be concentrated more on one of the lane edge markers when the driver had been exposed to CO than when he had been exposed to air. Carbon monoxide in conjunction with a deletion of visual spare capacity resulted in a similar horizontal shift. These results indicate that the drivers under CO tend to foveally obtain information that would normally be obtained peripherally. This suggests a loss of peripheral vision ability with COHb.

Blink rates, an indicator of stress, tended to decrease with task difficulty and also with presence of CO indicating the stressful effects of car following and carbon monoxide. An analysis of the blink rates observed in the baseline runs indicated that the wearing of the eye movement helmet and apparatus had a slightly stressful effect but not nearly as stressful as night driving on the open road.

Deletion of spare capacity tended to reduce the
speedometer usage exhibited by subjects while at the same time it tended to increase mirror usage slightly. This can be interpreted as indicative of a lessening of concern about vehicle speed control with a decreased capacity plus a need to obtain foveal information that might have been obtained peripherally with a larger spare capacity.

Vehicular Control Measures

With respect to vehicular control, carbon monoxide tended to increase the velocity mean exhibited by the subject in situations where it was possible for the subject to elect his own velocity. This effect was particularly apparent when the subject's spare capacity was eliminated. The magnitude of these increases was, however, slight.

Carbon monoxide also increased the velocity variance of the subject's vehicle in situations involving elected velocities.

Vehicle control actuation was also found to be sensitive to independent variables of interest. With respect to gas pedal reversals, task difficulty tended to increase the number of observed reversals while carbon monoxide and the elimination of spare capacity resulted in a reduction in the number of gas pedal reversals.

The number of times that a subject took his foot
off the gas pedal and the number of times that a subject put his foot on the brake also tended to increase with task difficulty but decrease with carbon monoxide and the loading imposed during the elimination of spare capacity.

Cognitive Loading

Attempts to eliminate spare capacity via cognitive tasks (mental arithmetic) yielded some results similar to those realized when spare capacity was eliminated via visual occlusion. These cognitive secondary tasks appeared more suitable, however, for distinguishing differences in task difficulty than they did for distinguishing differences due to COHb levels.

Laboratory Tests

In addition to the driving performance tests conducted on the highway, attempts were made to find laboratory tests which could be correlated with measures of spare visual capacity obtained on the highway. It was found that information processing channel capacity as measured on a choice reaction time task was negatively correlated to spare visual capacity as measured by the percentage of time that a driver voluntarily occluded his vision. On the other hand, visual spare capacity was positively correlated with "zero bit" simple reaction
time. Literature mentioned earlier in this report suggested that persons with a high channel capacity tended to have a better accident record (fewer accidents) than persons with low channel capacity. This suggests that persons with a low spare capacity might normally utilize or apply more of their total capacity to the driving task and thus avoid accidents. Their spare capacity might in fact be a "subjective" spare capacity that incorporates a built-in safety factor.

Time estimation ability was also found to be negatively correlated with a driver's spare visual capacity.

Determinations of Eye Fixation Time Distributions

In addition to the experiment and the analyses presented above, several investigations were made in order to obtain insights into the nature of the characteristics of eye fixation time distributions. In general it was found that the assumption of normality was not valid. The data suggested that a Weibull distribution or in some cases a negative exponential might be capable of being fitted to the data.

Revision of Model of Spare Capacity

Early in this research and early in the report of this research, two simple models were given for purposes
of explaining a driver's visual search and scan behavior and for demonstrating the existence of a visual spare capacity. The first model depicted the operator of a motor vehicle as an element in a simple "single track" man machine system. The second model suggested that there was a hierarchy of visual sampling behavior which the driver exhibited. The results of the research reported here do not refute or deny these simple models but rather the results obtained in this research suggests a more comprehensive model to describe the operator of a motor vehicle on the highway and his associated spare capacity.

In general, it might be said that the same visual parameters that effect visual search and scan behavior tend to affect visual spare capacity. It would appear that the relationship of the effects are of an inverse nature. That is, the parameters that would tend to cause an increase in search and scan behavior would tend to cause a decrease in spare visual capacity as measured by the ability or willingness of a subject driver to occlude his vision. The model of Figure 16 is, therefore, suggested to describe a number of the factors which influence driver search and scan behavior and driver spare visual capacity. This model has been expanded to indicate the effects of experimentation such as that
Noisefog, glare
night

Visual
Environment

Situation Variables
highway, traffic
speed, distraction

Experiment Imposed
Objectives:
instructions, motivation

Experiment Conditions: CO

Human Variables:
physical, psychological, age,
sex, experience

Subjective Constraints:
Flow, safety, comfort, economy,
risk acceptance

Immediate Objectives

Visual Search + Actuation
Scan
And
Spare
Capacity Behavior

Vehicle Performance

Operator

FIGURE 16. --SCHEMATIC DIAGRAM OF DRIVERS VISUAL SEARCH AND SCAN AND SPARE CAPACITY BEHAVIOR
reported here designed to determine the effects of low levels of carbon monoxide on driving performance. As can be seen from the diagram most of the parameters or variables of interest in a study of the nature of the one described in this report tend to affect control actuation behavior and/or visual search and scan behavior. These two types of behavior are in themselves related.

One variable of interest which is contained in the category of "subjective constraints" is the variable "risk acceptance." The wide range of differences in spare capacity noticed across subjects suggests that spare capacity as measured in this research might be primarily a function of a subject's willingness to deprive himself of his spare capacity. This would imply that spare capacity is in fact a subjective spare capacity perhaps related to a driver's willingness to accept risk or his tolerance for uncertainty. If this is in fact the case, then the diagram of Figure 17 might be used to explain the type of behavior found in this experiment. As can be seen in the diagram, normal behavior dictates that enough capacity is allocated to cover virtually any possible contingency that might develop in driving. The "low capacity individual" as determined in this series of tests and experiments is the one who is unwilling to give up his spare capacity, whereas the
FIGURE 17. --RISK AND SPARE CAPACITY
high capacity individual is willing to sacrifice his capacity particularly in the region of low probability of demand for that capacity. These curves would suggest that in tasks requiring visual occlusion that the "high spare capacity" or "high risk acceptance" driver's spare capacity as measured by the percent of time he keeps his eyes shut would tend to be more constant than the spare capacity measure for the low risk acceptance driver. If the data contained in Table 6 (Chapter 4) is examined it can be seen that this is the case. Drivers with lower spare capacities tend to adjust their capacity more to the demands of the task than do drivers with higher spare capacities. The difference in risk of the various drivers would be a function of the risk differential (Figure 17), the probability of demand, and the possible consequences of not performing the task adequately.

Another analyses that would indicate if risk is the sole factor in determining a subject's "spare capacity" involves examining the values obtained for the duration of the intervals that the subject keeps his eyes open in an occlusion task. If the mean open times are the same or nearly the same for all subjects then it is an indication that the high capacity subjects obtain about the same information per look as other subjects but they are willing to go longer without new information.
Unless gross differences in short term memory abilities are assumed it would seem reasonable to describe this willingness to go without new information as a tolerance for uncertainty or risk acceptance.

The average look duration for looks across all trials and levels of degradant are given in the table below:

**TABLE 47**

**MEAN LOOK DURATIONS (SECONDS)**

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Look Duration</td>
<td>.72</td>
<td>3.24</td>
<td>.73</td>
<td>3.20</td>
<td>2.61</td>
</tr>
</tbody>
</table>

As can be seen in the table, however, the mean look duration differs widely across subjects. In fact if this data is correlated with the "spare capacity rank" derived in Chapter 7 it can be seen that a correlation coefficient of 1 is achieved. This indicates that the high capacity subject keeps his eyes closed longer and open shorter in tasks involving visual occlusion. If risk is a major factor then it is reflected in a subject by a willingness to live with little information and an ability or willingness to perform for greater periods of time without new information.
Effect of the Degradant on Risk Assumption

Earlier in the report a decrement in spare visual capacity was found due to the presence of the degradant carbon monoxide. The purpose of this section of the report is to attempt to determine whether this reduction in spare visual capacity is due to a reduction in visual ability or whether it is due primarily to a change in the willingness of the driver to assume risk.

The measure of spare visual capacity used throughout this report has been the percent of time that the driver was able to keep his eyes shut while driving the automobile. This total percentage is directly related to the length of the individual "open" times and the length of the individual "occlusion" times. The differential effect of the degradant carbon monoxide on the mean open times and the mean occlusion times can serve to indicate whether the reduction in spare visual capacity is due to a reduction in visual skill in obtaining information or whether it might be due to a reduction in the willingness to assume risk or live with uncertainty. If the effect of CO is primarily one of reducing the mean occlusion time it would indicate that the degradant reduces the subject drivers tolerance for uncertainty. On the other hand, if CO tends to increase the mean open time exhibited by the subjects it would tend to indicate that the effect of CO is reflected in a
reduction of the subjects skill in obtaining visual information. (It should be noted, however, that large open times might not be made solely for purposes of obtaining information but might also be made in order to avoid periods of uncertainty.) A third possibility is that CO will tend to affect both visual skill and the tolerance for uncertainty. The magnitude of the effect on the mean open time and the mean occlusion time due to the degradant CO might also be expected to be greatest for subjects exhibiting the highest overall spare capacity.

Figures 18 and 19 depict the changes in the mean "open" time and the mean occlusion time due to CO as they relate to the overall measure of visual spare capacity.

As can be seen from the figures, the degradant carbon monoxide tends to both increase the mean "open" times exhibited by most subjects and decrease the mean occlusion time for most subjects. This would tend to indicate that the degradant affects both visual skill and risk acceptance. The positive correlation exhibited in Figure 18 suggests that the effects due to CO on decreasing the occlusion time are most pronounced for subjects with a high initial or overall spare capacity. The negative correlation between overall spare capacity
FIGURE 18. — SPARE CAPACITY VERSUS CHANGE IN OPEN TIME DUE TO CO
Figure 19. -- Spare capacity versus change in occlusion times due to CO
and differences in mean open time due to CO indicates that persons with a "low" overall spare capacity react to CO by increasing their "open" periods.

Overall these figures indicate that the effect of a degradant such as CO on an occlusion task is one of primarily decreasing the mean occlusion time for subjects who normally exhibit large occlusion times and one of increasing mean open times for subjects with normally large open times. This would indicate both a decrement in visual skill and a reduction in willingness to accept uncertainty due to the presence of carbon monoxide.

Comments on Results

The major results realized in this research have been summarized earlier in this chapter. The purpose of this paragraph is to attempt to tie some of the results together.

With respect to measures of eye movement performance, this research has shown that the major effects of a degradant such as COHb at a 20% level are an increase in the length of time needed for obtaining information from the environment (particularly noticeable in trials involving visual occlusion) and an increase in the foveal fixations made for purposes of lateral control. These results indicate a decrease in information acquisition ability and a decrease in peripheral vision abilities.
Several differences were found in the vehicle control and vehicle performance measures examined in this research. Some of these measures (e.g., a reduction in gas pedal reversals) are hard to interpret while others such as the significant increase in velocity variance, though easy to interpret, are of a small enough magnitude that their effect on "total system performance" might be considered negligible. Taken together, however, these measures seem to indicate an overall pattern of performance decrement. That is, they indicate that the driver is starting to become less concerned about maintenance of vehicle performance at the same time he is compensating his visual behavior to make up for his decrement due to the degradant COHb. These results might be considered similar to those of Belt (1969) who found that drivers under the influence of alcohol tended to lose vehicular control during periods when they weren't compensating for degraded visual search and scan abilities.

Conclusions Summary and Suggestions for Future Research

Driving is essentially an "error-free" task. In terms of total system failures, accidents, or near accidents (e.g., running off the road or violently disrupting flow) seldom occur. A degradant such as a low
level of COHb does not usually manifest itself by a noticeable increase in such complete failures because the driver has a sufficient amount of spare capacity to compensate for his degraded performance. Rather, the effect of the degradant is to cause a reduction in the amount of spare capacity that is available for coping with other degradants or unusual occurrences.

This research has demonstrated a method for determining the spare visual capability associated with certain types of driving and has demonstrated that a low level of a degradant such as COHb detracts from the amount of spare capacity while at the same time it begins to have an effect on the control behavior exhibited by the driver in achieving his "error-free" performance.

The laboratory tests which indicate that information processing channel capacity and time estimation ability correlate negatively with visual spare capacity suggest that a person's spare capacity might be capable of being predicted from laboratory tests and that spare capacity as measured by voluntary occlusions might ultimately be related to measures of "total system" performance such as accident experience or records.

The research that is presented here examined several interesting hypotheses and produced a number of interesting results. In summary it must be admitted,
however, that the results tend to raise more questions than they answer. These questions that are raised, however, can be used to suggest some topics for future research to extend the work begun here or to expand it to encompass other variables of interest not fully covered in this initial endeavor in the exploration of the "spare capacity" available to an automobile driver. A few of the possible new approaches suggested by this research are presented below:

The measure of spare capacity derived in this research was found to be sensitive to levels of task difficulty and to levels of the degradant carbon monoxide. Further research might enable a better quantification of the spare capacity associated with different types of driving tasks and might enable driving situations demanding the use of excessive amounts of spare capacity to be identified.

Carbon monoxide at a level sufficient to produce 20% COHb was found to have numerous undesirable effects on driver performance in terms of driver eye movements and vehicular control. Additional research at lower carbon monoxide levels would enable a more precise picture of this degradant's effects to be obtained.

The success of the experimental procedures employed here suggests that they might also be used to
determine the effects associated with the use of other degradants such as drugs, alcohol, fatigue, etc. The interactive or additive effects of these degradants might also be determined in the same manner.

The wide range of differences in spare capacity noticed across subjects suggests that spare capacity as measured in this research might be primarily a function of a subject's willingness to deprive himself of his spare capacity. This implies that the spare capacity is in fact a subjective spare capacity. Future research might attempt to determine the difference between a person's subjective spare capacity and his actual spare capacity. This difference might be taken as a measure of a subject's willingness to accept risk and might be able to be related to a person's driving record.

Work to relate individual eye movements and subsequent control movements might be fruitful. Elimination of spare visual capacity might also help enable the relationship between vision and control to be more easily determined.
APPENDIX A

DESCRIPTION OF RESEARCH EQUIPMENT
Introduction

The purpose of this appendix is to describe in some detail, the research equipment used in the collection and analysis of the data from the several highway research experiments reported earlier.

Instrumented Vehicle (1970 Chrysler)

The main instrumented vehicle used in this research (i.e., the vehicle which was driven by the research subjects in all experiments) was a 1970 Chrysler Newport, 6 passenger, 4 door sedan purchased by the Systems Research Group and owned by the Ohio Department of Highways. This automobile came equipped with automatic transmission, power steering with adjustable steering wheel, power disc brakes, power seats, and heavy duty suspension. This vehicle is powered by a 440 cubic inch, V-8 engine with a four barrel carburetor and dual exhausts. The automobile is equipped with a 3 speed automatic transmission and a 3.23 to 1 gear ratio differential. Electrical power for the vehicle and the instrumentation is furnished by a 105 amp Leece-Neville 12 Volt D.C. alternator and a 100 amp Leece-Neville 24 Volt D.C. alternator. A C.M.L. inverter is used to furnish 110 Volt A.C. to the research equipment.

This vehicle was modified by the Systems Research Group to enable the following parameters to be recorded
and monitored:

1. Velocity
2. Gas pedal position
3. Brake pedal actuation
4. Lateral acceleration
5. Longitudinal acceleration
6. Distance travelled (using a "fifth wheel")
7. Headway (using the "yo-yo" described elsewhere)
8. Relative velocity (using the "yo-yo" described elsewhere)
9. Driver eye movements (using the Systems Research Group's eye movement equipment described elsewhere)

The above parameters were recorded on a Honeywell model 2206 Visicorder oscillograph recorder mounted in the vehicle. Several coding traces were also available to enable the experimenter to manually encode data.

An auxiliary power brake which was capable of being actuated by the right front seat passenger (the "safety man") was also installed in the vehicle by the Systems Research Group.

Other Instrumented Vehicles

Two other instrumented vehicles were used in this research primarily as lead vehicles. These included a 1965 Plymouth station wagon and a 1969 Buick Electra sedan. Both of these vehicles, as well as the 1970 Chrysler described above, were equipped with two-way
F.M. radio transmitter-receivers to enable intervehicular communication.

**Oscillograph Recorder**

The recorder used in the instrumented vehicle was a Honeywell Model 2206 Visicorder, a portable direct writing oscillograph recorder. This recorder is capable of recording up to 12 channels of information on 150 foot rolls of six inch wide self-processing oscillograph paper. The Visicorder can be powered from either the 12 V DC or 24 V DC power sources in the instrumented vehicle.

**Headway and Relative Velocity Measurement Equipment**

Headway (the distance between a lead car and the following instrumented vehicle) and relative velocity were measured in the instrumented vehicle by utilizing a device built by the Systems Research Group. This device, often referred to as a "yo-yo", incorporates a 10-inch diameter drum which is mounted on the front of the instrumented vehicle and on which is wound up to 1,000 feet of thin stainless steel wire. One end of the wire on the drum is fastened to the rear of the lead vehicle and the rest is wound on the drum of the yo-yo. The wire is kept in tension by a clutch faced rotating disc powered by a McCulloch Model 49C two stroke gasoline engine. Rotary potentiometers are used to determine how far the drum
has turned on its axis and hence, the headway between the two vehicles while a Weston tachometer generator is used to determine the rate at which the drum turns and therefore, enables the relative velocity between the two vehicles to be determined. Outputs from the tach generator and the potentiometer are recorded on the oscillograph recorder in the instrumented vehicle and simultaneously displayed to the experimenter.

**Other Sensors**

Several other sensors were mounted on the instrumented vehicle to enable various items of information about vehicle control movements and vehicle performance to be determined. These included:

1. A potentiometer for measuring gas pedal position
2. A pressure sensitive switch for determining brake pedal actuation
3. A tachometer generator attached to the vehicle transmission to enable vehicle velocity to be determined.

**Television Eye Marker System**

A major instrumentation system used in this research was the television eye marker system developed by the Systems Research Group. This television eye marker system is basically composed of closed circuit television components connected in such a manner that it is possible to simultaneously photograph and record the scene in
front of an automobile driver and a small dot of light indicating the point on that scene on which the driver is foveally fixating.

The stability of the eye movement recording device is due primarily to the helmet worn by each subject participating in the research. This helmet designed by the Systems Research Group consists of a light weight epoxy outer shell and a light weight polyurethane inner shell molded to fit the subject's head. This helmet is attached to the subject's head and is stabilized using a "bite bar" with a custom molded dental impression connected to the helmet via adjustable side braces. This helmet enables the weight of the attached "eye marker" equipment to be distributed uniformly over the subject driver's skull.

A Shibaden model HV-50S television camera is attached to the left side of the helmet mounted on the subject's head and is used to photograph the roadway in front of the driver.

A lens system mounted on the right side of the helmet picks up the reflection of a light, also positioned on the right side of the helmet, off the cornea of the subject driver's right eye. This corneal reflection is transmitted by a coherent fiber optic cable to a Shibaden model HV-15 closed circuit TV camera mounted on the floor of the instrumented vehicle where it is
photographed.

A third television camera, a Shibaden model HV-15, photographs a picture of the driver's eye and the face of an accurate electric clock with a digital readout through a set of mirrors mounted on the left A pillar of the instrumented vehicle.

The signals from these three television cameras are combined using a Shibaden model SG-105L sync generator and a Shibaden model EA-101 affects amplifier. This combined signal is then simultaneously recorded on a Shibaden SV-700U video tape recorder and displayed for monitoring purposes in the vehicle on a Shibaden model VM-903 video monitor.

The recording of the subject driver's eye movement patterns is played back using another Shibaden SV-700U video tape recorder onto a 17 inch video monitor for data reduction purposes. Modification to the playback recorder enables the use of slow motion and stop motion techniques to be employed in the data reduction.

The schematic of Figure 20 indicates the manner in which the television components are connected to form the television eye marker system.
FIGURE 20—CHRYSLER T.V. EYE MOVEMENT SYSTEM
APPENDIX B

DESCRIPTION OF DATA REDUCTION TECHNIQUES
AND ANALYSES PROGRAMS
Introduction

As mentioned previously, in this report, two types of data collection systems were utilized in the Systems Research Group's 1970 Chrysler instrumented vehicle to obtain the data used in the analyses previously presented. A physical description of these systems was also presented in the last appendix. The purpose of this appendix is to briefly explain the method that was used to transfer the data from the recorders to the analysis.

Data Collection System

Both recorder systems (i.e., the oscillograph recorder with its sensors and the television eye marker system) function together in the manner shown in Figure 21. As can be seen from the figure, simultaneous recordings are made of the visual field in front of the instrumented vehicle, the driver's eye movements in that field, the control movements made by the driver, and the vehicle dynamics.

Data Reduction

Oscillograph traces are obtained on direct print permanent records. Data contained on these records is normally measured manually with the values transcribed on the oscillograph rolls. Values are then keyed onto
Data Collection

Recording of control movement performance measures

Recording of visual field and eye movements
SRG TV Eye Movement Equipment

Recording done for each experimental condition

Data Reduction

Sample velocity, headway, count and measure, gas pedal and brake pedal movements

Determine eyespot location and fixation durations and measure headways

Statistics

1. Velocity mean and variance
2. Headway mean and variance
3. Gas pedal and brake movements per unit time

1. Fixation duration, frequency, mean and variance
2. Fixation time on environmental features
3. Spatial frequency distributions
4. Temporal frequency distributions
5. Pursuit eye movements

1. Headway mean and variance
2. Relative velocity mean and variance

FIGURE 21.—SCHEMATIC OF ELEMENTS OF DATA COLLECTION SYSTEM
computer cards for subsequent calculations by computer. The sampling intervals for most continuous variables of interest is normally one second.

Television tapes obtained on the highway are played back in the lab on 19 inch television monitor using a television tape recorder identical to the one the data was collected on. The digital clock which is included in the television picture is capable of reading time increments as small as 20 milliseconds (although normally the time increment was kept at 50 milliseconds). Using this clock and the displayed picture, the following items of information were obtained:

1. eyespot location in the visual field
2. fixation duration
3. headway (if not obtained on the oscillograph)
4. fixation on environmental features
5. speedometer and mirror usage
6. eye closing and blinks.

Computation of Statistics

For the data obtained on the oscillograph recorder, computer programs were developed to determine:

1. velocity means and variances
2. headway means and variances
3. gas pedal and brake pedal movements per unit time
4. length of gas pedal and brake pedal actuations.
For the data obtained on the television tapes, computer programs were developed to determine:

1. fixation durations, frequencies, means and variances
2. fixation times, frequencies, and means and variances on environmental features
3. spatial frequency distributions
4. sequential plots of fixations times for fixations on specified categories.

All of these data collection techniques, data reduction techniques, and computer programs were utilized in the research reported in this document.
APPENDIX C

ANNOTATED BIBLIOGRAPHY OF REFERENCES RELATED TO RESEARCH TO DETERMINE THE SPARE VISUAL CAPACITY OF AUTOMOBILE DRIVERS
Introduction

During the design and conduct of the research reported in this document, a large number of references relevant to the research topic of determining the spare visual capacity of automobile drivers in selected driving situations and the determination of the effects of a low level degradant on that spare capacity were examined by the author. A number of these references have been mentioned elsewhere in the report. The purpose of this appendix is to furnish an annotated bibliography of selected references which are related to the research but which are not discussed elsewhere in this paper and to amplify the discussion of some references that were briefly treated in other chapters and appendices of this report.

For purposes of this appendix, the literature that will be discussed will be separated into two sections.

1. Literature relevant to vision and driving, and

2. Literature dealing with the use of "loading" and secondary tasks.

Literature Relevant to Vision and Driving

The following references were found to be particularly relevant to the research:
This study dealt with the sharing of time between two types of activities that the driver is forced to attend to as a part of the driving task. Steering and recognition were abstracted and explored in the laboratory by analyzing performance on a compensatory tracking task taken as an analogue of steering and on a filmed presentation of a sign search-and-recognition task. The relative effects of the interactions between tasks were explored. The main findings of the study were that:

a) where time sharing was required, each type of performance was degraded,

b) increasing the number of message units appearing in the recognition task did not differentially affect simulated steering performance but did increase the time required for recognition of a key message;

c) increased speed of the simulated steering task display decreased recognition time of the discrete visual task; and

d) where a specific message had equal likelihood of appearing or not appearing, recognition time was greater when the key word did not appear.

The authors comment that previous research on the independent aspects of tracking and search-and-recognition activities have not considered the interactions between these two tasks. Although studies of time-sharing between different sensory modalities, and two-dimensional tracking have indicated generalized degradation of performance beyond certain input loads, consideration of tasks having different basic functional properties but requiring use of the same sensory modality has been lacking.

Results of this research indicate a change in operator pacing as the complexity of the activity increases. This suggests that the frequency of "peeks" in a visual occlusion task might indicate the degree of stress associated with a task. This article also suggests that "loading" employed in driving situations ought to affect the visual sensory modality.


Data, in the experiment reported in this article, was obtained in actual "flight situations" where pilots had to observe instruments on a panel. Eye fixation times were recorded but the instrument readings were not.

The hypothesis in this re-examination of data was that the operators monitoring the instruments behaved like simple zero-order Markov processors subject to the constraints of sampling frequencies and input channel capacities.

Data was obtained by placing cameras behind the instrument panel which photographed the eye. This gave frequency and duration data. Using this data the probability that a given instrument was being looked at was obtained:

\[ P_A = P_a D_a \]

which indicated that the probability of looking at A was a product of the frequency at which A was looked at times the average duration. From these data transition probabilities were also calculated.

In general, the results of this analyses indicated the instruments could have been arranged on the basis of transition possibilities. Also, "links" would have been capable of being used for arranging or ordering instruments.

The author concludes that the zero-order model was relatively efficient in predicting transitions and that errors in prediction were due to the fact (maybe) that the operator acts as a higher order Markov processor.

Indications also were present to suggest that the amount of error indicated on instrument might also have an effect. The implications of the Markov model are:

1. Due to the requirement of other instruments for fairly frequent sampling, no instrument can be looked at for a very long time
2. As a result, those instruments which have high probabilities have them in consequence of having been sampled many times for a relatively short duration rather than infrequently for long durations
3. Thus, the instruments with high probabilities
must have a large number of arrivals and departures and, therefore, a large number of observable transitions.

4. Similarly, since there is some minimum time which can be spent in switching to an instrument and making the least observation of it, those instruments which have low probabilities must have a small number of arrivals and departures. (Senders' data indicated that this was true, but he points out that it must be true)

5. Therefore, large numbers of transitions cannot take place between instruments which have small numbers of arrivals and departures and most transitions must involve those pairs of instruments both members of which have large numbers of arrivals and departures.

In summary, it might be concluded the model probably holds, but transitions could be predicted from engineering analysis of functions of airplanes. The value of this analysis is in the theory presented. In terms of the research presented in this report, it suggests that if the relationship between "peeks" and taken during visual occlusion tasks and other variables of interest is studied that a "zero order" analyses is probably sufficient.


The method employed in the experiments reported by the author involved having the driver guide the car while looking through a helmet and mask device containing a small aperture. By decreasing the visual field, the drivers were forced to obtain information in separate visual fixations. The authors felt that the use of the aperture method was more advantageous than use of an eye-marker camera, because eye-marker cameras do not show the contribution of peripheral vision, and therefore, do not provide means for distinguishing essential from non-essential information.

In the experiments, the shifts in fixations of the drivers' eyes emphasized the requirements of perceptual anticipation and vehicular alignment which force the driver to look "far"ahead to obtain a general idea of conditions that he will have to meet while at the same time requiring the driver to take a "close" look for alignment purposes.
Results obtained in this study indicate that drivers obtain both types of information by viewing the edges and centerline of the road.

Distance from the driver's eye was obtained by noting the width of the road at the center of aim.

It has been proposed (by Wohl) that the driver has a fixed forward fixation distance, which increases with vehicular speed. Forward reference distance should increase with vehicular speed to compensate for increased stopping time.

Apparently the eye moves to the left on a right curve (whereas, normally, it is on the right side) but on the average it does not cross into the opposing lane. The results support the practice of placement of signs and pavement edge markings on the side of the road.

Perceptual anticipation requires the driver to look far ahead to obtain a general idea of conditions that will have to be met whereas, alignment behavior requires close-up viewing to ensure that the vehicle is on the road.

The essential information required by a driver is provided by the road edges and the center lane marker. At least one of these road features was included in 98.2% of the fixations made when the large aperture was used (9 3/4) (the small one was 4°). Driver statements indicated the importance of the road edges and lane markers.


Case, et al., concluded in their studies that the judgmental skills of drivers do not decline with advancing age, but that the rate of shifting attention does fall off.

They also observed that aged drivers who make compensatory changes in their driving habits to match their physiological deterioration have lower accident rates than those who do not compensate. In compensating, the aged drivers adjust the pace at which the motor skill aspects of the driving task must be performed.
In general, the result they found in their driving simulator was that aged drivers reduced their speed to allow themselves more time to assimilate the information in the environment necessary to enable them to drive safely. Older drivers also exhibited a greater number of speed changes indicating an awareness of performing a driving task that has both lower and upper speed bounds. Lack of difference in steering reversals indicates that speed reversals were not due to nervousness.

Case, et al., conclude further, that 90% of the older drivers who failed the simulator driving task at the initial pace speed were able to perform the task when tested a second time at a 10 mph slower pace (learning was apparently not a factor). This, they claim, is clear evidence of the importance of the rate aspect of task load. Because most driving is a self-paced task, the aging driver can, and does, compensate for the gradually reducing rate at which he can perform the dual aspects of driving; namely, tracking and the avoidance of obstacles.

The authors point out that there are at least two major instances in which reduction of pace via speed reduction may not be adequate for avoiding accidents. First, many potential accident situations involve a rapid sequence of events where the rate (pace) at which events unfold is completely independent of the driver. For example, multiple car intersection situations and certain passing head-on situations can be relatively independent of the vehicle speed of a struck vehicle. Secondly, the very act of reducing speed can itself be a cause of traffic accidents, particularly to the extent that such reduced speed is relatively unexpected by the other motorists making up the total traffic. These two factors have to do essentially with the steady-state, reduced-pace behavior exhibited by the driver, but there is even a potentially greater hazard associated with the dynamic interaction with other drivers by these drivers who characteristically reduce speed drastically whenever task load increases.

In these bases it would appear that the lower a driver's threshold is, the more hazardous he becomes. Conversely, drivers whose task-load threshold is too high would also constitute an unusually hazardous group.

These "problems" might be found in selected groups of younger subjects or in persons affected by some degradants.

It was found that there was less traffic on foggy than on clear days and that there were fewer personal injury accidents on foggy days. In London fewer personal injury accidents per vehicle mile occurred on foggy days (not statistically significant).

The authors report on work done by Lauer, DeSilva, and Forbes who tried to find the correlation coefficient between the results of tests on drivers with the number of reported accidents per year. The average number of accidents per year for the drivers tested was .099. They point out that it should be realized that a statistically significant but low correlation between test results and accidents per year does not mean that a poor performance in a test is not likely to result in a large increase in the accident rate. It means that the variation in accidents with the quality which the test measures is small compared to the total variation in accidents per year, i.e., it means that there are other factors which also have a large effect on the accident rate. In view of the large number of factors known to be associated with the accident rate, a low correlation between any one of them and accident rate is all that can be expected.

Results of this included:

1. Better acuity tends to be associated with better accident records (fewer accidents).

2. The wider the visual field the higher the accident rate. (It may be however, that number or proportion of open road accidents in which side vision is important is low.)

3. There was not much evidence to show that depth perception is related to accidents and yet what evidence is available indicates good depth perception is associated with good accident records.

4. Muscular imbalance associated with higher rates. (When a driver with inadequate muscle balance becomes fatigued or is under the influence of alcohol, diplopia (or double vision) is more likely to occur.)
5. No significant differences were found between the accident groups with respect to simultaneous binocular perception.

6. No significant differences were found between accident groups with respect to dark adaptation.

7. No significant correlations between accidents and eye dominance, lateral phoria, esophoria, exophoria, hyperphoria, forced convergence, forced divergence, and resistance to glare were found.


Visual acuity measures for right, left and both eyes have been found to be correlated somewhat with accident records or estimates of "good" and "bad" driving. Many other studies have failed to show any correlation.

Visual measures other than acuity fail to correlate with accidents.

"Apparently not many drivers become involved in accidents because of visual differences."

This apparently contradicts the previous article slightly. Both articles suggest that "static" measures of visual ability are not highly correlated with driving performance. This supports the hypothesis that driving will not be affected by a driver's visual ability per se, but rather, by how he uses his ability. Further comments on this subject are made in the literature referenced below.


"To what extent is vision involved in accidents and to what extent is the visual status of the driver responsible for them?"

Analyses of accidents to determine the role played by measurable aspects of vision, such as visual acuity, color vision, and dark adaptation, have been disappointing. The most reliable studies to date are those
from the Institute of Transportation and Traffic Engineering of the Department of Engineering of the University of California, Los Angeles, in cooperation with the California Department of Motor Vehicles. Starting in 1962, 17,500 test subjects were studied in depth. Summarizing these studies, Burg, 1967, reports:

'Among the vision variables studied, dynamic visual acuity shows the strongest and most consistent relationship with driving record. There is substantial but not conclusive evidence that static visual acuity, glare recovery, and visual field also are related to driving record.'

'The data suggest differential vision driving relationships as a function of age; however, at the present stage of analysis, the precise nature and extent of these differential relationships cannot be determined.'

'The data strongly suggest differential vision-driving relationships as a function of sex. More definitive information will be provided by planned analyses involving specific accident types and qualitative exposure.'

As to predicting a person's driving record, Burg, in the same report, states:

'Among vision variables, the results support the original research hypothesis by showing that dynamic visual acuity is by far the most consistent contributor to prediction, followed by static acuity, glare recovery, and visual field. The two remaining vision variables (glaremeter threshold and phoria) do not contribute consistently to prediction of a driving record variable; this does not imply that they might not contribute significantly in prediction of specific accident types, a possibility that future analyses will examine.'

These findings of Burg's, reported by Allen, suggest that it is not necessarily a person's visual abilities, as such, that determine how he drives or his accident record but, rather, how he uses his vision to obtain information.

Allen hypothesizes that carbon monoxide and other degradants act, in part, to destroy visual acuteness, visual motor coordination and perceptual alertness. He points out that any compensable visual anomaly becomes progressively less compensable under the influence of
carbon monoxide or other degradants. He also hypothe-
sizes that persons with measurable higher levels of
carbon monoxide in their blood would have more asthenopia
and more binocular vision and accomodative problems than
persons not exposed to carbon monoxide. Carbon monoxide
symptoms would be increased at higher elevations above
sea level and would be aggrevated by alcohol, darkness,
and fatigue.

Allen maintains that one should not and cannot
depend upon central vision for anything in driving except
studying those details brought to ones attention by
peripheral vision. A foveal search of the entire scene
is helpful but without peripheral vision, the totality
and interrelationships of the perception could not be
maintained.

As Allen points out: The importance of peripheral
vision can be appreciated from the following example: We
know that from eye-movement studies that 0.20 to 0.25
seconds are required per visual fixation. At 60 miles
per hour, a person covers 88 feet of highway per second.
With 0.25 second fixations we can inspect the road
foveally every 22 feet. The remainder of the scene with
its many details and spatial relationships must be
sensed by peripheral vision.

Relative velocity judgment is dependent on the
ability to detect the increasing size of the lead car.
This ability is a function of the distance and the size
of the object. Halving the distance doubles the size.
A car traveling at 60 miles per hour covers half a mile
in thirty seconds. It doubles its size in thirty seconds
if it is first noted one mile away. Assuming its size
is about 7.25 feet wide, its angular size will have
increased from 5 minutes to 10 minutes of arc. It takes
only fifteen seconds for the size to double again as the
car travels from .5 miles to .25 miles. As the car
continues to approach, doubling in apparent size occurs
at increasingly short intervals and the angular size
rapidly increases. Thus, it can be seen that it is
difficult to judge the speed of an approaching automobile
until the rate of its angular size change exceeds the
threshold value for a given individual.

Judgment of closing speed is a function of vehicle
size distance and rate of travel. Trucks would seem to
approach faster than regular cars which would seem
faster than compact or sports cars or motorcycles. In
general, the changing angular size is of little value for judging a vehicle's speed when it is more than 1,000 feet away.

(Note: Burg reference mentioned frequently by Allen is:


Doses of intoxicating levels of alcohol result in deterioration of performance in almost all aspects of driving behavior. This is not necessarily true of lower doses.

Familiar tasks deteriorate less than ones that are unfamiliar.

The additional stimulation provided by a new task frequently enables the subject to compensate, for a short time, for conditions which have produced an overall reduction in efficiency. For this reason, short interpolated tests may fail altogether to measure this deterioration and may show normal or even above normal efficiency. Reasonable long lasting tests seem necessary unless the deficiency is a gross one.

The authors of this article seem to support the idea that is presented by others, that drivers are capable of compensating for their degraded performance by utilizing part of their spare capacity.


Poulton mentions two recent works which further support the idea presented above by Drew (et al.) and many others.

Work by Brown, Tichner, and Simmonds (1969) which showed that drivers who were telephoning ran through too narrow gaps 28% of the time, as opposed to 21% while not
driving, is interpreted to show that it is not possible to make two decisions at the same time.

Other work by Brown and Simmonds (1970) found that speed decreased and errors on a listening task increased after one glass of sherry (Brown, I.D. and Simmonds, D.C.V.: Effect of small amounts of alcohol on selective attention and control skills in car driving, 1970, (in preparation)).


Mourant discusses another aspect of visual behavior that is hypothesized to be related to the stress associated with driving. Blink rate is hypothesized to decrease with increasing levels of task difficulty and secondary task loading. Blinks might also be expected to decrease with increasing levels of a degradant.

One of the functions of any eyeblink, is to keep the eyes functionally active. Every eyeblink is accompanied by tear secretion. The eyelid closing distributes the secretion over the surface of the cornea. Three types of eyeblinks are commonly observed:

1. voluntary,
2. periodic, and
3. reflexive.

The reflex blink occurs as part of the response to sudden or bright stimuli. The rate of periodic blinking is controlled by the central nervous system and varies widely among individuals. The average rate of blinking is, however, 12.5 blinks/minute. Since during the average blink, the eyelid is closed for a period of 130 msecs., an average blink rate of 12.5 blinks per minute means that most persons experience a pattern of 4.870 msecs. of light followed by 1.30 msecs. of darkness.

Mourant found also that increased task difficulty in driving tended to reduce the blink rate for novice drivers.

In order to determine the incidence of blinks during visual tracking, their effect and the nature of the effect, two experimental arrangements were used. In one experiment, the subject had to keep a pen moving upon a line, his blinks being recorded without his knowledge both electronically and by two observers. In the second, he had to keep two pointers in line using a positional control, the display being occluded intermittently in one part by a wheel tachistoscope, in another by his own voluntary blinks.

It was found that the blink rate was raised when the subject expected the tracking to start and again after the tracking. During tracking it was reduced, particularly initially. The lowest blink rates were recorded during or immediately before the difficult periods of the course. It was not possible to predict the blink rate while tracking from a knowledge of the true "resting" blink rate.

Although blinks were infrequent when the course was difficult, it was here that they caused the largest errors, especially when anticipation was not possible. This effect was due partly to interference with vision, but only temporary inattention could account for the delayed deterioration following blinking. It has been suggested that the blink rate might serve as an index of attention, blinking being one of the earliest signs of inattention.

Experimental evidence, reported by the authors, indicated that blinking can interfere with performance of tasks requiring constant visual attention might be a factor in accidents in driving or flying.

The effect of blinking on performance might be purely one of interference with vision or it might be due partly to the blinking response competing with the responses required of the subject by the task. On the other hand, blinking and poor performances might be associated simply because both are associated with inattention.

It was found in pilot experiments that if a subject was allowed to pause in the tracking task, every two or three minutes, that his blinking was practically confined to these points.

Mechanical "blackout" and voluntary blink experiments were conducted to determine the effect upon tracking of interference with vision of about the same duration.
as the blink "blackout," and to compare this effect with the effect of voluntary blinks.

The mean number of blinks per minute before, during and after tracking in their main blink experiment was as follows:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Blinks per Minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;resting&quot; before experiment</td>
<td>17.6</td>
</tr>
<tr>
<td>immediately before tracking</td>
<td>23.5</td>
</tr>
<tr>
<td>tracking - straight course</td>
<td>8.6</td>
</tr>
<tr>
<td>tracking - curved course</td>
<td>2.7</td>
</tr>
<tr>
<td>immediately after tracking</td>
<td>41.6</td>
</tr>
<tr>
<td>&quot;resting&quot; after experiment</td>
<td>21.6</td>
</tr>
</tbody>
</table>

(All of these means were significantly different at the 0.05 level and some were different at the 0.01 level).

The blink rate immediately before tracking was determined under conditions identical with the "resting" blink rate except that the subject held a pen in his hand and knew he was about to start the experiment.

The blink rate was relatively low in the first half hour of vigilance task performance when few signals are usually missed, and higher in succeeding half-hours when more signals are missed. Blinks, however, never apparently coincide with missed signals. It seems likely that the blink rate is inversely associated with the degree of "concentration" or "attention." It may be possible to use this as an index of attention.

In estimating the amount of time for which vision is obscured in visual tasks due to blinking, it is misleading to use "resting" blink rates.

Blinking can have a detrimental effect upon a task such as tracking. However, it has no effect when the course is almost a straight line and does not always have an effect when the course is curved. The effect due to blinking is considerable reduced when anticipation is possible.

Apparently the average blink lasts for 0.55 seconds.

Significant deterioration in tracking was found about 15 seconds after a blink. This effect could have been caused by the blinking or by the inattention of which blinking was an indication.

In order to throw light upon the nature of the subjects decisions during normal blink "blackouts,"
theoretical errors were estimated for the three conditions under which he tracked curved courses on two assumptions. These assumptions were (1) that the subject ceased initiating all movement during the "blackout" period and (2) that he ceased initiating any new movement during this period maintaining instead his initial speed of movement. In all cases, the theoretical errors were much greater than the subject's actual errors. The constant-speed-of-movement hypothesis gave the less inaccurate approximation. It seems clear that the subject must have been responding to an acceleration component of the course during his blink "blackouts" as well as to a velocity component. He must, in fact, have been tracking an expected course during his "blackouts."

**Literature Related to the Use of Loading and Secondary Tasks**

The following articles were found to be particularly relevant to the research reported elsewhere in this report. Most of these references annotated below, point to the usefulness of secondary tasks for the measurement of secondary tasks for the measurement of human performance in complex tasks. Most of them, therefore, allude to the existence of a spare capacity.


The author points out that the fact that operators slow down when paced too fast indicates that human input-output is analogous to a communication channel of limited capacity and reaction time is a valuable (potentially) measure of this capacity. On the other hand, performance cannot be adequately studied since behavior typically involve a stream of signals and responses, each in part, dependent on those that have gone before and influencing those that come after. This does not mean that these dependencies will be easy to measure, however.

With respect to complex tasks, there is some question whether the primary task occupies the single channel "continuously" but not completely at any one instant or
whether occupation is complete but intermittent so that spare capacity is in the form of "gaps" during which the single-channel is free. Many experiments seem to favor the latter point of view especially those where the tasks utilize the same sensory channel. The latter would also seem likely in the "no peek" type of experiment. It is, however, true that instructions such as "react as quickly as possible" force the subject to utilize his entire capacity in responding.

It has been tacitly assumed in most studies using dual tasks that the subject's basic capacity is constant; i.e., man is the same whether or not a secondary task is added to a primary, and however severe the demands of a secondary task may be. Some studies involving use of a "paced" secondary task raise the question of whether some genuine increase in capacity occurs under pressure for speed. Effort as measured by increased regularity of heart rate has been shown to increase with load imposed by a secondary task and this indicates an "apparent" increase in channel capacity. It may be that these studies indicate differences in what a subject is "willing to do" from what he can do in an emergency.

Coordination of primary and secondary tasks can improve performance in some situations.

Welford also discusses learning by stating that:

Phenomena, such as retrograde amnesia, has led to the view that learning is a two stage process. Material being learned is held for a few seconds in a short term "store" consisting of some kind of brain "activity" while an enduring memory trace is built up.

If the breakdown of high grade judgment under stress can be attributed to a lowering of channel capacity, an important approach is opened up to the problem of defining "levels" of mental activity. It is often suggested that in states of fatigue and under stress, the "highest levels" are impaired first. What is meant by highest is not clear. Some attempts have been made to define it in terms of the newest acquired ability in either the individual or the race. On this basis, the "highest" tasks would be those demanding the handling of most data or those relying most heavily on short-term retention.

Results of stress: mild degrees of emotion, producing moderate degrees of arousal, are likely to be
beneficial in terms of "organizing" performance.


Fitts and Posner present a concise discussion particularly pertinent to the question of measuring human performance in view of the humans adaptive behavior.

"Skilled performance always involves an organized sequence of activities. Persons do not, however, execute by rote long sequences of predetermined acts. Instead almost every act is dependent upon comparison either of feedback with input so that an operator may determine the appropriateness of his previous responses, or a comparison of progress towards a goal with some conception of what is desired. For example, in driving an automobile, one does not respond randomly to stimuli on the road. Instead, one makes responses in accordance with some internal model which involves reaching a destination at a certain time while obeying various traffic regulations, accommodating oneself to the other traffic on the road, and adapting one's driving in numerous other ways to the immediate environmental situation."

"One way of viewing the relation of motivation to performance is in the 'hypothesis of par or tolerance.' This hypothesis states that in most tasks, individuals set for themselves some standard of excellence and are content to meet but do not strive to exceed this standard. This adaptation or aspiration level is habitually set below the level of performance they actually are capable of achieving."

Evidence that performance rarely lives up to the potential of the subject is obtained by an analysis of the relation between subjective reports and actual levels under stress. Temperature and humidity, for example, do have some effect on performance of certain tasks, but this occurs at a point well beyond that at which subjects begin to complain strenously about discomfort. Left to his own devices, man will stop work before he has to.

Stress is defined not as a condition that feels stressful to the individual, but rather by a specification of the demands that the environment places on the individual.

When stress is defined by the demands of the task,
it becomes apparent that people do their best under intermediate conditions of stress.

Several possibilities exist for the individual faced with the condition in which the rate of incoming signals is beyond his capacity. The first strategy that is available to the individual is to work faster and faster and let errors increase.

Another method for adapting to input overload is to disregard or filter out part of the information. In a sense, filtering is analogous to committing errors since omissions are often equivalent to errors. On the other hand, filtering or omitting may be selective. Wherever there is some basis for establishing priorities and provided there is some readily available cue or tag that identifies the less important information, filtering may permit the individual to do a relatively effective job.

A third mechanism is queuing. With queuing, input messages are simply allowed to wait in line. This method permits irregularities in the input to be smoothed out and allows irregularly spaced input to be turned into uniformly flowing information transfer.

Other mechanisms, such as complete cessation of task performance, are possible but are relatively extreme in nature.

In driving, however, the choices for handling information overload are not as plentiful. Since driving must be essentially "error-free" if catastrophic situations are to be avoided, the allowance of errors must not be considered an acceptable means for dealing with information overloads.

Queuing of information inputs is usually not possible in driving situations because of the nature of the information that is presented to the driver.

Cessation of task performance is a method that is usually available for the driver faced with an informational overload, but this can only be used as an "escape" after any immediate informational overloads are handled.

In essence then, it seems that the only viable alternative for the automobile driver faced with an informational overload to engage in, is one of selective attention to informational inputs.
Tests designed to measure space capacity usually force a driver to selectively attend to information in his environment and then measure his overall task performance while behaving in that manner.

The authors also point out the concept of channel capacity as employed in information theory, should not be confused with concepts regarding man's capacities and limitations. Man does have a limited capacity for many tasks. Some of man's capacities can be discussed in terms of the amount or rate of information transmission. However, there is not a single human channel capacity for all tasks and codes. It is not possible to predict on purely rational grounds the limits to the rate at which human beings process information. Instead, the limitations on many different aspects of processing must be analyzed from empirical studies.


Rolfe presents an excellent review of the literature relating the use of secondary tasks for measuring human performance. Some of the things brought out in his review are presented below.

Within certain limits, the human operator is renowned for his adaptability which allows him to adjust the level of his response to match the perceived requirements of the task situation. In consequence, at times, direct measurement of performance in terms of system output is not always adequate. In addition, if it is assumed that the operator has a spare capacity, then task performance measures become relatively invariant with ever important changes in conditions affecting task difficulty.

The major assumption behind the use of secondary tasks is that both tasks require the operator's conscious attention, and because there exists a limit to the amount of information which an operator can handle in a given time, differences in perceptual motor load imposed by the experimental task, while not apparent on the performance of that task, will show themselves in terms of different levels of response on the secondary task.

Perceptual motor load is used in reference to measuring performance on tasks which are primarily mental and only partly physical.
Capacity, a term derived from communication theory implies single channel processes. Evidence for the single channel theory is present in the presence of phenomenon known as the psychological refractory period. This term refers to the period which follows the presentation of a stimulus during which responses to further signals are delayed beyond their normal latency.

Using different sensory modalities for the presentation of successive stimuli enables the demonstration of a "central locus of refractoriness," if such a central locus of refractoriness exists, then primary and secondary tasks operant on the same channel might not be limited by this locus. Some other point would then be a limiting factor.

Other work referred to by Rolfe indicates that delay times are the same for stimuli presented on one modality as for stimuli presented on separate modalities—Evidence of some common single channel.

On the other hand, single channel theory may not hold in situations requiring attention (i.e., where temporal uncertainty was present as opposed to event uncertainty).

Rolfe reviewing Brown's (1964) work pointed out that secondary tasks can be related to channel capacities. The function of the secondary task is to absorb the reserve capacity.

Use of the secondary task is essentially an applied research tool, but one which has its origin in basic experimental psychology.

Secondary tasks have been used in three categories of applied investigation:

a) comparison of alternative methods of performing the same operation or comparison of performance in alternative environments
b) investigation of performance differences in various phases of a complex task
c) investigation of operator learning in terms of the modification to the capacity available to deal with other tasks at the same time as performing the task to be learned.

If the subject, in a dual task experiment, is instructed to produce error-free performance on the
secondary task at the expense of the primary task, the second task is called a loading task. But, if the subject is instructed to avoid making errors on the primary task, the secondary task is called a subsidiary task.

In this case of loading, the second task is generally used to "stress" the primary task and performance on the "loading" task is generally of little interest per se. One difficulty with loading is that it sometimes induces enough stress to completely alter the mode of behavior normally employed by the operator. Subsidiary tasks are used to determine how much additional work the operator can undertake while performing the primary task to some degree of satisfaction.

The subsidiary task method of approach might be more suitable in experiments involving driving because satisfactory performance is required at all times.

It is usually necessary to measure performance on both tasks in order to check assumptions about task performance remaining constant.

Rolfe cites the work of Trlesman and Gaffen (1967) which leads them to argue that interference between primary and secondary tasks occurs at the perceptual level rather than at the response. The conflict between interpretations of their studies and studies which indicate that the interference occurs in the selection and implementation of responses may be one which arises because of differences between the tasks employed in the experiments and particularly in relation to the complexity of the response which accompanies the perceptual component leading up to the response. When the response is of a discrete nature following a complex discrimination task, the perceptual argument may be the case, but when the response is continuous, requiring the operator's attention in order to achieve the required end point, the demands of the response component may also make themselves apparent.

Instructions are important but it can't be assumed that subjects will perform as desired. This fact necessitates measurement of both the primary and secondary task performance. An alternative is to control performance on one of the tasks.

Rolfe mentions the work of Miller. Miller (1960-61) lists seven mechanisms that an operator used in reacting to stress:
1. omission - simply not processing information
2. error - processing information incorrectly
3. queuing - delaying responses
4. filtering - systematic omission of certain categories of the task according to some priority scheme
5. approximation - making less precise responses
6. "multiple" channelization - synchronizing responses to similar task demands so that they appear to be handled as a single task
7. escape - leaving the situation entirely and making no attempt to deal with the task.

References mentioned by Rolfe


Classically, experiments in the area of "selective attention" have been designed to enable the experimentors to gain insights into the "mechanisms" which enable human operators to respond selectively to important features of their environment while ignoring features which are of little or no importance relative to the task being performed. Egeth has summarized the "state of the art" of selective attention experimentation and much of the following discussion can be attributed to his excellent summary.

Common to all experiments in selective attention is the conceptual model of the human nervous system which assumes that input information is held briefly in a large capacity short-term sensory storage, from which it is withdrawn at a rate consistent with the limited information processing capabilities of the remainder of the nervous system.

Most experiments in selective attention incorporate the presentation of a complex stimulus and require the subject to respond to the stimulus on the basis of
some specified feature or set of features contained in the complex stimulus.

Most previous selective attention experiments have utilized one of the four types of experimental tasks listed below:

1. Recognition of tachistoscopically presented visual stimuli
2. Listening and responding to one of several simultaneously presented auditory messages
3. "Speeded" classification of multidimensional objects
4. Visual search through complex visual fields

Of primary interest in this review of literature pertinent to the measurement of driving performance are results accruing from experience utilizing tasks 1 and 4 from the list above. Some of these results are presented below.

Attention to tachistoscopically presented visual stimuli is the oldest form of selective attention experimentation and, in general, results in this area have shown that preparatory set improves ability to identify stimuli with specified features. Critics of this research, on the other hand, point out that there is no way to determine whether the original perception of incidental features is less accurate than the perception of features emphasized in the task performance instructions or whether it was the additional time in memory which caused performance to deteriorate. This criticism seems largely irrelevant in the application of results of selective attention experiments to driving and it seems, therefore, reasonable to assume that "set" will influence the speed and accuracy of response to selected aspects of visual stimuli presented to a driver.

In selective attention experiments utilizing visual search tasks, subjects are usually presented with an array of stimuli and are instructed to locate a specific stimulus or set of stimuli contained in the array. The object of the search is usually called a target and the collective set of all other stimuli in the array is usually called the field in this type of experimentation. Several types of responses have been employed in these visual search studies: subjects may have to indicate whether or not an array contains a target; or they may be required to identify the location of the target or targets; or if several targets are present in
the array, they may have to remember their identity. The dependent variable in these search problems is usually the latency between the onset of the stimulus array and the response indicating that the subject has located the target. In those situations where several targets are present in the stimulus, accuracy of recall can also be used as a response measure.

Results from experiments in selective attention employing visual search tasks have indicated that target recognition, at least during visual search, may best be described as a hierarchical system of decision processes. In searching for a target there presumably are elementary tests for certain target attributes which are made on all visual inputs. Inputs which fail these low level tests are passed by without being subjected to higher level testing. Experiments have indicated that several elementary tests may be carried on simultaneously since multiple-target searches can be performed as fast as single-target searches. This hierarchical model suggests that the perception of targets is, in fact, different from the perception of field items. The latter are rejected as non-targets since they fail low-level tests. By virtue of this early failure, they are not subjected to higher level tests and hence are not given any positive classification and are not identified. This model has readily identifiable parallels in the driving task.

The adoption of a hierarchical model to describe the results of selective attention research has other implications in driving. Since items in the field not containing the necessary attributes to qualify them as stimuli do not engage the full depth of the recognition hierarchy, it might be that these items may be scanned quickly. It might also hypothesized that the search for presence of a target may be substantially faster than the search for the absence of a target. It is also likely that the similarity of the target to the field items ought to affect the search rate since it is necessary to subject field items that are similar to the target to a more detailed examination than is required for dissimilar field items in order to reject them as non-targets. Supposedly, field items that are similar to the targets will pass some of the low-level tests appropriate to the target and must be rejected at a higher level. Since they engage more than the minimal depth of the hierarchy, they require more time to process than items that are very dissimilar to the target since the latter may be rejected at a lower level.
Egeth concludes his summary of selective attention experimentation by asserting that when a multi-dimensional visual stimulus is available for only a short time, information may be extracted from it, one dimension after another, and that it is possible to train subjects so that they are capable of varying the order of examination of dimensions in accordance with the relative values of the dimensions. The first dimension thus encoded will enjoy an advantage in later recall over the other dimensions since the visual trace from which information is encoded fades rapidly with time. Egeth also concludes that recognition, in both vision and audition, is the result of a hierarchy of tests performed upon sensory input. It is possible to adjust the testing procedure so that only a particular pattern or set of patterns will be recognized. All others will go unrecognized.

These concepts are based on simple tasks and performance observed in the simple tasks. An extension of this theory to more complex situations can be proposed. This extension would suggest that the recognition hierarchy may be conceived of as a system in which sensory inputs are encoded, and then according to the demands of a particular task, these coded items are examined in various combinations, the results of which form the basis for a still higher order of coding response. This process repeats itself until a given character is either rejected or recognized.

Egeth suggests also that the most profitable area for future research would involve the analysis of situations in which subjects do not exhibit the ability to respond solely on the basis of specified stimulus attributes. Driving is such a situation. In driving, stimuli of interest are multidimensional with respect to identifying attributes, and many non-relevant stimuli are present in the driving environment to compete for the driver's attention. In fact, that presence of large numbers of non-relevant items and the relative lack of relevant stimuli in the driving items means that all the stimuli are more likely to be examined in more depth than they would be otherwise.


Michon states that numerous methods have been devised to measure perceptual load. Unfortunately the concept is ill defined, which makes different approaches
practically incomparable.

There is more to work than physical load only. Perception and fine immeasurable manipulation features of a task are becoming increasingly more important and place a burden on the information processing channels of an operator. Considerations of this nature are fundamental to the concept of perceptual load or rather Perceptual Motor Load (PML).

One way of defining a concept such as "perceptual motor load" is to devise a method of measuring it. This has been done in quite a number of ways. One way is the employment of a secondary task. This method assumes that human beings have only a restricted capacity for handling information and that if this capacity is not fully engaged by a particular task, it should be possible to perform some other task simultaneously. The extent to which this second task can be performed is indicative of the spare capacity left by the primary task.


The author of this article hypothesizes a relationship between performance level and the "arousal continuum." He suggests that there is an inverted U relationship between level of arousal and performance level.

This hypothesis was tested by comparing the performance of 31 subjects on an auditory tracking task under different conditions of incentive. These conditions ranged widely from one in which S was under the impression that his scores were not even being recorded to one in which his score determined whether or not he avoided a 150-volt shock and earned bonus money from $2.00 to $5.00. When the effects of learning on performance scores were controlled and an interaction effect of the order of presentation of the experimental conditions had been partialled out, the data of this study gave strong support to the hypothesis. The hypothesis held regardless of whether palmar conductive level or the EMG response of any one of four different muscle groups was used as the criterion of arousal.

In general, the results of this experiment support the hypothesis that an inverted U relationship exists between performance level and the level of arousal, although the results do not provide an indication of the
actual shape of the U relationship. Results also provide definite support for the hypothesis that incentive is the most important experimental variable in terms of increasing measures taken to be indicative of arousal.

This concept must be considered in tests incorporating secondary tasks since it indicates that low levels of stress induced by a secondary task might improve performance on the primary task.


This work was predicated on the assumption that a driver's attention is, in general, not continuously but only intermittently directed to the road. Between observations, uncertainty about both the position of his own vehicle on the road and the possible presence of other vehicles or obstacles increases until it exceeds a threshold. At that moment the driver looks again at the road.

Driving is, in one sense, an error-free performance since no normal driver deliberately undertakes to get into an accident or into a collision and this indicates a spare capacity.

Depriving a driver of part of his input artificially or naturally (in a snowstorm, etc.) can affect performance (e.g., cause psychological speed limits or other performance limits).

The authors suggest a parallel between the sampling of a time function (in which the minimum sampling rate for signal reconstruction is related to the bandwidth of the signal) and the sampling of a road (a space function) where the minimum sampling rate is related to the characteristics of the road and to the velocity at which it is transversed. One might imagine that the road has a certain information rate built into it (i.e., so many bits per mile). The faster one traverses a portion of road, the more bits per unit time that must be processed.

There are a number of factors which can be expected to influence the selection of a driving speed. These include the frequency with which the road deviates from a straight path by enough to require a corrective action. Another factor is the overall density of significant obstacles in the road.
Also a factor, but less easily quantified, is the driver's estimate of the probability that some new object will enter the road or the probability that opposing traffic will deviate into the path of his vehicle between observations.

In general, all of these factors can be reduced to an uncertainty estimate per unit length of road.

The rate at which one would look at the road ordinarily would not be constant. Instead, it would be a continuous variable function of the instantaneous state of affairs.

The point at issue is that a road demands attention. The attentional demand of a road is a characteristic of that road and of the traffic situation which may exist upon it as well as the velocity which it is traversed.

A rather important notion which underlies this theoretical work is that drivers tend to drive to a limit. The author suggests that the limit is determined by that point when the driver's information processing capacity, either real or imagined, is matched by the information generation rate of the road, either real or estimated. The drivers may be wrong in their estimates but they will tend to achieve this balance of input information rate and information processing rate.

Finally, drivers will accept different levels of risk and will drive to a limit such that the probability of an accident is no greater than, but approaches some upper threshold. Subjective acceptable risk level is a measurable characteristic of drivers and directly influences their behavior on the road.
APPENDIX D

CARBON MONOXIDE AND GASSING TECHNIQUES
USED IN HIGHWAY RESEARCH PROGRAM
Introduction

Throughout this research report references have been made to the degradant carbon monoxide and several tests and experiments were reported where comparisons were made of driving performance under air and under carbon monoxide. The purpose of this appendix is to discuss in more detail the nature of the degradant carbon monoxide and its possible effects on drivers, and to more completely specify the methods utilized in preparing subject for highway testing.

It should be pointed out at this time that this data for inclusion in this report was collected in conjunction with data being collected for a research project entitled "An Investigation of the Effects of Low Levels of Carbon Monoxide on Humans Performing Complex Tasks With Particular Emphasis on Actual Driving." This project (Ohio State University Research Foundation Project RF 3141) was funded by the Coordinating Research Council, Inc., of New York City. The project was a interdisciplinary research effort involving the Department of Preventive Medicine of The Ohio State University.

Carbon Monoxide

Carbon monoxide is an extremely poisonous gas
which causes more deaths per year than all other gases combined. As might be expected, therefore, the literature on carbon monoxide is quite extensive. Most of this literature, however, deals with the effects of CO at near lethal concentrations and relatively little is known about the effects of CO at lower levels. Further, almost nothing is known about the effects of low levels of CO on driving performance. This is a fairly serious lack of knowledge because the automobile is one of the most common sources of CO that the average individual is likely to encounter. In addition, the results of mistakes which do occur during driving can be extremely hazardous.

Carbon monoxide is not a simple asphyxiant, but rather competes with oxygen in combining with the hemoglobin in the blood (Ray, 1970). Hemoglobin's affinity for CO (carbon monoxide) is about 210 times greater than its affinity for oxygen. In other words, blood that is in equilibrium with an atmosphere containing equal partial pressures of oxygen and CO would have approximately 210 times more hemoglobin combined with CO than with oxygen. A customary and convenient measure of the level of CO poisoning is the percentage of hemoglobin that combined with CO or the percentage of carboxy-hemoglobin (%COHb).

The research that is reported here, is concerned
with the subacute poisoning due to CO and its effects on automobile driving. "Subacute poisoning" is usually taken to mean that poisoning resulting from an exposure of relatively short duration (not chronic) and of relatively low concentration (not lethal) (Ray, 1967).

In terms of symptoms associated with CO poisoning, subacute exposures would result in COHb levels of less than 50%. The common symptoms of CO poisoning are as follows:

<table>
<thead>
<tr>
<th>% COHb</th>
<th>Signs and Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>No signs or symptoms</td>
</tr>
<tr>
<td>10-20</td>
<td>Possible tightness across the forehead, possible slight headache, dilation of the cutaneous blood vessels</td>
</tr>
<tr>
<td>20-30</td>
<td>Headaches and throbbing in the temples</td>
</tr>
<tr>
<td>30-40</td>
<td>Severe headache, weakness, dizziness, dimness of vision, nausea, vomiting and collapse</td>
</tr>
<tr>
<td>40-50</td>
<td>Same as above, greater possibility of collapse and increased pulse and respiratory rates</td>
</tr>
<tr>
<td>50-60</td>
<td>Increased respiratory and pulse rates, coma, intermittent convulsions</td>
</tr>
<tr>
<td>60-80</td>
<td>Depressed heart action and respiratory rate, and possible death</td>
</tr>
<tr>
<td>80+</td>
<td>Death likely in less than an hour</td>
</tr>
</tbody>
</table>

During rapid CO poisoning, it is possible that a driver might not notice any of the early symptoms before passing into a coma.

**Carbon Monoxide and Driving**

A next logical question to ask is what kind of CO
levels and resulting COHb levels is a driver likely to be exposed to in the normal course of driving.

The sources of CO are quite numerous (and are all additive). Measurement of cabin concentrations of vehicles on the highway indicate that approximately 4% of the automobiles sampled had greater than 100 ppm (parts per million) CO. Many city streets obtain a CO concentration in excess of 100 ppm (50 ppm CO is the limit recommended in industrial environments in the U.S. and in many other countries the maximum allowable concentration is less).

No research studies are available which indicate the actual COHb levels of drivers on the highways, but some inferences can be made considering the work of Forbes (1945), who developed a mathematical model of CO uptake based on the time-concentration of the gas, lung ventilation and body activity level. Their work indicates that concentrations of 100 ppm for prolonged periods (3 to 4 hours) can result in equilibrium concentrations of 14% COHb. Using these facts, plus the results of research that indicates that over 4% of the automobiles have concentrations greater than 100% we can make some inferences about the number of people driving at a given COHb level on specific highways where records are kept.

During 1965, for example, 505,398 passenger cars
made full length uninterrupted trips on the 241 mile long Ohio Turnpike. If it is assumed that on the average they maintained the posted speed and did not stop for long periods at the rest areas, this trip would average about 3.4 hours. Using Forbes model, we can hypothesize that 20,216 of these drivers were driving with a COHb level greater than 14% when they exited the Ohio Turnpike onto the Indiana or the Pennsylvania Turnpike. In addition, those drivers who were smoking while driving might have an additional 10% of their hemoglobin combined with CO.

It appears therefore, that the low level CO problem might be greater than has been thought.

Research Aims

The major hypothesis of the "carbon monoxide" research reported in this study was that significant changes in driving performance can be elicited by the presence of COHb in the blood at levels of 20% or lower. This hypothesis was not blindly made. The Systems Research Group and the Department of Preventive Medicine of The Ohio State University participated in the past on a small scale pilot study on the effects of low levels of CO on human performance in driving. That study funded by The Ohio State University and the U.S. Public Health Service indicated that effects of 20% COHb could be seen in driving performance.
Three major differences due to COHb were noted in this previous experiment. These effects are included:

1. Effects of COHb on Ability to Detect Relative Velocity Changes:

Subjects in a following instrumented vehicle were required to estimate whether a lead vehicle was increasing headway (distance between vehicles), decreasing headway, or maintaining a constant. The lead vehicle was in fact, going either plus or minus 2.5 miles per hour faster or slower than the subject's vehicle or was maintaining the same speed. Subject estimation errors and the time to respond both increased with increasing COHb levels. This result is important from a traffic flow theory standpoint, particularly if it is kept in mind that on a crowded urban expressway many drivers may be exposed to carbon monoxide.

2. Effect of COHb on Headway Performance in Car-Following:

Subjects under CO exposure had a tendency to maintain larger headways than when not under CO exposure. This also has important implications in terms of traffic flow. This tendency might also be due to the subject compensating for his decreased relative velocity detection ability.

3. Effects of Carbon Monoxide on Ability to Estimate Distances:

Increasing amount of COHb tended to increase the distance estimated to be one-half mile. This indicated an effect on some "internal" process.

The results of this past research and a thorough review of the literature were used to suggest hypothesis in the current research and were used in designing the procedures of the current testing. More specifically, the past research and the literature indicated that carbon monoxide was most likely to effect a driver's vision (particularly his search and scan patterns) and
his psychophysical capabilities with respect to intervehicular dynamics. It was also felt that loading could be used to enhance the effect of the decrements.

Some of the research results of this carbon monoxide research have been presented in this report. A more complete description of the testing and a more thorough review and discussion of the literature relative to carbon monoxide and driving will be found in the final report for Ohio State University Research Foundation project RF3141.

Description of Subject Preparation Procedures

The following procedure was used in preparing subjects who participated in the "carbon monoxide" research for highway testing. This description is somewhat abbreviated and many details of the subject preparation have not been mentioned. For a more exact and detailed description, the reader is again referred to the final report for Ohio State University Research Foundation project RF3141. It should also be mentioned that the actual procedures followed for some of the initial subjects who were tested deviated from the generalized procedure presented here. These deviations which were due to the fact that procedures were being developed at the time were minor and consisted primarily of the following:
1. Fewer research personnel were "blind" to knowledge of what gas was being administered (all subjects were, however, "blind").

2. Fewer blood samples were taken (although the same number were taken on the different days of testing for each individual subject).

3. Somewhat longer "soak" times were used in order to get the subject to an initial COHb level.

With the exception of these deviations the following narrative of the procedure used in preparation of subjects held for all subjects tested in this research.

Subjects participating in the highway research, first reported to the Department of Preventive Medicine. There they were placed in the preparation chamber, an 8' x 8' x 8' cubical chamber into which prepared concentrations of gas could be fed. These subjects had all been previously given a physical exam by personnel of the Department of preventive Medicine in order to determine that they were not likely to be adversely affected by the testing procedures (see table at the end of this appendix). After being placed in the chamber, one of two gases was administered to the subject. These included:

1. air, or

2. Carbon monoxide in a concentration designed to bring the subject to a 20% level of Carboxyhemoglobin.

Periodic blood samples were taken (via venus punctures
and "finger sticks") to monitor the subjects COHb build up while in the chamber. After the subject reached a nominal level of 20% COHb, he began driving. The research subject normally drove the vehicle to the testing site which for the research reported here was a section of limited access highway (Ohio State Route 33 between U.S. Route 42 and U.S. Route 36). There, the subject participated in the research tests described earlier in this report. Periodically during the testing (as close to every hour as possible), the testing was stopped and the subject was "refreshed." This refreshment required the subject to breath a measured amount of gas designed to reestablish the subject at either his base level (when air was used as a gas) or his 20% COHb level (when CO was used as a gas). Prior to and after each gassing, a blood sample was obtained from the subject via a finger stick. These samples were later analyzed to determine the accuracy of the gassing technique (for a complete description of the subject's COHb levels see figure at the end of this appendix). Subject blood pressure and respiration rate were also checked at this time.

At all times during the road tests, the subject was accompanied by a "safety man." The safety man who was a member of the staff of the Department of Preventive Medicine, monitored the subject at all times in
order to detect any extremely adverse effects of CO and also monitored the subject's driving behavior in order to detect any extremely hazardous driving situations. The safety man had an auxiliary brake available for his use in the event that corrective action needed to be taken.

After the road testing was ended, the subject was required to remain in the laboratory until the COHb level in his blood dropped sufficiently to allow him to be released.

Subject COHb Data

As mentioned previously in the report, when carbon monoxide was administered to the subjects it was administered at a level designed to bring the subject to a 20% level of carboxyhemoglobin. As was also mentioned previously, the subjects were initially gassed in a chamber and were "refreshed" on the road from a cylinder of gas carried in the vehicle.

The actual COHb levels achieved by the subjects on the days during the main series of experiments when CO was administered is given in the schematic diagram of Figure 22. (Note: The times for refreshment for the individual subjects varied slightly. These variations which are not indicated in the diagram of Figure 22 may be obtained from the final report for project RF 3141.)
FIGURE 22. --SUBJECT COHb LEVELS

Achieved Values

NA = Data not available
-- = No refreshment given
* (measured at 90 minutes)
As can be seen from the data presented in Figure 22, most of the subjects were somewhat below the nominal level of 20% COHb chosen for this research. This suggests that if the subjects had been at 20% COHb perhaps even greater performance decrements would have been realized.
APPENDIX E

ANNOTATED DATA TABLES AND FIGURES
Introduction

This appendix contains tables and figures illustrating data relevant to analyses reported earlier in this report. Notations accompanying each table and figure identify the analysis to which the data belongs.
TABLE 48

SPEEDOMETER USAGE OBSERVED FOR SUBJECTS PARTICIPATING IN MAIN EXPERIMENT

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>3</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial &amp; Measure</td>
<td>Gas</td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
<td>CO</td>
</tr>
<tr>
<td>1. Open Road Normal Vision</td>
<td>No.</td>
<td>10</td>
<td>29</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>6.0</td>
<td>13.7</td>
<td>14.9</td>
<td>10.4</td>
</tr>
<tr>
<td>2. Open Road Occluded Vision</td>
<td>No.</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.0</td>
<td>1.1</td>
<td>2.6</td>
<td>5.9</td>
</tr>
<tr>
<td>3. Constant Car Following Normal Vision</td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.0</td>
<td>0.0</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>4. Perturbated Car Following Normal Vision</td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.0</td>
<td>0.0</td>
<td>1.1</td>
<td>0.7</td>
</tr>
<tr>
<td>5. Constant Car Following Occluded Vision</td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.0</td>
<td>0.0</td>
<td>2.7</td>
<td>0.4</td>
</tr>
<tr>
<td>6. Perturbated Car Following Occluded Vision</td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.0</td>
<td>0.0</td>
<td>0.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Note: This table contains data indicating the number of times and the percent of time that the speedometer was looked at in the trials of the experiment reported in Chapter 4. NA = not available
**TABLE 49**

REAR MIRROR USAGE OBSERVED FOR SUBJECTS PARTICIPATING IN MAIN EXPERIMENT

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial &amp; Measure</td>
<td>Gas</td>
<td>Air</td>
<td>CO</td>
<td>Air</td>
<td>CO</td>
</tr>
<tr>
<td><strong>Trial 1</strong></td>
<td>No.</td>
<td>1</td>
<td>0</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>.7%</td>
<td>0%</td>
<td>10.1%</td>
<td>16.1%</td>
</tr>
<tr>
<td><strong>Trial 2</strong></td>
<td>No.</td>
<td>3</td>
<td>0</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>.4%</td>
<td>0%</td>
<td>10.9%</td>
<td>10.7%</td>
</tr>
<tr>
<td><strong>Trial 3</strong></td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0%</td>
<td>0%</td>
<td>12.3%</td>
<td>4.4%</td>
</tr>
<tr>
<td><strong>Trial 4</strong></td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>38</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0%</td>
<td>0%</td>
<td>18.8%</td>
<td>4.6%</td>
</tr>
<tr>
<td><strong>Trial 5</strong></td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0%</td>
<td>0%</td>
<td>24.7%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Trial 6</strong></td>
<td>No.</td>
<td>0</td>
<td>0</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>

**Note:** This table contains data indicating the number of times and the percent of time that the rear view mirrors were looked at in the trials of the experiment reported in Chapter 4.
TABLE 50
"GAS PEDAL OFF" - "BRAKE PEDAL ON" SUMMARY

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gas Trial &amp; Measure</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Air CO</td>
<td>Air CO</td>
<td>Air CO</td>
<td>Air CO</td>
<td>Air CO</td>
</tr>
<tr>
<td>1. Open Road</td>
<td>-Gas</td>
<td>NA NA</td>
<td>0 1</td>
<td>3 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td>Normal Vision</td>
<td>-Brake</td>
<td>NA NA</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>2. Open Road</td>
<td>-Gas</td>
<td>NA NA</td>
<td>2 1</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Occluded Vision</td>
<td>-Brake</td>
<td>NA NA</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>3. Constant Car</td>
<td>Following -Gas</td>
<td>NA NA</td>
<td>20 25</td>
<td>6 8</td>
<td>6 8</td>
<td>10 7</td>
</tr>
<tr>
<td>Normal Vision</td>
<td>-Brake</td>
<td>NA NA</td>
<td>0 2</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>4. Perturbated</td>
<td>Car Following -Gas</td>
<td>NA NA</td>
<td>12 NA</td>
<td>12 10</td>
<td>8 4</td>
<td>11 13</td>
</tr>
<tr>
<td>Normal Vision</td>
<td>-Brake</td>
<td>NA NA</td>
<td>3 NA</td>
<td>4 3</td>
<td>0 0</td>
<td>4 4</td>
</tr>
<tr>
<td>5. Constant Car</td>
<td>Following -Gas</td>
<td>NA NA</td>
<td>7 8</td>
<td>7 12</td>
<td>1 1</td>
<td>7 10</td>
</tr>
<tr>
<td>Occluded Vision</td>
<td>-Brake</td>
<td>NA NA</td>
<td>0 0</td>
<td>1 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>6. Perturbated</td>
<td>Car Following -Gas</td>
<td>NA NA</td>
<td>12 6</td>
<td>10 9</td>
<td>5 9</td>
<td>6 7</td>
</tr>
<tr>
<td>Occluded Vision</td>
<td>-Brake</td>
<td>NA NA</td>
<td>2 3</td>
<td>4 4</td>
<td>1 0</td>
<td>2 3</td>
</tr>
</tbody>
</table>

Note: This table contains data indicating the number of times that a subject took his foot off the gas pedal and the number of times he applied the brake for each trial of the experiment reported in Chapter 4. NA = not available
<table>
<thead>
<tr>
<th>Trial &amp; Measure</th>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Open Road - Gas</td>
<td>NA</td>
<td>NA</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Normal Vision - Brake</td>
<td>NA</td>
<td>NA</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2. Open Road - Gas</td>
<td>NA</td>
<td>NA</td>
<td>6.40</td>
<td>12.75</td>
<td>6.40</td>
<td>12.75</td>
</tr>
<tr>
<td>Occluded Vision - Brake</td>
<td>NA</td>
<td>NA</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3. Constant Car Following - Gas</td>
<td>NA</td>
<td>NA</td>
<td>2.09</td>
<td>2.65</td>
<td>1.63</td>
<td>1.59</td>
</tr>
<tr>
<td>Normal Vision - Brake</td>
<td>NA</td>
<td>NA</td>
<td>0.0</td>
<td>1.09</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4. Perturbated Car Following - Gas</td>
<td>NA</td>
<td>NA</td>
<td>4.86</td>
<td>NA</td>
<td>4.85</td>
<td>4.43</td>
</tr>
<tr>
<td>Normal Vision - Brake</td>
<td>NA</td>
<td>NA</td>
<td>2.10</td>
<td>NA</td>
<td>4.18</td>
<td>5.17</td>
</tr>
<tr>
<td>5. Constant Car Following - Gas</td>
<td>NA</td>
<td>NA</td>
<td>2.93</td>
<td>6.14</td>
<td>2.34</td>
<td>2.71</td>
</tr>
<tr>
<td>Occluded Vision - Brake</td>
<td>NA</td>
<td>NA</td>
<td>2.93</td>
<td>0.0</td>
<td>0.0</td>
<td>0.76</td>
</tr>
<tr>
<td>6. Perturbated Car Following - Gas</td>
<td>NA</td>
<td>NA</td>
<td>4.09</td>
<td>11.47</td>
<td>4.39</td>
<td>3.74</td>
</tr>
<tr>
<td>Occluded Vision - Brake</td>
<td>NA</td>
<td>NA</td>
<td>2.40</td>
<td>1.91</td>
<td>2.20</td>
<td>3.80</td>
</tr>
</tbody>
</table>

Note: This table contains data indicating the mean duration of time the gas pedal releases and the brake pedal applications associated with the trials of the experiments reported in Chapter 4. NA = not available
<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>47.5</td>
<td>66.4</td>
<td>84.1</td>
<td>57.4</td>
<td>47.5</td>
</tr>
<tr>
<td>CO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33.05</td>
</tr>
<tr>
<td><strong>3. Constant Car</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following - <em>Normal Vision</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4. Perturbated Car</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following - <em>Normal Vision</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5. Constant Car</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following - <em>Occlusions</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6. Perturbated Car</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following - <em>Occlusions</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 23. --SAMPLE HISTOGRAM OF LOOK DURATIONS--SUBJECT K
TABLE 53
HEADWAY VARIANCES OBSERVED FOR SUBJECTS PARTICIPATING IN "MAIN" EXPERIMENT

<table>
<thead>
<tr>
<th>Subject</th>
<th>K</th>
<th>D</th>
<th>N</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant Car Following Normal Vision</td>
<td>14.6</td>
<td>61.3</td>
<td>147.7</td>
<td>96.7</td>
<td>238.8</td>
</tr>
<tr>
<td>Perturbated Car Following Normal Vision</td>
<td>1239.9</td>
<td>325.7</td>
<td>1563.5</td>
<td>275.9</td>
<td>310.4</td>
</tr>
<tr>
<td>Constant Car Following Occlusions</td>
<td>312.0</td>
<td>235.2</td>
<td>684.3</td>
<td>2452.3</td>
<td>119.0</td>
</tr>
<tr>
<td>Perturbated Car Following Occlusions</td>
<td>8388.5</td>
<td>1316.3</td>
<td>4112.8</td>
<td>10734.1</td>
<td>715.1</td>
</tr>
</tbody>
</table>
FIGURE 23. — SAMPLE HISTOGRAM OF LOOK DURATIONS—SUBJECT K
Theoretical Values

\[
\chi^2 = \frac{(\text{observed} - \text{expected})^2}{\text{expected}}
\]

\[
= \frac{(-1.6)^2 + (1.6)^2 + (1)^2}{2.6} + \frac{(12)^2 + (1.3)^2 + (1.3)^2}{6.6} + \frac{(2.6)^2}{2.6} + \frac{1.0 + 6.5 + 2.8}{0.6}
\]

\[
= 0.98 + 0.14 + 0.08 + 11.1 + 1.0 + 6.5 + 2.8
\]

\[
= 16.75
\]

for 6 degrees of freedom

\[
(\chi^2 - 10.6) = 0.10
\]

Therefore the hypothesis of normality is rejected at the 0.10 level of significance.

FIGURE 24. --CHI SQUARE GOODNESS OF FIT TEST EMPLOYED IN CHAPTER 6
APPENDIX F

INFORMATION THEORY
Introduction

The following discussion of information theory is adapted from Fitts and Posner (1967) and Krenek (1970). It is presented as background information for the analysis presented in Chapter 7.

Information Theory

Information theory defines the "average information" or "uncertainty" in a series of N discrete events as a quantity which can be calculated by:

$$ H(x) = \sum_{i=1}^{N} p_i \log_2 \left( \frac{1}{p_i} \right) $$

where:

- $H(x)$ = "average information" or "uncertainty"
- $N$ = number of discrete events
- $p_i$ = probability of the occurrence of event i.

In a choice reaction time experiment, the terms "average stimulus information" or "average stimulus uncertainty" are defined in the same manner as $H(x)$ above.

The "average response information" in a choice reaction time task is contained in the subject's response and is given by

$$ H(y) = \sum_{j=1}^{M} r_j \log_2 \left( \frac{1}{N_j} \right) $$
where:

\[ H(y) = \text{"average response information"} \]

\[ M = \text{number of possible responses} \]

\[ r_j = \text{probability of response } j \]

The "cell information" is that information contained in both the stimulus and the response. It may be obtained from the stimulus-response probability matrix from a given experiment using the formula:

\[ H(x, y) = \sum_{i=1}^{N} \sum_{j=1}^{M} C_{ij} \log_2 \left( \frac{1}{C_{ij}} \right) \]

where:

\[ H(x, y) = \text{cell information} \]

\[ C_{ij} = \text{probability of response } j \text{ to stimulus } i \text{ and for all } C_{ij} \neq 0 \]

The "information transmitted" can then be defined as:

\[ H_T = H(x) + H(y) - H(x, y) \]

or, the information transmitted is defined as that portion of the stimulus information which is present in the subject's response.

In the case where no response errors are made (i.e., errors due to incorrect responses or errors of omission) stimulus information is equivalent to cell information, or

\[ H(x) = H(x, y). \]

Also in this case, the information transmitted is that
amount contained in the response information, that is:

\[ H = H(y) \]

If each of the \( N \) stimuli in the stimulus response matrix have a unique response and no errors are made, then

\[ H(x) = H(y) \]

and it can be said that all information is conserved. In cases, however, where more than one stimulus evokes the same response and where no errors are made:

\[ H(x) \neq H(y) \]

and it can be said that information is reduced.

The average "information-transmission rate" is given by

\[ H_T = \text{Transmission rate} \]

where

\[ \frac{T}{H_T} \] (\( T = \text{Time increment} \)) is the mean time per response.

The "noise" introduced by the subject can then be defined as:

\[ H_r = H(y) - H_T \]

or noise is the excess of response information over transmitted information and is the result of subject response errors.
APPENDIX G

ANALYSIS OF VARIANCE
Introduction

The purpose of this appendix is to outline the procedure used in the various analyses of variance performed in the research detailed previously in this report and to give a numerical example to illustrate the procedure.

Analysis of Variance

The analysis of variance performed on the data obtained in this research were for the most part "three factor" analyses of variance. The three factors that were considered in most of these analyses included:

Factor 1: Trials (e.g., open road, car following, perturbated car following, open road with occlusion, etc.)

Factor 2: Subjects

Factor 3: COHb level (i.e., the nominal levels of 20% and 0% COHb.)

All of the factors considered in these analyses were taken to be "fixed" factors. This does not allow generalization of results beyond the levels of the factors considered in the experiment and does not allow a generalization of results to the population from which the subjects were drawn. On the other hand since no replications were successfully obtained across subjects, it is
not possible to consider any of the factors as random without assuming that the effect due to the three way interaction is equal to zero.

The basic model for this fixed factor three way analysis of variance is given by the formula

\[ X_{ijk} = \mu + a_i + b_j + c_k + a_i b_j + a_i c_k + b_j c_k + e_{ijk} \]

where \( \mu \) = the grand mean of all the different treatment combinations and where \( a, b, \) and \( c \) are effects of sizes 1, 2, and 3 respectively. For purposes of this research \( a_1 \) was normally used to represent the 1th level of Factor 1 (trials), \( b_j \) was used to denote the jth level of Factor 2 (subjects and \( c_k \) was used to express the Kth level of Factor 3 (COHb level). If we further assume that \( t, s, \) and \( c \) can be used to express the maximum number of trials, subjects and COHb levels considered in the analysis, then Table 5 can be used to describe the procedures for calculating the expected mean squares associated with each factor.

From the analysis of variance tables obtained from the computer the following F ratios were calculated

1. For main effect due to trials
\[ F = \frac{MS_1}{MS_{123}}; \quad (t-1), (t-1) (s-1) (c-1) \text{ d. of f.} \]

2. For main effect due to subjects
\[ F = \frac{MS_2}{MS_{123}}; \quad (s-1), (t-1) (s-1) (c-1) \text{ d. of f.} \]
<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>D. of F.</th>
<th>Mean Square</th>
<th>Expected M.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial</td>
<td>$s_1 = sc \sum_{i} (\bar{x}_i - \bar{x})^2$</td>
<td>t-1</td>
<td>$s_1/(t-1)$</td>
<td>$\sigma_e^2 + sc\sigma_1^2$</td>
</tr>
<tr>
<td>Factor 2: Subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjects</td>
<td>$s_j = tc \sum_{j} (\bar{x}_j - \bar{x})^2$</td>
<td>s-1</td>
<td>$s_j/(s-1)$</td>
<td>$\sigma_e^2 + tc\sigma_2^2$</td>
</tr>
<tr>
<td>Factor 3: COHb</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COHb</td>
<td>$s_k = ts \sum_{k} (\bar{x}_k - \bar{x})^2$</td>
<td>c-1</td>
<td>$s_k/c-1$</td>
<td>$\sigma_e^2 + ts\sigma_3^2$</td>
</tr>
<tr>
<td>1x2</td>
<td>$s_{1j} = \sum_{1} (\bar{x}_{1j} - \bar{x}_1 - \bar{x}_j)^2$</td>
<td>(t-1)(s-1)</td>
<td>$s_{1j}/(t-1)(s-1)$</td>
<td>$\sigma_e^2 + c\sigma_{12}^2$</td>
</tr>
<tr>
<td>2x3</td>
<td>$s_{jk} = t \sum_{k} (\bar{x}_{jk} - \bar{x}_j - \bar{x}_k + \bar{x})^2$</td>
<td>(s-1)(c-1)</td>
<td>$s_{jk}/(s-1)(c-1)$</td>
<td>$\sigma_e^2 + t\sigma_{23}^2$</td>
</tr>
<tr>
<td>1x3</td>
<td>$s_{1k} = \sum_{1} (\bar{x}_{1k} - \bar{x}_1 - \bar{x}_k + \bar{x})^2$</td>
<td>(t-1)(c-1)</td>
<td>$s_{1k}/(t-1)(c-1)$</td>
<td>$\sigma_e^2 + s\sigma_{13}^2$</td>
</tr>
<tr>
<td>1x2x3</td>
<td>$s_{1jk} = \sum_{1} (\bar{x}_{1jk} - \bar{x}_1 - \bar{x}_j - \bar{x}_k + \bar{x})^2$</td>
<td>(t-1)(c-1) + (s-1)</td>
<td>$s_{1jk}/(t-1)(c-1)(s-1)$</td>
<td>$\sigma_e^2$</td>
</tr>
</tbody>
</table>
3. For main effects due to COHb levels
\[ F = \frac{MS_3}{MS_{123}} \text{, } (c-1), (t-1) (s-1) (c-1) \text{ d. of f.} \]

4. For trial by subject interaction
\[ F = \frac{MS_{12}}{MS_{123}} \text{, } (t-1) (s-1), (t-1) (s-1) (c-1) \text{ d. of f.} \]

5. For subject by COHb interaction
\[ F = \frac{MS_{23}}{MS_{123}} \text{, } (s-1) (c-1), (t-1) (s-1) (c-1) \text{ d. of f.} \]

6. For trial by COHb interaction
\[ F = \frac{MS_{13}}{MS_{123}} \text{, } (t-1) (c-1), (t-1) (s-1) (c-1) \text{ d. of f.} \]

**Other Sources of Variation**

In addition to the sources of variation considered in the above model and analysis procedure, three other sources of variation were considered. These included

1. variation due to error in experimental procedures (e.g., gassing of subjects or differences in testing protocol)

2. variation due to subject differences from day to day, and

3. variation due to learning.

All of the variance from these sources was assumed to be equal to zero. If, however, this assumption is not correct then the actual variation added by these sources is confounded in the factors that were considered separately. (If this were the case then variation due to experimental error and subject daily differences
would be confounded with COHb levels while the variation due to learning would be incorporated in differences across trials.)

A numerical example of how this type of analysis was performed is presented below. The data contained in Table in the main part of the text was subjected to an analysis of variance and Table 55 was generated. This analysis indicated, as reported earlier, that differences due to trials and subjects could be considered significantly different at the .05 level of significance while differences due to COHb level were significant at the .10 level. Interactions were not found to be significant.

**TABLE 55**

ANALYSIS OF VARIANCE (FOR DATA FROM TABLE ) OF DATA PERTAINING TO THE NUMBER OF TIMES LEAD CAR WAS LOOKED AT IN OCCLUSION TRIALS

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>D. of F</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1: Trials</td>
<td>1361.25</td>
<td>1</td>
<td>1361.25</td>
</tr>
<tr>
<td>Factor 2: Subjects</td>
<td>5924.3</td>
<td>4</td>
<td>1481.07</td>
</tr>
<tr>
<td>Factor 3: COHb</td>
<td>938.45</td>
<td>1</td>
<td>938.45</td>
</tr>
<tr>
<td>1 x 2</td>
<td>595.50</td>
<td>4</td>
<td>148.87</td>
</tr>
<tr>
<td>2 x 3</td>
<td>198.45</td>
<td>1</td>
<td>198.45</td>
</tr>
<tr>
<td>1 x 3</td>
<td>784.30</td>
<td>4</td>
<td>196.07</td>
</tr>
<tr>
<td>1 x 2 x 3</td>
<td>640.30</td>
<td>4</td>
<td>160.07</td>
</tr>
</tbody>
</table>
BIBLIOGRAPHY
REFERENCES


Belt, Brian L., Driver Eye Movements as a Function of Low Blood Alcohol Concentrations. The Ohio State University, Engineering Experiment Station, Technical Report, June, 1969.


Sneed, R. J., "Some Factors Affecting Visibility From a Driver's Seat and Their Effect on Road Safety," British Journal of Physiological Optics, June, 1953, 10 (2), 63-85.

Sperling, George, "Three Models for Short Term Memory," (reported in Norman (1969)).


Sneed, R. J., "Some Factors Affecting Visibility From a Driver's Seat and Their Effect on Road Safety," British Journal of Physiological Optics, June, 1953, 10 (2), 63-85.

Sternberg, Saul, "Two Operations in Character Recognition: Some Evidence from Reaction Time Experiments (reported in Haber (1968)).

Sternberg, Saul, "High Speed Scanning in Human Memory," (reported in Haber (1968)).


Whalen, J.T., Rockwell, T.H., and Mourant, R.R., A Pilot Study of Drivers' Eye Movements. The Ohio State University, Engineering Experiment Station, Project Station, Project 2773, Interim Report, April, 1968.

Zell, John K., Driver Eye Movements as a Function of Driving Experience. The Ohio State University, Engineering Experiment Station, Technical Report, Number IE-16, June, 1969.