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THE PRESENTATION OF INFORMATION
IN CARS

by

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ABSTRACT

The Presentation of Information in Cars

MARGARET GALER

Considerable effort has been put into the development of display technologies such as liquid crystal displays, vacuum flourescent displays, CRTs and so on. In the aviation field in particular, much ergonomics effort has been expended on specific aspects of the display technology such as the contrast ratios, effects of glare, font and so on. However, very little is known about the ergonomics aspects of new display technology applications in cars.

In a series of experiments reported in this thesis three electronic display designs for a car instrument panel comprising speedometer, tachometer and minor gauges were tested by potential users. The experiments comprised:

Study 1 - laboratory tests in which a range of designs were presented to drivers in photographic form using projection tachistoscope techniques

Study 2 - tests of dynamic models of the display designs in a computer generated vehicle simulator

Study 3 - road trials with the pre-production prototypes in cars in normal driving conditions.

The electronic digital display was read most accurately and preferred by drivers on a number of criteria in all three studies. The response to the other electromechanical and electronic displays was varied according to the test conditions and tasks undertaken.

The ergonomics information arising from the studies and from the literature has been collated and structured into a design guide for designers of electronic displays. The design guide is also presented.

The three studies and the development of the design guide reported in this thesis were contracted to the Institute for Consumer Ergonomics by the Advanced Research Group of Ford Motor Company. The author was the principal investigator in all the contracts but the work was conducted in association with many other researchers in the Institute for Consumer Ergonomics.

Study 1 was conducted with Nigel Claridge and Tim Moore. Study 2 was undertaken with Ann Baines and Tim Moore, and Study 3 with Ann Baines and Julie Spicer. A number of other people assisted with the data collection including Jill Jones, Colin Jones and Julie Fitzpatrick. Margaret Stead and Ann Baines assisted with the literature search for the design guide.

I was responsible for the conceptualisation of the full research programme and for the realisation of that programme. I actively took part in all aspects of the research programme including the design of the experiments, experimental procedures, conduct of the experiments and the data analyses. I was responsible for the direction of the research from 1978 to the publication of the design guide in 1984. I wrote all the company reports and the design guide (SP 576). Additional data analysis, the setting of the research in the context of ergonomics knowledge, the automotive industry and design procedures, and the interpretation and discussion of the research findings beyond the company reports were the author's sole responsibility.

CONTENTS

PAGE

VOLUME 1

PAGE

CHAPTER 5 STUDY 2 DRIVER RESPONSES TO FOUR DESIGNS OF INSTRUMENT PANEL TESTED IN A VEHICLE SIMULATOR 113

PAGE

PAGE

LIST OF APPENDICES

LIST OF TABLES

Chapter 4

LIST OF FIGURES

CHAPTER 1 INTRODUCTION: THE STUDY IN CONTEXT

1.1 In-car information - a revolution in progress

Information on the status of various vehicle components and systems has been presented to drivers since the advent of the car. This information has been presented formally as visual displays and informally as audible feedback. In the earliest cars the amount of information presented was limited by the availability of transducers to monitor the various functions. Vehicle road speed, fuel level and coolant temperature were among the first to be commonly displayed. The displays were invariably electromechanical circular dials. As Fowkes (1984) points out in an historical review of information presentation in cars.. "Over the last 80 years vehicle systems and measuring transducers have in general become more sophisticated. However, until recently the basic means of presenting this information visually have changed very little."

Over the last fifteen years there has been a technological revolution which has fundamentally changed concepts of information presentation in cars. The revolution arose from a number of sources and has found expression in the presentation of information in cars. A great deal of research in the automotive industry has gone into the development of new methods of monitoring the condition of vehicle components and vehicle performance. The Society of Automotive Engineers has a range of special publications dealing with the application of electronics in the automobile. For example SP 536 (1983) deals with sensors and actuators; SP 540 (1983) deals with electronic engine and drive train control. As Grimm et al show in SP 565 (1984) the temptation to present the output from the vehicle monitors to the driver becomes irresistible. A 1985 advertisement describes a BMW trip computer as presenting the driver with 120 pieces of information about the vehicle or the journey.

Research and development in the telecommunications field has produced flexible information transfer systems which can also be applied in vehicles. For example, cars can now act as an electronic mailbox; the vehicle information system can act as an electronic diary and message centre; teleconferencing can take place in vehicles and in-car telephone and recording systems are now commonplace. Moreover the developments in telecommunications have also meant that drivers can receive information about the traffic environment (Sandell 1981) and about the journey such as route guidance (Becker et al 1981).

Research and development in electronics engineering has meant that major advances have been made in display technology for both audible and visual displays. The automotive industry has been quick to realise the potential for applying the new display technology in vehicles and the special requirements of the automotive environment, temperature ranges, lighting conditions, power supply and so on have been actively addressed. The Society of Automotive Engineers publication P103 (1982) describes a number of studies to address these special requirements.

The application of these and other areas of development in new technology to vehicles means that the driver can now receive information about the state of the vehicle and its components; about traffic conditions and other aspects of the environment in which the vehicle is being used; and information unrelated to the vehicle but of relevance to the driver such as messages from the office. The information can be presented to the driver in a variety of forms as the design constraints inherent in electromechanical systems are to a great extent no longer applicable. Although it had been possible in the past to move away from the classic circular dial displays and produce linear displays or fixed pointer moving scale speedometers these novel electromechanical designs were very much in the minority. It is only since the development of electronics display technology that it has been possible seriously to contemplate novel display design concepts such as linear or curvilinear scales, dynamic pictograms and so on. Digital displays also changed from the rotating drum counter to segmented or dot matrix numerals.

In the post war period a great deal of ergonomics research was carried out on visual display design and almost entirely on electromechanical displays. This interest arose particularly for aeronautical applications and examined many aspects of the effectiveness of reading displays that could be applied appropriately in automobiles. For example, Baker and Vanderplas (1956), Barber and Garner (1951), Reynolds and Grether (1968) looked at the design of scales and instrument panel lighting. Some of the ergonomics principles can be applied equally to the design of electronic displays but many queries are left unanswered.

Where the advent of electronics display technology has removed many of the constraints on the designer, its application has also produced many queries for the designer and the ergonomist. The basic question asked by designers and ergonomists alike is .....

"If we can now design displays in almost any form, what is the most appropriate form for the user?"

The very rapid developments in vehicle systems monitoring devices and telecommunications, together with the advances in display technology have fundamentally changed the nature of the interaction between the user (the driver), the machine (the vehicle) and the environment. The advances have been so rapid that only a limited amount of fundamental ergonomics research has been possible, and frequently, as the display technologies have developed and improved, the research findings become rapidly out of date.

1.2 The structure and focus of the thesis

The automotive industry has been quick to apply the fruits of the technological revolution in vehicles. This application has frequently gone ahead without due consideration for the requirements and capabilities of the user (the driver).

The basis of this thesis is a series of studies carried out for Ford Motor Company Ltd. which examined driver response to novel electronic vehicle instrumentation. It was refreshing and far sighted of the company to ask fundamental ergonomics questions about the suitability of the novel display designs for the range of people who were likely to use them. The research studies were structured in such a way that the novel designs were evaluated in experiments which simulated reality to different degrees. Hence, the effectiveness of the research methods, the levels of simulation, in predicting reality could also be investigated.

The thesis has two main themes:

A Driver response to novel electronic display designs

B The effectiveness of different levels of simulation as evaluation tools.

In Chapter 2 the literature on display design is reviewed. Those principles, developed in relation to electromechanical displays which are equally relevant to other display technologies are highlighted. The literature relating to ergonomics aspects of electronics displays tends to be concerned with technical factors such as contrast ratios and glare. There is also a very small body of literature based on user response to electronic displays and it is this area that the thesis particularly addresses. The thesis has provided one of the few scientific studies of user response to certain aspects of electronics technology in the vehicle environment. In addition, the debate over the appropriateness of analogue or digital displays in automobiles is also addressed.

The effectiveness of different levels of simulation in training has been well researched and reported in the literature (Stammers 1983). However, simulation as used in evaluation exercises has been less well reported. Simulation is an important part of systems design and development and it is in this area that the thesis is most appropriate. Chapter 3 reviews the research methods used in the studies. It is not often that researchers have the opportunity to try out different research methods within the same programme, particularly different levels of simulation, given the constraints imposed on commercial research. It is hoped that the findings of this thesis will provide insight into the effectiveness of different levels of simulation in product evaluation. Chapter 3 also addresses other issues relevant to evaluation methods such as conducting user trials, experimental design and control of variables.

Chapters 4, 5 and 6 describe three studies carried out to assess driver response to three novel designs of electronic instrument panels. In Study 1, reported in Chapter 4, the simulation was carried out by using photographic representations of the instrument panel designs tested in controlled laboratory conditions. As drivers' response to these novel designs was likely to be influenced by the dynamic properties of the designs, working models of the instrument panels were installed in a computer controlled vehicle simulator and tested in laboratory conditions. This second study is reported in Chapter 5. The working models used in Study 2 did not employ the same electronics technology as would be found in production instrument panels, hence liquid crystal displays (LCD) were installed in cars and tested under normal driving conditions. This third study most closely approximated to reality in many respects but the level of control over a number of variables was reduced or non-existent. Study 3 is described in Chapter 6.

Chapters 7 and 8 take the two main aspects of the thesis and discuss the implications. Chapter 7 is concerned with the findings from the evaluation studies and their implications for electronic display design. The interaction between the objective measures of accuracy and speed of use of the designs and the subjective measures of driver preference, perceived ease of use and so on is explored for each of the three levels of simulation. The particular characteristics of the display designs which have influenced the research findings are discussed. Chapter 8 discusses the advantages and disadvantages of the three levels of simulation used in the studies. It also assesses the usefulness and predictive abilities of each type of simulation. The chapter also takes a wider view and examines the role of simulation in the product/system development process.

Chapter 9 draws conclusions from the studies in terms of the two main themes of the thesis, the driver response to novel electronic display designs and the effectiveness of different levels of simulation as evaluation tools. The need to draw together ergonomics information on electronic display design to assist designers is discussed and the development of a guide for designers is presented as a conclusion to the research programme. The conclusions also examine the contribution made by the study to ergonomics and the motor industry. Future developments in the presentation of information in cars is also speculated upon.

1.3 Acknowledgements

The research on which this thesis was based started in 1978 and continued over several years. The last road trial ended on 21st January 1981 and I am eternally grateful for having survived. The development of the guide for designers continued until it was published by the Society of Autmotive Engineers in 1984, having previously been in private circulation in Ford Motor Company.

Over this length of time the author worked with many other people conducting the experiments, building the test equipment and so on.

The Ford Motor Company, Advanced Research Group provided the commercial impetus for the work and fully funded it. The members of that group including Mr. M. Westbrooke and Mr. R. Robins provided help, guidance, cars and the liquid crystal displays. Mr. G.R.W. Simmonds acted as the company liaison officer throughout the work and took a personal interest in its conduct and outcome.

Professor N.S. Kirk, Professor F.D. Hales and Professor N. Ashford formed part of the project Steering Group in the early years and gave valuable advice and guidance.

The Audio Visual Services at Loughborough University produced the several hundred slides used in Study 1. Tim Folkard, Bob Harding, Roger Wood and the technicians in the Department of Transport Technology designed, built and programmed the vehicle simulator used in Study 2. The dynamic models of the instrument panels were built by Communications Complex Design and Smiths Industries Limited (Aviation Division) kindly loaned the collimating lens. Ford Motor Company provided the three Ford Granadas and the liquid crystal instrument panels used in the road trials of Study 3.

I am also indebted to the driving experts who fearlessly assisted with the road trials and the several hundred drivers from the locality who took part in the three studies.

My colleagues in the Institute for Consumer Ergonomics, Tim Moore, Nigel Claridge, Ann Baines, Julie Spicer at various times ably assisted with conducting the experiments and the analysis of the data for the company reports and Margaret Stead assisted with the literature search for the design guide.

Alison Mott tirelessly transformed manuscript into type script, Elaine Laws did the graphics and Carl Sutton produced the photographs.

I wish to thank Gordon Simmonds particularly for encouraging the publication of the work. Professor N S Kirk acted as supervisor and he and Professor F D Hales advised and curbed my enthusiasm when the thesis looked as if it would grow endlessly. I would like to thank Professor Hales particularly for putting the idea of this thesis into my head.

My husband Ian saw a lot less of me over the years that this thesis was in preparation than either of us wished and I am delighted he tolerated this for so long. His encouragement and support made it all worthwhile.

CHAPTER 2 DISPLAY DESIGN AND AUTOMOTIVE APPLICATIONS

2.1 Introduction

Display design has been a fundamental component of ergonomics since the Second World War and the amount of published literature on the subject is overwhelming. A number of enthusiastic ergonomists have, undaunted by the task, drawn together excellent design guidelines based on the literature (Bailey 1982, McCormick 1976, Van Cott and Kinkade 1972). The vast majority of the literature reports research on electromechanical display devices such as moving pointer/fixed scale displays and rotating drum digital counters. The ergonomist has addressed in detail scale design, scale selection, interval values, scale interpolation, scale layout, zone markings, pointer design, various forms of coding, and other aspects.

The ergonomics information provided tends to fall into two main categories

- performance criteria
- technical specifications.

Hence a performance criterion may state "designers should ensure that numbers and letters on indicator dials, panels and consoles are as clear as possible, taking into account space restrictions and range of illumination" (Bailey 1982).

A technical specification adopted to achieve that criterion may recommend "The width of all numbers should be 3/5 of the height, except for the '4' which should be one stroke width wider than the others, and the '1' which should be one stroke width wide. In addition, the stroke width should be from 1/6 to 1/8 to the numeral height" (Bailey 1982).

The main emphasis in this thesis is on electronic display designs although the bench mark design against which the electronic designs were assessed was an electromechanical design. A review of the ergonomics literature indicates that the amount of research reported on the ergonomics design criteria for electronic displays by no means matches that for electromechanical displays. The majority of ergonomics research has been reported on displays for aeronautical application or CRT displays rather than on other forms of electronic displays such as liquid crystal (LCD), light emitting diodes (LED) and vacuum fluorescent displays (VFD). As the work on CRT displays has been almost exclusively for VDU applications in offices and similar environments rather than automotive applications the literature will not be discussed in detail. There are a number of reasons for this imbalance in reported research data. The most obvious one is that electromechanical displays have been available for research for several more decades and continue to be of value in many aspects of equipment design. Moreover, the basic format and engineering of electromechanical displays has not changed significantly over the last forty years or more. There has been ample opportunity for ergonomics research to be conducted and valued.

The situation regarding electronic displays is dramatically different. The display technologies are changing and improving all the time. The development time has been extremely short and in less than two decades electronics displays have become commonplace in many diverse applications. Another major difference is the great diversity of display technologies which the ergonomist has to address. Not only are there LCDs, LEDs, VFDs and so on but there are many variants on each display type. For example there are dichroic LCDs and twisted nematic LCDs, each with different properties which effect the legibility of the displays. Furthermore, these various electronic display technologies can be extremely expensive to produce in small numbers for ergonomics research purposes. For example, the curvilinear LCD panel used in the road trials of Study 3 cost Ford Motor Company 250,000 dollars to produce. The rate of development of the display technologies is also extremely fast and it could be argued that ergonomics specification data would be out of date before the work was published.

As mentioned previously ergonomics information tends to fall into two main categories, performance criteria and technical specifications. It could be argued that in terms of performance criteria there is very little which needs to be changed to accommodate electronics technology. Displays should still be visible, intelligible, easy to read and so on. It is only the technical specifications which need to be amended to take account of the particular characteristics of electronic display technologies.

2.2 Classification of displays

The purpose of a display is to transmit information from the machine to the user in an appropriate manner. A good display is one which allows the best combination of speed, accuracy and sensitivity when transferring the information from the machine to the user.

There are two main sorts of display mode, visual and audible and a great variety of display types within these two modes.

Generally displays present information in one or more of the following ways:

Quantitative information ie information giving exact numerical values. Visual quantitative displays may indicate a digital or scalar readout, an audible display may emit a set number of sound impulses or speak the value.

Qualitative information ie judgements about the approximate value, trend, rate of change or direction of deviation from a desired value. Visual qualitative displays may indicate the response by the inclination of a pointer on a scale or by a direction indicator arrow. Audible qualitative displays may indicate the response by a change in frequency of a tone or by speech.

Audible displays can be tonal or noise signals such as warning sirens or buzzers, or can be speech communication such as voice synthesis messages. Audible displays are not considered in this thesis.

Visual displays can be classified in the following way:

Analogue displays: these are so called because the position of the pointer or indicator on the scale is analogous to the value it represents (quantitative). An analogue display can also be used to convey qualitative information, as when a red portion of the scale signifies danger. Analogue displays include circular dials, linear scales and curvilinear combinations.

Discrete displays: these are analogue displays where the readings are discrete rather than continuous. Discrete displays can give quantity information but not in such detail or with such accuracy as the scalar displays described above. The display is formed as discrete sections or segments.

Digital displays: the information is presented directly as a number. The changing values are indicated by the rotation of drums as with electromechanical counters or by the change of shape of electronic dot matrix or segmented digits.

Alphanumeric displays: these displays consist of information presented as messages in full or abbreviated form.

Representational displays: these provide the user with a working model or mimic diagram of the process or the machine. They enable the user to observe the function of each part in relation to the whole, and to locate items quickly.

The displays described in this thesis are primarily concerned with the presentation of vehicle road speed information, although other information such as engine revolutions, vehicle miles, fuel and temperature level were also included in the instrument panels. The electromechanical dial displays are analogue circular dial displays providing scale values by the position of a continuously variable pointer. The electronic dial and curvilinear displays are discrete analogue displays providing scale values by the position of the last lit segment in a cumulative lit arc. The electronic digital display is a seven segment multiple digit display which indicates the display value by illumination of segments to form numerals. Alphanumeric displays are not considered in this thesis. (For further details see Appendix 1).

2.3 Electronic displays

There is a vast body of technical literature concerned with the physical properties of electronic displays, the drive requirements (Horikiri et al 1981), microprocessor control requirements (Muller 1981, Wilson 1981), brightness control (Stricklin et al 1982), operating temperature range (Riordan 1980), multiplex drive (Riordan 1980) and so on. These aspects are only of interest to the ergonomist in as far as their satisfactory performance or otherwise may affect the application of the displays. Hence further reference to these aspects will not be made in the thesis.

In addition to the literature on the physical properties of electronic displays there is also literature, although in much smaller volume, on the aspects of the technology which affect the user. This is of considerable interest to the ergonomist but great care must be taken in the acceptance of the data available. In a recent study carried out by the author (Simmonds and Galer 1984) to review the literature prior to developing a guide to ergonomics for designers of electronic displays (Galer and Simmonds 1984) it was found that much of the published literature was based on tests with very small samples of people often the authors and their colleagues only. Furthermore, much folklore had grown up and had become accepted as fact when the evidence was not readily available to substantiate certain claims.

Electronic displays tend to fall into two main categories

- Passive displays such as LCDs which control or modify the passage of externally generated light.
- Emissive displays such as LEDs and VFDs which have light generating or emitting properties.

The relative merits of passive and emissive displays have been excellently reviewed (Shepherd and Beatty 1981) with particular reference to automotive applications. A more general overview of the qualitites of electronic displays has been produced by Bailey (1982). Snyder (1980) has developed a flow chart which should result in the logical elimination of unacceptable technologies or devices. At each of the decision points, design variables are used in the flow chart to eliminate candidate technologies/devices based upon design requirements. The design guide referred to earlier (Galer and Simmonds 1984) describes, from the literature and from in-house research, the ergonomics specifications for presentation method, types of display, intelligibility and installation. Physical characteristics including brightness, contrast, glare, resolution, percent active area, character size, character width and height, character spacing, font and colour are also presented in the design guide with design recommendations. The methods of character generation and the various types of display such as dot matrix, segmented, and raster displays are also covered. Attention is also given to the characteristics of the display technologies including LED, LCD and VFD in terms of their particular performance including maximum viewing angle, luminance and so on. In view of the fact that the design guide was written by the author and is presented in Appendix 1 it is not considered appropriate to repeat the information in any greater detail.

2.4 Automotive applications

Electronics display technology has been applied successfully in many diverse fields including CRT/VDU displays in offices; electronic clocks and watches; electronic displays on photocopiers and washing machines; in industry and commerce. One area in which electronics display applications have been advancing very rapidly is in aeronautics and a great deal of research has been undertaken to optimise the applications of electronic displays in that particular environment. Another major area in which electronics display technology is now being applied is in the automotive field. Only in recent years have the fruits of research been manifest in vehicle instrument panels. Many companies claim to have produced the first vehicle with electronic instrumentation. The BL Maestro and Montego high series vehicles were the first to make an impression on the mass market, and as late as 1982/83.

A typical automotive panel is required to indicate road speed, engine speed, fuel level, cooling system temperature, and a total vehicle mileage count as continually changing values. Supplementary instrumentation showing oil pressure, battery voltage, trip mileage, etc. may also be included. In addition a considerable number of on or off lights of varying colour for failure monitoring, direction indication, main beam and accessory useage are incorporated. The motor vehicle environment is particularly harsh. The display must be able to withstand wide variations in temperature and humidity. It must be inherently robust to permit handling and installation, and it should be unaffected by vibration. It must also maintain its legibility in both day and night time ambient illumination (Smith and Shepherd 1977).

Initially the electronic displays in vehicles were small discrete displays dedicated to supplying supplementary information as an additional component to be mounted alongside conventional electromechanical instruments. Commonly these devices gave a digital display, the earliest application being a clock. Electronic displays then made an appearance replacing electromechanically displayed functions item-for-item. Now whole instrument panels are produced as single or modular units using electronics technology. Sometimes the panels are entirely of one technology others are hybrid, employing the most appropriate technology according to the requirements of the display. For example VFD bar graphs are commonly used for fuel and temperature gauges, LCDs for circular speedometer and tachometer displays.

Once the industry moved away from replacing displayed functions item-for-item a re-asessment of display format was possible. Each display could be assessed as to whether an analogue or digital display would be most appropriate. Certain displays such as the odometers are clearly best displayed digitally. However, debate has raged long and hard over whether fuel level, temperature, road speed and engine speed should be analogue or digital presentation. There is considerable pressure for technical reasons to present information digitally because this is easiest for all electronic display technologies. The appearance of the electronic digital displays is also much more acceptable aesthetically than electromechanical drum counters. There are counter arguments for quasi-legal reasons against digital displays for functions such as fuel level and temperature. The argument is that people may take the digital readings as exactly accurate, unlike analogue readings, and may endeavour to sue the manufacturer if the readings are not exactly correct. The debate on the presentation of road and engine speed has been more on functional and aesthetic lines and a great deal of strong feeling has been expressed.

Let us now consider the presentation of road speed, the subject of the experiments reported in this thesis.

It is generally acknowledged (Bailey 1982, Van Cott and Kinkade 1972) that analogue displays, particularly of the fixed scale and moving pointer variety, are best suited to convey rate or trend information and for check reading. Digital displays are considered most useful for fast and precise reading, particularly of more static data.

Evidence from car driving research (Denton 1967) suggests that there is a tendency, in the absence of a display, to underestimate speed when decelerating and to overestimate speed when accelerating. These tendencies are likely to become more marked over a long journey and with the magnitude of the speed change. To counteract this the well designed speedometer should be clear and easy to read by virtue of good contrast, optimal scale configuration and numbering, lack of clutter, lack of ambiguity and compatibility with other displays on the instrument panel. Branton (1977) has shown for train drivers and Denton (1967) for car drivers that a variety of information sources are used to judge speed, change of speed, and the rate of change. These sources include visual information from the outside environment; auditory information from the vehicle, wind noise and so on; kinaesthetic information including vibration; as well as from inspection of appropriate displays. In the car driving environment however, Denton (1969) indicates that the vehicle speed display is rarely referred to except when driving on motorways as distinct from at the turn off points. Studies by Reason (1974) substantiate the views that drivers use two main sources of velocity information: the 'mental' speedometer, which is subjective and based on his/her perception of the world outside and on best guesses; and the objective display inside the vehicle. In using the display as a check reading instrument the driver needs to have great confidence in its mechanical and ergonomic quality, otherwise he/she reverts to the 'mental' speedometer in an emergency (Shipley and Branton 1977).

The ergonomics literature, therefore, leads one to suppose that analogue displays are most appropriate for the speedometer because they provide rate of change information, check reading is facilitated and if well designed, should be read accurately. Digital displays would be lacking in the first two criteria but would be read very accurately provided that the update rate of digits did not render the display illegible. However, it has already been argued (Reason 1974) that drivers use other sources of velocity information and Denton (1969) suggests that the vehicle display may only be a secondary source of information.

Although a considerable amount of ergonomics research has been carried out comparing the qualities of analogue and digital electromechanical displays there are few references to comparisons of the two types of display when produced as electronic designs. Sinclair (1971) in a review of analogue and digital time displays considered that digital time displays had their disadvantages. Zeff (1965) found that with respect to speed and accuracy of reading and logging it took 3½ to 4 times longer to read from an analogue time display compared with a digital display. However, the user's requirements of time displays are not necessarily comparable with user's requirements of speed displays. Ishii (1980) reported a comparison of analogue and digital displays in automobiles where a seven segment 21.5 mm character height vacuum fluorescent display was tested in road trials under controlled road and weather conditions. It was found that the visual recognition time of the digital display was on average 0.1 sec. faster than the analogue display. The analogue display was not described in detail but was most likely to have been an electromechanical dial. Armour (1985) reporting a study carried out in the early 1970s showed speed reading times of 1.04 sec. for a 25 mm character height digital display compared with 1.10 sec. for a 6.4 mm digital display, 1.62 sec. for a circular dial and 2.07 sec. for a strip indicator.

Analogue displays come in a variety of formats, typically fixed scale and moving pointer circular or linear displays; or moving scale fixed window or pointer displays. The analogue electronic displays in the studies reported in the thesis can most closely be described as being of the fixed scale moving pointer variety except that the 'pointer' was the edge of a cumulative band of lit segments. Hence angular displacement information was not provided by the line of the pointer but by the arc of the segments. (However, the curvilinear design became linear at 50 mph). Linear displays tend to take longer to read than circular displays as the amount of scanning required to locate the pointer is greater because linear scales tend to extend over a greater area for the same scale range as circular designs. Graham (1956) reported that in a comparison of horizontal, vertical and circular scales, the vertical scale was clearly less easy to read than the other two displays. The success of the circular scale may be attributable to the fact that it presents a smaller area to be scanned. Sleight (1948) attributed the differences between the linear and circular scales used in his experiment to the variation in their 'effective' area; the larger the area to be scanned the less accurate the reading.

The majority of the literature concerned with electronic digital displays has been with CRT generated displays or more recently segmented and dot matrix numerals. Vartabedian (1971) carried out a study to determine the influence of various fonts on legibility using CRT generated displays. Radl-Koethe and Schubert (1971) tested discrete readouts of different font, technology, intensity and colour. It was observed that subjective and objective ranking differed markedly.

Simpson (1971) compared the legibility of three different types of electronic digital display, under varying ambient light levels and viewing positions. He found a significantly poorer performance for the side illumination display. A number of studies (Ellis 1978, Van Nes and Bouma 1978, Payne et al 1981) have also investigated the readability of segmented numerals and other forms of presentation (Cornog and Rose 1967).

Details of character size, font, character stroke width to height ratios, and other factors influencing the legibility of digital displays are given in Galer and Simmonds (1984), see Appendix 1.

No studies have been found where drivers' preferences as opposed to their performance with electronic analogue or digital display designs as speed indicators in vehicles have been reported. The series of studies reported in this thesis may fill a gap in the ergonomics literature with information on driver performance in terms of speed and accuracy of reading and check reading; and driver preference in terms of ease of reading and check reading, attractiveness, choice and so on for two forms of analogue electronic display and a digital electronic display for vehicle speed readings. In addition these data can be compared with identical data for an electromechanical circular dial display.

CHAPTER 3 THE RESEARCH METHODS

3.1 Introduction

The Ford Motor Company Ltd required information on driver responses to a number of novel electronic instrument panels for cars. The literature available at the time, 1978, had not provided the company with the information they required and this is discussed in more detail in the preceding chapter. A programme of research was devised which would provide the company with information on which they could make decisions about the future design and development of vehicle instrumentation for their cars.

3.2 Aims

- To compare the performance of drivers using three electronic display designs with their performance using an electromechanical display; in terms of the accuracy of using the instruments for speed readings.

- To obtain drivers' preferences and opinions regarding the instrument panel designs.

The programme was essentially an exercise to evaluate a range of product designs from an ergonomics point of view.

3.3 The structure of the research programme

The research programme comprised three studies separated in time by months and extending over several years from 1978 to 1981. The studies were sequential and the conduct of each study depended on the outcome of that preceding.

3.3.1 Study 1 Photographic simulation

In the first study an investigation of drivers' response to photographic simulations of five instrument panel designs was carried out. These were two electromechanical dial displays, an electronic dial, an electronic curvilinear display and an electronic digital display. The display designs were presented in the form of slides using a projection tachistoscope. The speed readings on the displays were static and did not fluctuate in response to driving conditions. Seventy five drivers read the speed shown on the speedometer and stated whether a speed was within a specified speed limit. Measurements were taken of driver accuracy in completing these tasks. These two objective measures provided data on the accuracy of using the various display designs. Drivers also gave their opinions about the display designs and these were noted using subjective measures. All drivers saw all five displays.

3.3.2 Study 2 Dynamic in-vehicle simulation

In the second study tests on the ease and accuracy of use of four instrument panel designs under simulated driving conditions were carried out. Dynamic models of the four instrument panels were installed in a computer controlled vehicle simulator. The readings on the speedometers and tachometers responded to the operation of the simulator controls by the driver. The displays were similar in design to those tested in Study 1. One of the electromechanical designs was omitted. One hundred drivers read the speed shown on the speedometer and stated whether a speed was within a specified speed limit. They also used the displays to drive to a speed target. Each driver saw all four display designs. Measurements of driver accuracy of completing these tasks were taken, and drivers' opinions recorded.

3.3.3 Study 3 Road trials

In the third study tests were carried out on the ease and accuracy of reading four instrument panel designs broadly similar in design to those tested in Study 2. The instrument panels were installed in Ford Granada cars. In three sets of road trials an LCD electronic dial display, an LCD electronic curvilinear display and an electronic tungsten filament digital display were compared with the electromechanical dial display. The readings on all the instruments responded to the operation of the vehicle controls, as in normal driving. The same tasks were carried out by the driver as in Studies 1 and 2 except for driving to a speed target. The display designs were tested by a total of 204 drivers in either day or night time lighting conditions. The ease and accuracy of reading the displays was recorded and drivers also gave their opinions. In each test only one electronic display design was compared with the electromechanical display.

The results for each study were noted and compared with the preceding studies.

3.4 The experimental designs

The purpose of the studies described in this thesis was to assess driver response to various designs of instrument panels with a view to indicating which design(s) would be most easy to use and most acceptable. From this purpose a number of indications for the experimental design can be identified. These are, firstly that the tests should involve users (drivers); secondly that comparisons are to be made between different designs of the same product (the instrument panels); thirdly that the criteria on which the designs are to be assessed include both objective performance measures (eg accuracy of use) and subjective preference measures (eg acceptability).

3.4.1 The choice of appropriate users to act as measuring tools in product evaluation is most important. Typically, in product evaluation a panel of subjects is chosen to use and assess the product (Rennie 1981). The sample should be drawn from the population most likely to use the product. In the studies reported in this thesis the subjects were recruited from the general driving population by local advertisement. In Study 1 the subjects were recruited to reflect the age and sex distribution of drivers generally, as described by Sheppard (1971). However, it was noted that the numbers of female drivers in the over 50 years age group was small, as there are few in the driving population. In Studies 2 and 3 drivers were recruited such that there was an equal number of men and women in each of three age groups. Apart from the age and sex distribution the only other specification was that drivers should have held a full driving licence for a year or more; and in Study 3 for insurance reasons, that they should be over 21 years of age with no endorsements on their driving licence. Within these broad criteria the sample then provided a variety of physical and psychological characteristics including stature (and hence angle and distance of view of the displays), eye sight, colour vision, reaction time and preferences.

Relatively large sample sizes were employed in the studies, Study 1 75 subjects, Study 2 100 subjects, Study 3 total of 204 subjects. Subjects were only allowed to take part in one study. The sample sizes were largely dependent on the time and resources available within the commercial constraints of the contract.

3.4.2 The tasks the users are given should be selected according to a task analysis; and should follow a logical sequence (Rennie 1981). In these studies the number of tasks which the driver carried out were strictly limited although there was some variation as the tests allowed. The main tasks given to the drivers were:-

Read the speed

Check read the speed against a speed limit

Drive to a speed target (Study 2 only, omitted from Study 3 for safety reasons).

These tasks were repeated within each test and practices were also given, the results for which were discounted.

	Study 1	Study 2	Study 3
No of speed readings per subject per display	15	10	10 DAY 10 NIGHT
No of check readings per subject per display	15	10	10 DAY 10 NIGHT

In Studies 1 and 2 reading the speed was the first task and check reading was the second task for each display. In Study 3 the order varied according to the requirements of the test route.

Although there is considerable debate about what drivers actually use speedometer information for, it was considered essential that drivers should as a minimum, be able to read, and use the instruments for check reading, both accurately and easily.

3.4.3 The order of presentation of products for evaluation should not introduce any bias into the findings. In Studies 1 and 2 the subjects saw each display design according to a prescribed order, such that each display had an equal chance of appearing first, second and so on. In Study 3 each subject saw either the electromechanical display or one of the electronic displays first. Each display had an equal chance of being seen first.

3.4.4 The responses made by subjects were on topics which were the same throughout the three studies, with some additions as were appropriate to the tests (see Section 3.5). However, in Study 1 the drivers saw all five display designs and compared them in their responses; in Study 2 similarly the drivers saw all four display designs; in Study 3 the drivers only saw one electronic display design and compared it with the same electromechanical design throughout that study. For ease of comparison of results it would have been preferable for Study 3 to be designed along the same principles as Studies 1 and 2. However, this was not possible for two main reasons. First, in order that the display characteristics could be assessed under a variety of road and lighting conditions the test route took approximately 45 minutes to cover for each display. Hence, if drivers tested all four designs the experiment would have been of about four hours duration including introduction and questionnaire completion. Experiments of this length have inherent problems such as subject fatigue, subject recruitment difficulties and so on. The second reason was that the display designs were not all available for test at the same time.

3.5 The measurements

The principle measuring tool in these studies was the user, although in Study 2 it was possible to take physical measures of response time. The criteria against which products are evaluated should be fair and realistic (Kirk and Ridgway 1970) such that the conditions under which each product is tested should simulate as realistically as possible the likely conditions of use in everyday life. As mentioned in section 3.4.2 the primary criteria against which the displays were tested were:

- the displays should be read easily and accurately

- the displays should be used for check reading against a speed limit easily and accurately.

However, as the designs were to be marketed in the real world it was also reasonable to expect the designs to be acceptable to users in terms of for example,

- perceived ease of reading
- perceived ease of use for check reading
- perceived distraction from the driving task
- attractiveness
- choice for own car.

The user was required to perform two main tasks, reading the speed and check reading the speed against a speed limit. These two tasks, formed the basis of the users controlled experience with the display designs. They also gained informal experience of the designs during the duration of the tests. From the performance of the two tasks a number of measurements were possible. These measurements were in two categories:-

Objective performance measures

- accuracy of speed reading

- accuracy of check reading the speed against a speed limit

Subjective preference measures

- ease of use for speed reading
- ease of use for check reading
- attractiveness of design
- choice of design for own car
- ease of keeping to a speed target (Study 2 only)
- general preference (Study 3 only).

The only physical measure which was possible was response time in Study 2. The mean response time was calculated as the time from the stimulus to the experimenter pressing a single known key on the computer keyboard. It, therefore, included subject response time, display reading time and experimenter reaction time. The response time was fixed in Study 1, and in Study 3, real driving, response time could be influenced by the traffic environment and would be an unreliable measure on which to assess display designs.

3.5.1 The objective measures were relatively straightforward to record but differed in detail according to the constraints of the test conditions. In Study 1 the displays were presented as static, photographic representations. Hence the correct reading was known in advance. The subject's response was recorded on the response sheet and errors noted. As the displays were static the criterion for accuracy of speed reading was that the correct response and the subject's response should co-incide. It was also possible to investigate the nature of the errors in more detail as the correct response was known and the subjects were responding to a static display (see Table 4.2 in Chapter 4).

In Study 2 the displays were presented as dynamic models which responded to the vehicle simulator controls as in normal driving. The vehicle simulator's computer controlled and recorded the speeds shown on the speedometer and the experimenter keyed into the computer the subject's speed reading response. In this study the displays were dynamic hence it was not possible to be certain of the speed shown on the speedometer when viewed by the subject. As some subjects were slow to respond to the stimulus sound, the speed reading may have changed between the time of the stimulus and the subject's response. The computer noted the speed at the stimulus and recorded it until the response key was pressed by the experimenter. The average of the speeds between the stimulus and the response time was considered to be the 'correct' reading.

However, the displays were different in the amount of information they provided for speed reading. The electromechanical dial display was continuous in that the pointer could indicate any speed to any degree of accuracy within the scale range. The electronic dial display was discrete in that it could only provide speed reading information in 2½ mph segments, ie one unit was 2½ mph. The electronic curvilinear display was also discrete and could only provide speed information in 2 mph segments ie one unit was 2 mph. The electronic digital display presented speed in digits of one unit only, this unit being 1 mph. The criterion for accuracy of speed reading was that the subject's response should be within one unit of the correct response. The correct response was the average of the speeds recorded between the stimulus and the response time. Hence the electromechanical dial display and the electronic digital display responses were considered 'correct' if the subject's response was within $\pm$ 1 mph (one unit) of the correct response. The electronic dial display responses were considered 'correct' if the subject's reponse was within $\pm$ 2½ mph (one unit) of the correct response. The electronic curvilinear display responses were considered 'correct' if the subject's response was within ± 2 mph (one unit) of the correct response. The implication of this is that certain display designs presented the driver with fewer opportunities for error when making their speed readings.

Electromechanical dial display - range 0-140 mph, continuous readings, but assume 1 mph units, 140 opportunities for error, 10 opportunities per 10 mph.

Electronic dial display - range 0-120 mph, 2½ mph units, 48 opportunities for error, 4 opportunities per 10 mph.

Electronic curvilinear display - range 0-130 mph, 2 mph units, 65 opportunities for error, 5 opportunities per 10 mph.

Electronic digital display - range 0-140 mph, 1 mph units, 140 opportunities for error, 10 opportunities per 10 mph.

It could, therefore, be argued that the electromechanical dial display and the electronic digital display should be the most difficult to read because they present the user with the greatest number of opportunities for error. The electronic curvilinear display would be easier to read and the electronic dial display easiest to read. In the studies the accuracy of reading scores have not been weighted for opportunity for error as it was considered more useful to examine the results in uncorrected form.

In Study 2 the subjects' responses were elicited by a stimulus sound from the computer at set times into the experimental period.

In Study 3 the LCD displays were installed in vehicles and responded to the controls as in normal driving. Hence the experimenter had no control over the speeds adopted by the drivers and subsequently shown on the instrument panel.

The experimenter manually recorded the speeds shown on a digital readout linked directly to the vehicle speedometer, and also recorded the subjects' responses. As in Study 2 the displays were dynamic hence it was not possible to be certain of the speed shown on the speedometer when viewed by the subject. The experimenter noted the speed at the time of the verbal stimulus and recorded the vehicle speeds until the subject's response was noted. As in Study 2 the average of the speeds between the stimulus and the response was considered to be the 'correct' reading. The same concept of opportunity for error applies to the display designs in Study 3. The only difference is that the range of the electromechanical dial display was less, ie 0-120 mph hence the opportunities for error were reduced.

The criterion for accuracy of check reading the speed against a speed limit was that the subject's response should co-incide with the correct response, namely above or within a speed limit. (When a speed reading was the same as the speed limit subjects were instructed to consider it to be within the speed limit). The criterion was the same in all three studies. However, the method of presentation of the speed limit was different in each study. In Study 1 the experimenter presented the speed limit verbally before the display slide was exposed. In Study 2 the speed limit was presented visually on the video monitor together with the road scene. In Study 3 the speed limits were those in operation on the test route. As it was noted that subjects rarely knew the current speed limit it was also presented verbally to the subject by the experimenter. This also ensured that any errors of decision making were due to misreading the displays rather than lack of knowledge of the speed limits.

It is possible that some bias may have been introduced into the results from the different methods of presenting speed limits. However, it is not clear how the bias would operate and what effect it would produce. On the road the speed limits are presented visually as digits on a road sign, hence it could be argued that this visual presentation favoured the digital speedometer design, as the mode of presentations could readily be compared, digits with digits. However, drivers also check their speed against speed limits at times when the speed limit sign is not visible. Hence drivers must hold a mental image of the current speed limit. It is not known whether this mental image is held visually as an image of the road sign, or as a mental 'verbal' note of the speed limit; nor whether each driver holds an image in the same way. As was noted during Study 3 some drivers clearly have no idea of what are the current speed limits.

The objective measures used in the three studies provided information on the accuracy with which each of the display designs could be used by a variety of subjects, for reading speed, and for check reading speed against a speed limit.

3.5.2 The prime reason for going to the user to evaluate subjectively a product is that the user can be considered the important final judge (Duncanson 1970). For ease and comfort and general acceptability of a product the user's expressed opinion is the direct evidence (Kirk and Ridgway 1971).

The objective measures described in section 3.5.1 above provide information which reflects the abilities and characteristics of users but is not greatly influenced by their opinions. It is not enough in consumer product evaluation, to know how easily or accurately a product can be used. The users' opinions of the perceived ease of use, attractiveness and so on will greatly influence the acceptability of that product. This concept is more than a marketing guide. It has been shown that no matter how satisfactorily a product performs its function, if it is not acceptable to the user then it runs the serious risk of not being used at all (Galer et al 1975).

The users' opinions were sought on the ease of using the displays and also on certain aesthetic qualities of the display designs such as attractiveness. The question of whether or not the subject would choose the display design for their own car was considered to be a synthesis question in which the subject weighed all the qualities of the designs.

At the end of the experiment the subjects completed a questionnaire shown in the appendices to this thesis. In Study 1 this meant that the subjects had seen all five display designs, in Study 2 that they had seen all four display designs and in Study 3 that they had seen one electronic display design and the electromechanical dial display. In all studies the questions were of the form-

"Which of the designs did you find most ....."
"Which of the designs did you find least ....."

The purpose of using this form was to identify both the positive and negative poles of the scales. The data were then analysed in terms of the numbers of subjects who considered which display to be the best/worst on each scale. In the pilot study to Study 1 an attempt was made to use a ranking technique such that subjects ranked each display on each topic. It was clear, however, that the subjects found this to be a very difficult task. They knew which of the designs were best or worst but could not readily use the middle of the scale. This meant that the reliability of the data concerning the middle ranks was low, and the experiment took a long time to complete as subjects spent a disproportionally long time over the decision making for the middle ranks.

The form of subjective response may well have had an influence on the results, particularly for the less spectacular or novel display designs. The electronic curvilinear display design was novel, unusual and colourful. The electronic digital display design was novel, unusual but otherwise rather plain in design. Many subjects mentioned that the electromechanical dial was one with which they were familiar and the electronic dial design was considered to be rather ordinary. Hence when asked which design was best or worst on a topic the more ordinary designs may have been somewhat neglected. This was clearly not always the case, however, as on all occasions each of the display designs is mentioned by the subjects. In Study 3 the electronic display designs are compared singly with the electromechanical design. This meant that each design had the opportunity to be compared directly with the standard. However, as none of the subjects in Study 3 saw all four of the designs it was not possible to address directly the question of which of the three electronic designs was the most satisfactory. The answer could only be inferred from the relative strength of response to each of the separate designs.

The positive and negative poles of the two scales were investigated by direct question. This can also be done by inference from a single question. However, it was clear that certain designs, particularly the electronic curvilinear display, generated strong positive and negative responses (see Table 5.7).

Some of the subjective preference measures were a reflection of the tasks which the subjects had carried out, and for which objective performance data were also available. These were:

- ease of reading
- ease of check reading against a speed limit
- ease of driving to a speed target (Study 2 only)

In effect this latter measure is only interesting as a subjective measure as the results showed that all the drivers were capable of driving to speed targets regardless of the display design. For safety and other practical reasons this test could not be carried out in road trials. As Kirk and Ridgway (1971) note "it is always valuable to have confirmatory evidence in the form of directly expressed opinion".

However, directly expressed opinion does not always accurately reflect the outcome of performance measures. Galer and Simmonds (1985) reported that in a simulation study of drivers' response to five colours of instrument panel lighting the performance measures showed no difference between display colours in terms of accuracy of use. However, the subjective measures showed significant differences between drivers' preferences for the colours on a number of criteria. Chapter 7 assesses the conformity between the performance and preference measures.

Other subjective measures were based on drivers' responses to the aesthetic qualities of the designs and these were repeated in each of the three studies. These were:

- attractiveness
- choice for own car

It was therefore possible to investigate the change in drivers' perception of the display designs from the static designs of Study 1 to the dynamic designs in Study 2, and in the various traffic and lighting conditions of Study 3.

The concept of distraction while driving was of great concern particlarly due to the discrete nature of the electronic display dynamics. It was not possible to assess this aspect of the design in the static conditions of

Study 1. However, in Studies 2 and 3 it was possible to question the subjects on their perception of distraction. Physical measures of the times that the drivers eyes were attracted to the displays, or away from the road would have been possible in Study 2 as there were no safety consequences. However, it was considered extremely difficult to separate out the variables associated with ease or difficulty of reading the displays, namely long 'eyes-off-road' time and those associated with distraction. There is also an attention component of distraction as well as a visual component and this would also have been very difficult to investigate. As the equipment available at the time to measure eye movement was large and intrusive it was decided to abandon any physical measures of distraction and concentrate on drivers' opinions concerning distraction. As Kirk and Ridgway (1971) conclude "...although physiological observations may often be capable of producing decisive information in brand comparison tests, it is sometimes expedient to avoid them because of the complexities involved".

The subjective measures used in the three studies provided information which could be used to supplement the objective measures, and information on drivers' responses to novel methods of presenting speed information in cars.

3.5.3 The only physical measure taken in the studies was that of response time in Study 2. Even this was a conglomeration of times including subject's reading time and experimenter's reaction time. The results did indicate a difference between the display designs in terms of speed of response for reading the displays. However, due to the design of the electronics this can only be considered a comparative rather than an absolute measure.

3.6 The concept of design verification

Design verification is more likely to be carried out when designing and evaluating complex systems where the main purpose is to determine by testing whether the system will perform as required under operational conditions. Meister and Rabideau (1965) suggest that the design verification stage begins formally when the first prototype equipment is installed for testing and ends when the last production model is turned over to the customer. In the context of this thesis the design verification stage started when the first instrument panel design had been produced as a drawing by the company stylists and was completed, as far as the company was concerned, when the results of the last user assessment were known. Further evaluation of the designs in production has not been attempted by the author.

One argument which is put forward in the thesis is that design verification can usefully be carried out at an early stage in the design process, before design flexibility has to be compromised by the specification of hardware, and by the financial investment necessary for the production of prototypes. An essential element in the success of the design verification process is the suitability of the simulations of the real environment which can be produced for the tests.

3.7 Simulation

Simulation can be defined as an attempt to reproduce the characteristics of a system (...or product...), situation, event or phenomenon in a setting other than the one in which the original occurs (Meister and Rabideau 1965). Studies 1 and 2 in this thesis can be described as tests using two levels of simulation. Study 3 is almost real life. The structure of the research programme also enables a comparison of the usefulness of different levels of simulation.

A high degree of simulation requires that equipment personnel and procedures as well as the feedback from the environment are as nearly identical as possible to those which will eventually be found in real life. Chapters 4, 5 and 6 describe the degree of simulation in each study and also describe in detail the conduct of the experiments.

3.7.1 There are certain parameters which must be reproduced in order to represent the system or product for assessment. These include the environmental inputs which influence the performance of the product, the intermediate responses to these inputs consisting primarily of user actions or behaviour, the responses of the product to the user behaviour and the user's perception of that response, and feedback from those responses.

The different levels of simulation used in the studies addressed these parameters more or less effectively. To provide a meaningful reproduction of the operational situation, certain conditions must be met concerning the equipment used in the simulation, the tasks or procedures carried out by the test subjects, the choice of test subjects and the environment in which the tests are conducted.

3.7.2 The equipment used in the studies closely resembled the production displays in some respects but was quite unlike in others. In all three studies the display design concepts were the same, they were two or three (Study 1) forms of analogue dial display, an analogue curvilinear display and a digital display. The design details were the same throughout; with the exception of the curvilinear display, the display colours remained the same; and the size of the displays (in terms of angle subtended at the eye) was the same throughout. As the designs used in Study 3 were as near the production item as possible this indicates that in these respects the primary equipment closely resembled the production displays.

However, in other respects the equipment was dissimilar. In Study 1 the displays were static and produced as photographic (slide) representations. In Study 2 the displays were dynamic models produced using LED technology rather than LCD hence the illumination properties were different.

The test equipment other than the displays also differed markedly in the three studies. In Study 1 the display slides were projected on to a screen using a projection tachistoscope where they were viewed by groups of five subjects. The subjects were sitting on office chairs. In Study 2 the display models were installed in a Ford Granada vehicle simulator the interior of which closely resembled the Ford Granadas used in Study 3. The subjects sat in a vehicle seat and could operate pedals and steering wheel. The vehicle simulator was computer controlled. In both studies the pace of the experiment was set externally. In Study 3 LCD production displays were installed in Ford Granada cars and the subjects adopted a normal driving position. The pace of the experiment was set partly by the subject (who was driving) and partly by the experimenter in response to external environmental cues.

3.7.3 The tasks or procedures carried out by the test subjects were chosen from the many tasks and procedures which make up driving a car. The tasks were chosen for their direct relevance to the performance of the products under test, the vehicle speed displays. The tasks chosen were reading the speed shown on the speedometer; check reading the speed against a speed limit and deciding whether or not that limit was being complied with; using the instruments to drive to a speed target (Study 2 only).

Many other tasks are carried out while driving, most of which are often more important to the successful fulfilment of the driving task than reading the speedometer (Brown 1962). These additional tasks were reproduced to different degrees in the three studies.

In Study 1 the subject's main activities were watching the screen on which the display designs were projected, observing the speed readings on the speedometer and noting them on a response sheet as actual readings or as a decision as to whether the speed was within a speed limit. Nothing more was demanded of the subject except the completion of a questionnaire at the end of the experiment.

In Study 2 some aspects of driving and the road environment were reproduced in the vehicle simulation. The subject's main activity was driving the vehicle simulator along a computer generated road scene. The road scene had random fluctuation so that in order to stay on the road, attention and steering activities were required. When the subject drove off the road an unpleasant buzz noise occurred. In addition the subject was required to operate the primary controls, brake, accelerator, clutch, gear selector, hand brake and steering wheel as if in a normal car. As far as the subject was concerned the tasks associated with using the instruments were secondary to the main driving activity.

In Study 3 subjects drove a car along a test route on ordinary roads. The main difference from normal driving was that the subject was required to read and use the instruments at the experimenter's instigation.

The experience of the display designs gained by the subjects varied in each study. In Study 1 all subjects saw all the display designs showing exactly the same range of speed and tachometer readings. These were predetermined and strictly controlled. In Study 2 each subject could drive the simulator as they wished hence the speed and tachometer readings seen by the subjects varied greatly. In addition the rate of change of the readings was determined by the driving style of the subjects. In Study 3 each subject drove the vehicles in their normal way but had to respond to traffic conditions. Although an attempt was made to keep the traffic conditions as similar as possible for each subject by avoiding known peak traffic times, there was still considerable variation in conditions. Driving style and traffic conditions clearly influenced the experience the subjects gained of the displays both in terms of indicated speeds and rate of change of readings.

3.7.4 The subjects who took part in the studies were recruited from the local driving population. At the time of the studies very few cars were installed with electronic instrumentation, hence the subjects were all naive but potential users of the equipment under test. (For further details see section 3.4.1). There was no reason for any difference between the subjects who took part in each of the studies. Because it was thought likely that experience of the display designs in one study could influence the responses obtained in another study, subjects could not take part in more than one study.

3.7.5 The environment in which the tests were conducted was markedly different in each of the studies. In Study 1 all the display slides were presented in a darkened room, to optimise the visibility of the slides. There was no opportunity for the displays to respond to the ambient illumination, nor was it appropriate for this form of presentation. There were no other visual aspects of the environment which were related to driving. The experiments took place in a blacked-out laboratory. The displays were always projected at the same distance from the subjects. There were no audible or proprioceptive aspects of the environment which were related to driving, nor were there any driving related distractions or attention diversions. Two experimenters conducted the experiments, but apart from the prescribed establishment of rapport with the subjects interaction was minimal. There was always one male and one female experimenter.

In Study 2 some aspects of the driving task were introduced. The experiments were all conducted in a darkened room with illumination from the monitors and instruments. The display illumination was optimal under these conditions. However, as the LED technology employed to produce the dynamic models was not the same as the LCD production displays there was no advantage in testing the displays in a variety of lighting conditions. The subjects drove along a road scene projected to infinity by an aspheric collimating lens. The road scene provided visual information in forward vision about the rate of movement relevant to vehicle speed estimation. There was no movement in peripheral vision, although the subject could view the darkened laboratory through the simulator windows. The subjects had to refocus from infinity (the road scene)to 750 mm to read the instruments, as they would have to do in normal driving. There was no proprioceptive feedback, the simulator was entirely static, however, there was an engine noise which was linked to gear position and accelerator depression. Some drivers in the pilot studies found it extremely difficult to drive the simulator without the engine noise. The engine noise provided information on the rate of change of engine revolutions. The subject's attention was focused on the road scene in order to stay on the road. If the vehicle was driven off the road an unpleasant buzz noise sounded for the duration of the time off the road. Apart from fluctuations in the road scene which required steering adjustments there were no visual distractions, however, the off road buzz and the stimulus beep may have been slight auditory distractions. There was only one experimenter present and interaction was limited. Unlike Study 1 the main task was perceived as 'driving' and reading the instruments was secondary.

In Study 3 the LCD displays were installed in a normal car and driven along ordinary roads. The lighting environment varied in the tests to enable assessments of the performance of the LCD technology. Tests were conducted in daylight and at night. The daylight ambient illumination varied according to the season and the weather. The night time illumination included lit streets, unlit streets and various positions of headlamps from other vehicles. Times of day when the illumination changed over the duration of the test, such as at dusk, were avoided. The LCD displays responded according to the ambient lighting environment. The visual environment varied throughout the duration of the test but was controlled as far as possible between subjects. The visual environment included shops and houses, trees and fields. The route, and hence the general visual environment was the same for all subjects. Visual information relevant to vehicle speed estimation such as rate of movement was as in normal driving. Proprioceptive information was as in normal driving although the Ford Granadas used in the tests were luxurious cars with a smooth drive. The engine and wind noises were as expected from a luxurious car and hence somewhat quieter than that found in less expensive vehicles. Drivers not used to driving such vehicles occasionally remarked on the quietness. There was much in the visual and traffic environment to hold the driver's attention. The primary task was clearly driving the vehicle safely in the variety of traffic conditions. Reading the instruments was much lower in priority for the subjects than in Studies 1 and 2. There was an experimenter in the near side rear passenger seat who initiated the instrument reading tasks. An expert driver, introduced as the person who would provide initial instruction and then route guidance, sat in the front passenger seat. The presence of two relative strangers in the vehicle may have influenced the driving behaviour of the subjects but it is not clear how this influence would be manifest in terms of reading the instruments. To balance the sex ratio during the tests the experimenters were female and the expert drivers male, hence there was always one male and one female plus the subject in the car.

In many respects Study 3 could be considered to be real life conditions and generally in this thesis will be treated as such. However, there were some important differences which may influence the long term real life response to electronic instrumentation in cars. The main point is that although the tests were conducted in a real car on real roads nevertheless clearly a test was being conducted. The subjects were unfamiliar with the test equipment, sometimes with the test environment. There were two strangers in the car during the test and the subjects were being asked to read the instruments and give responses. Moreover, no matter how indifferent the experimenters may be to driving performance the subjects often remarked that their driving performance was under scrutiny. No opportunity has arisen to conduct long term non-intrusive studies of driver response to electronic instrument panel design, hence the influence of this high level simulation, Study 3 cannot be adequately assessed.

CHAPTER 4 STUDY 1 DRIVER RESPONSES TO PHOTOGRAPHIC SIMULATIONS OF FIVE DESIGNS OF INSTRUMENT PANEL

SUMMARY

In the first stage of an investigation of drivers' responses to electronic instrument panel designs, tests on readability and ease of use were carried out. Photographic simulations of five instrument panel designs were evaluated. These were two electromechanical dial displays, an electronic dial display, an electronic curvilinear display and an electronic digital display. The display designs were presented to the subjects in the form of slides using a projection tachistoscope. The readings on the displays were static and did not fluctuate in response to driving conditions. Seventy-five drivers were asked to read the speed shown on the speedometer and also to say whether a speed shown was within a specified speed limit. These two objective measures provided data on the readability and accuracy of use of the different display designs. The drivers also gave their opinions about the displays and subjective measures were taken.

CONCLUSIONS

- The three electronic display designs performed better than the two electromechanical displays on the objective measures.
- The subjective measures did not clearly discriminate between electronic displays and electromechanical displays in general.
- The digital display performed better than the other two electronic display designs, particularly when drivers were asked to read the speed.
- The digital display was the most preferred on all the subjective measures.

4.1 Introduction

The Ford Motor Company Limited, in 1978, was considering alternative technologies for instrument panels and in particular it wished to evaluate the acceptability and effectiveness of electronic displays. The technology employed in such displays and the form in which the information is displayed are likely substantially to influence the effectiveness of the displays in conveying information.

4.2 Aim of Study 1

To evaluate instrument panel designs from an ergonomics point of view, under static conditions in the laboratory.

4.3 Preliminary studies

Two preliminary studies were carried out prior to the main experiment to provide information which was not available from the literature.

4.3.1 Preliminary Study 1 - aim

This study was carried out to obtain data on the range and pattern of speedometer readings over a typical journey.

4.3.2 Preliminary Study 1 - subjects

Twenty subjects took part. They were all drivers who had driven within the last year. There were equal numbers of men and women and a range of ages were included.

4.3.3 Preliminary Study 1 - equipment

A recording sheet was used to note the readings shown on the speedometer. A stop watch was used to indicate when the readings were to be taken.

4.3.4 Preliminary Study 1 - procedure

A route was devised which included a small town (30 mph speed limit), rural roads (60 mph speed limit), dual carriageway (70 mph speed limit) and a village (40 mph speed limit). Each subject was instructed to drive normally along the route, accompanied by an experimenter. At 15 second intervals throughout the 18 minute journey the experimenter noted the speed shown on the speedometer and the speed limit.

4.3.5 Preliminary Study 1 - results

The readings indicated the speeds travelled by 20 cars over a specified route and over certain speed limits. These data were used in the specification of the pattern of speeds shown on the speedometer displays in the main experiment.

For the experimental design a range of speedometer readings which conformed to the patterns observed were allocated for Task 1 - Reading the speed. Speedometer readings for Task 2 - Whether the speed was above or below the speed limit, were allocated to give an equal number of readings above or below the three speed limits 30 mph, 50 mph and 70 mph.

4.3.6 Preliminary Study 2 - aim

To obtain data on the illumination levels in cars under day time and night time illumination levels for comparison with those obtained in the main experiment.

4.3.7 Preliminary Study 2 - experiment

A recording sheet was used to note the illumination levels.

A Hagner photometer was used to measure the illumination levels in cars under various lighting conditions.

4.3.8 Preliminary Study 2 - procedure

Using the Hagner photometer luminance readings were taken of the instrument panel from the drivers' seat (approx 750 mm from the facia), and of the ambient light levels inside the vehicle. This procedure was repeated under day time and night time conditions.

4.3.9 Preliminary Study 2 - results

The data were to be used to compare the illumination levels during the main study with actual conditions of day light and night time. However, because of the illumination requirements of the projection tachistoscope, it subsequently proved impossible to simulate the different levels of illumination in the laboratory. In the event, the main experiment was carried out in dark conditions similar to an unlit street (approximately 70 lux).

4.4 Pilot study

4.4.1 Pilot Study - introduction

One of the critical aspects of the experiment was the length of time for which each slide was presented to the subjects. Originally it was expected that the exposure time for each slide would be related to the length of time that drivers normally look at the speedometer during driving. The Transport and Road Research Laboratory has developed equipment to measure the time taken to read a speedometer (Armour 1972). However, the only reference to any measurements taken was in a TRRL leaflet (Armour 1975) which gave a maximum measurement of 5.76 seconds and a mean of 3.38 seconds. These data were clearly not suitable for use in the present study as they were extremely long. The literature on the readability of alphanumeric characters provided data which were used to specify the range of exposure times for test in the pilot study. A number of references (Anderson & Fitts (1958), Buckler (1977), Christensen (1952), Cornog & Rose (1967), Kerchaert & Sauter (1972), Radl-Koethe & Schubert (1971)) indicated that the critical exposure time would be between 1 second and 300 milliseconds. The studies reported in this thesis were mainly concerned with simple displays with little information content compared with those described in the literature above. In addition, it was essential that the subjects made errors while attempting to read the displays so that comparisons could be made between error rates for the different display designs. Hence a pilot study was conducted to specify the critical exposure time for the slides, to be used in the main experiment.

4.4.2 Pilot Study - aims

To identify the critical exposure time for the slide presentations. The critical exposure time should discriminate between display designs in terms of reading error rates.

To check the experimental method; the illumination levels; the timing and duration of the experiments; the sampling procedures; the response sheet and questionnaire design and the use of vision tests.

4.4.3 Pilot Study - experimental design

The instrument panel designs included in the study were:-

Electromechanical dial display - original
Electromechanical dial display - revised*
Electronic dial display
Electronic curvilinear display
Electronic digital display.

* The revised version of the electromechanical dial display was designed and included in the tests as a comparison between the electromechanical dial design and the electronic dial design. The scale graduatious and markers of the revised electromechanical dial design were identical to the electronic dial, only the 'pointer' was different.

Each display was tested under two conditions. These were:-

speedometer only

speedometer, tachometer, fuel gauge and odometer.

These two conditions were included in order to investigate the effects of additional information on the ease of reading the displays. The instrument panel content and design were specified by Ford Motor Company.

A complete block design was used such that:-

1. All subjects saw all five display designs under both conditions.

2. Each design occurred first, second, third, fourth and fifth in order of presentation an equal number of times.

3. Each of the two conditions occured first or second in order of presentation an equal number of times.

There were ten experimental conditions. These were:-

C1	ELECTROMECHANICAL DIAL (ORIGINAL)	SPEEDOMETER only
C2	ELECTROMECHANICAL DIAL (ORIGINAL)	SPEEDOMETER, tachometer, odometer, fuel gauge
C3	ELECTRONIC DIAL	SPEEDOMETER only
C4	ELECTRONIC DIAL	SPEEDOMETER, tachometer, odometer, fuel gauge

C5	ELECTRONIC CURVILINEAR	SPEEDOMETER only
C6	ELECTRONIC CURVILINEAR	SPEEDOMETER, tachometer, odometer, fuel gauge
C7	ELECTRONIC DIGITAL	SPEEDOMETER only
C8	ELECTRONIC DIGITAL	SPEEDOMETER, tachometer, odometer, fuel gauge
C9	ELECTROMECHANICAL DIAL (REVISED)	SPEEDOMETER only
C10	ELECTROMECHANICAL DIAL (REVISED)	SPEEDOMETER, tachometer, odometer, fuel gauge.

Two tasks were carried out by the subjects during the experiment. These were each repeated for 20 slides. The results for the first five slides of each task were regarded as a practice and were not included in the analysis. Task 1 always preceded Task 2.

Task 1 - Note on the recording sheet the exact speed shown on the speedometer.

Task 2 - Note on the recording sheet whether the speed shown on the speedometer was within a speed limit spoken out before each slide.

The speeds shown on the speedometer in Task 1 were based on the results of Preliminary Study 1 (see Section 4.3). The speeds shown on the speedometer in Task 2 were specified such that:-

the speed limits 30 mph, 50 mph and 70 mph were included five slides were shown for each speed limit plus five practice slides

within each group of five slides associated with a particular speed limit there were, overall, an equal number of readings above, below and equal to the speed limit.

The experiments were all conducted under night time illumination levels (approximately 70 lux).

4.4.4 Pilot Study - subjects

Fifty-five subjects took part in the pilot study. All the subjects were drivers who had driven within the last year and were representative of the ages and sexes of drivers found in the population (Sheppard 1971, Galer & Dillon 1974).

The experiments were conducted using groups of five subjects at a time. Each group was representative, as far as possible, of the age and sex of the general driving population.

4.4.5 Pilot Study - equipment

The instrument panel displays were made up of photographic simulations in the form of slides. There were forty slides for each of the ten conditions. Each subject viewed 400 slides.

The display designs are shown in Appendix 2.

Two carousel slide projectors projected the display designs on to a screen. One projector showed an example of each display design for demonstration purposes. The other projector was used in conjunction with a projection tachistoscope to present each slide for a fixed response time.

The Snellen chart for distance vision and the shortened version of the Ishihara test for colour vision were used to assess subjects' eye sight.

A response sheet was designed on which subjects noted the speed (Task 1) and whether the speed was within a speed limit (Task 2). Each presentation was numbered (1-80) and a bold line divided each five presentations, to enable rapid checking that the subjects were noting their responses in the correct space. Each subject received five response sheets (one per display design).

A self-completion questionnaire was designed to obtain information on the subjects' age, sex, driving experience and other demographic data; and the subjects' opinion about each display.

A Hagner photometer was used to measure the ambient illumination levels.

4.4.6 Pilot Study - procedure

The study was described briefly to the subjects and they were given standard instructions. Subjects' eyesight was then tested using the Snellen and Ishihara tests. Groups of five subjects at a time were shown the photographic simulations of the instrument panel designs as slide presentations and were instructed to complete Task 1 for 20 slides, then Task 2 for 20 slides. The first five slides in each task were a practice. There was a short break between each display presentation (80 slides).

The exposure time for the slides was systematically varied for each group of subjects. The exposure times used in the pilot study were 1 sec., 600 m secs., 500 m secs., 450 m secs., 400 m secs., 300 m secs. The order of presentation of the displays was also varied for each test. This meant that a large number of pilot tests had to be carried out before the critical exposure time could be reliably specified.

The ambient illumination levels in the laboratory were varied to achieve daylight and night conditions.

The questionnaire, response sheets, instructions, and eyesight tests, were assessed during the pilot studies and amended where appropriate.

4.4.7 Pilot Study - results

The results from the pilot study indicated that:-

1. The critical exposure time for the slides was 450 m secs. At longer exposure times the number of errors was small, and did not clearly discriminate between displays. At shorter exposure times the subjects were clearly under stress during the experiment, which was considered unsatisfactory, and the error rate was very high.

2. A satisfactory response time for the subjects to write down their answers was 4 sec. 550 m secs.

3. The response sheet and the vision test recording sheet required no amendment.

4. The questionnaire required the re-wording of some questions to avoid ambiguity and a small number of questions added.

5. The experimental procedure was altered to enable subjects to familiarise themselves with the display designs prior to presentation of the slides. The display designs were shown to the subjects and standard information on the scale characteristics and the method

of reading the speed was presented verbally.

6. It was found to be impossible to simulate the effects on the displays of different ambient illumination levels using slide projection techniques. The majority of the pilot tests were, therefore, conducted under night time conditions.

The findings from the pilot study were incorporated into the main study.

4.5 Main Study

4.5.1 Main Study - introduction

The extensive pilot study enabled the main study to run smoothly. The slide exposure time and response time were specified and the equipment had been tested. The main study, therefore, concentrated on obtaining comparative data on the different instrument panel designs.

4.5.2 Main Study - aim

To evaluate five instrument panel display designs from an ergonomics point of view, under static conditions in the laboratory.

4.5.3 Main Study - experimental design

The experimental design was the same as that used in the pilot study (see Section 4.4).

4.5.4 Main Study - subjects

Seventy-five subjects were used in the main study. All the subjects were drivers who had driven within the last year and were representative, as far as possible, of the age and sex groups within the driving population (Sheppard 1971 Galer & Dillon 1974).

The experiments were conducted using groups of five subjects at a time and each group represented, as far as possible, both sexes and a range of the ages in the general driving population.

4.5.5 Main Study - equipment

Instrument panel designs in the form of slides.

Forty slides per condition, a total of 400 slides. (See Appendix 2 - Display designs).

Two carousel slide projectors, a projection tachistoscope, and an electronic switching device.

A Snellen chart and the Ishihara colour test and recording sheet.

Response sheets and questionnaire. (See Appendix 3 - Study 1 Experimental materials).

The equipment is described in more detail in Section 4.4.

4.5.6 Main Study - procedure

Groups of five subjects at a time took part in the experiment. The project was described briefly to the subjects and they were then given standard instructions. Each subject was then tested using the Snellen test for distance vision, and the Ishihara test for colour vision. The vision tests were conducted both with drivers wearing the spectacles they normally used for driving and with drivers not wearing their spectacles.

Subjects were instructed to wear their driving spectacles during the experiment.

The five designs were shown to the subjects prior to the start of the experiment and standard information on the scale characteristics and the method of reading the speed was presented verbally.

In the experiment the designs were shown to the subjects using one of five orders of presentation as described in Section 4.4.3 Pilot Study - Experimental Design. The subjects completed Task 1 for 20 slides and then Task 2 for 20 slides. The first five slides in each task were regarded as a practice and the results were not included in the analysis. There was a short break between each display presentation (80 slides). Each slide was presented on the screen for 450 m secs. The subjects then had 4 secs 550 m secs to write down the response on the response sheet. There was one response sheet per display.

All 75 subjects saw all five displays under both conditions, i.e. speedometer only and speedometer, tachometer, odometer and fuel gauge.

At the end of the experiment the subjects completed the questionnaire shown in Appendix 3. The questionnaire obtained demographic data about the subjects, and also their opinions and comments about each display design. The subjects were shown the demonstration slides to remind them of the characteristics of each display while they completed the questionnaire.

One complete test with five subjects took approximately 1½ hours. (See Figure 4.1 - Sequence of operations and Figure 4.2 - The experiment in progress).

4.5.7 Main Study - data handling and analysis

The responses for each subject were compared with the correct responses and the following scores were computed by hand.

For each subject:-

1. Sum of errors by condition 1 - 10 (excluding 2 and 3 below)

2. Sum of don't knows by condition 1 - 10

3. Sum of missed responses by condition 1 - 10

4. The extent and direction of errors.

The raw data were transposed from the response sheets and questionnaires on to coding sheets using transparent overlays and hence to a data file.

The data were analysed using the computing packages "Statistical Package for the Social Sciences" (SPSS) and GENSTAT.

4.5.8 Main Study - results

4.5.8.1 Introduction

The first stage of the programme of research to evaluate driver responses to electronic instrument panel designs consisted of experiments conducted in controlled laboratory conditions. The limitations of such experiments are outlined below, in order to put the main findings into context.

The displays were photographic simulations of the instrument panel presented as slide projections and did not show fluctuations in speed or engine revs during the presentation as they would do in normal driving.

The display designs were viewed under ideal conditions with ample contrast and brightness. Slide projection techniques cannot replicate the differences in illumination at the facia of electronic displays compared with the electromechanical displays, nor can they replicate the differences between display technologies under different ambient lighting conditions.

Unlike normal driving the 'driver' had only one task to carry out at a time.

The slides were presented for a fixed exposure time of 450 m secs, whereas, in normal driving, the driver sets the instrument reading time. The exposure time was set at a critical level in order to produce errors, whereas a driver can adjust his/her reading time to reduce errors.

The subjects did not need to re-focus their vision from effective infinity (the road) to 750 mm (the instrument panel). They looked from effective infinity (the screen) to the response sheets (approx 300 mm).

The subjects did not have any cues from the vehicle or from the environment to indicate what the speed was likely to be prior to presentation of the displays.

OBJECTIVE MEASURES

4.5.8.2 Reading the speed

Table 4.1 shows the number of errors made by subjects for each display design when reading the speed.

Table 4.1 The number of errors made when reading the speed

DISPLAY	ERROR(1)		MISS(2)		DON'T KNOW		TOTAL ERRORS		CORRECT	
	freq	%	freq	%	freq	%	freq	%	freq	%
ELECTROMECHANICAL DIAL (ORIGINAL)										
Speedometer	292	26	5	(4) -	5	-	302	27	823	73
Speedometer plus (3)	372	33	29	3	8	1	409	36	716	64
ELECTROMECHANICAL DIAL (REVISED)										
Speedometer	425	38	7	1	0	0	432	38	693	62
Speedometer plus	279	25	19	2	0	0	298	26	827	74
ELECTRONIC DIAL										
Speedometer	123	11	17	2	13	1	153	14	972	86
Speedometer plus	119	11	18	2	2	-	139	12	986	88
ELECTRONIC CURVILINEAR										
Speedometer	245	22	33	3	5	-	283	25	842	75
Speedometer plus	190	17	59	5	14	1	263	23	862	77
ELECTRONIC DIGITAL										
Speedometer	19	2	0	0	3	-	22	2	1103	98
Speedometer plus	23	2	2	-	1	-	26	2	1099	98

Total number of responses per display = 1125
See Figure 4.3.

(1) Error - an error was recorded when the response was not exactly the same as the speed shown on the speedometer.

(2) Miss - a miss was recorded when the subject gave no response.

(3) Speedometer plus - this refers to the condition in which the speedometer, tachometer, odometer and fuel gauge were shown. This was the 'cluttered' mode.

(4) A '-' means that the percentage is less than 1 but not 0.

It can be seen from Table 4.1 that:-

1. There was no significant difference between the accuracy of reading the displays in the 'cluttered' and 'uncluttered' conditions, with the exception of the two electromechanical dial displays original and revised.

2. The electromechanical dial displays were clearly more difficult to read than any of the electronic displays.

3. The electronic digital display produced least errors (2%) when reading the speed compared with the analogue displays. There was no difference between the two conditions for the digital display. It was noted that the majority of errors were made by one person.

4. Although the electronic dial display and the electromechanical dial display (revised) were apparently similar in design there was a considerable difference in the number of errors. The electronic dial display produced 11% errors in both conditions whereas the electromechanical dial display produced 38% (uncluttered) and 25% (cluttered).

5. The trends were reversed for accuracy of reading the electromechanical displays when considering the conditions. The original design was easier to read when in the uncluttered mode and the revised design was easier to read in the cluttered mode.

6. The error scores are a reflection of the total error scores in that the 'missed' and 'don't know' responses do not alter the pattern established by the error scores.

4.5.8.3 The nature and extent of the errors made when reading the speed

The nature and extent of the erors made when reading the speed varied according to whether the speed indicated was on a numbered graduation, on an unnumbered graduation, or between graduations.

Table 4.2 indicates the number of errors made, and the range of erroneous scores.

The complete distribution of errors are given in Tables 4.13, 4.16, 4.19, 4.22, 4.25.

Table 4.2 The nature of the errors made when reading the speed

DISPLAY	NUMBERED GRADUATION			UNNUMBERED GRADUATION			BETWEEN GRADUATIONS		
	No of(1) errors freq	%	Range of errors mph	No of errors freq	%	Range of errors mph	No of errors freq	%	Range of errors mph
ELECTROMECHANICAL DIAL (ORIGINAL)									
Speedometer	5	7	-2 to +2	9	12	-5 to +15	51	68	-10 to +13
Speedometer plus	8	11	-28 to +3	25	33	-20 to +18	57	76	-27 to +9
ELECTROMECHANICAL DIAL (REVISED)									
Speedometer	4	5	-3 to +8	10	13	-10 to +25	45	60	-26 to +2
Speedometer plus	3	4	-10 to +5	9	12	-16 to +20	48	64	-8 to +2
ELECTRONIC DIAL									
Speedometer	0	0	-	22	29	-2 to +10	not		possible
Speedometer plus	0	0	-	15	20	-2 to +12	by		design
ELECTRONIC CURVILINEAR									
Speedometer	14	19	-4 to +5		no	data	25	33	-2 to +4
Speedometer plus	16	21	-10 to +2	11	15	-2 to +14		no	data

Table 4.2 (continued)

DISPLAY	No of errors freq	%	Range of errors mph
ELECTRONIC CURVILINEAR			
Speedometer - below 30 mph (green)	25	33	-6 to +10
Speedometer plus - below 30 mph (green)	20	27	-10 to +10
Speedometer - above 30 mph within 10 (green & amber)	16	21	-11 to +10
Speedometer plus - above 30 mph within 10 (green & amber)	10	13	-2 to +19
Speedometer - above 30 mph over 10 (green & amber)	26	35	-8 to +4
Speedometer plus - above 30 mph over 10 (green & amber)	12	16	-7 to +2
ELECTRONIC DIGITAL			
Speedometer - including digit '4' (45) (2)	1	1	-9
Speedometer plus - including digit '4' (43)	1	1	-1
Speedometer - including digit '1' (31)	1	1	-21
Speedometer plus - including digit '1' (61)	1	1	-17
Speedometer - single digit (5)	1	1	miss
Speedometer plus - single digit (7)	1	1	-1
Speedometer - two digits (45)	1	1	-9
(31)	1	1	-21
Speedometer plus - two digits (43)	1	1	-1
(61)	1	1	-17

Total number of responses per display = 75

(1) Errors include missed responses.

(2) Actual digits shown in brackets.

It can be seen from Table 4.2 that:-

1. The greatest number of errors with the electromechanical dial displays and the curvilinear display occurred when the speed shown was between graduations. In the case of the electromechanical dial displays between 60% and 76% of the errors were made when interpolating the speed between the graduations. There were considerably fewer errors with the electronic curvilinear display (33%). The electronic dial display design did not show readings between graduations.

2. The speeds shown on unnumbered graduations were more accurately read than speeds between graduations producing between 12% and 33% errors. The electromechanical dial displays produced the greatest range of errors.

3. Reading the speed when the pointer was on a numbered graduation caused difficulty to very few people, and no errors were recorded for the electronic dial display. The electronic curvilinear display produced the greatest number of errors (19%-21%).

4. The range of errors made by subjects when reading the speed was variable both across displays and within displays. However, with the exception of the errors made with speeds on unnumbered graduations, the tendency was to under-read the speed ie to report the speed was less than was actually the case. This trend was reversed on almost all displays when speeds on unnumbered graduations were presented. In this case drivers tended to over estimate the speed and report that it was greater than was actually the case.

5. The electronic curvilinear display speedometer had green segments up to 30 mph and amber segments from 30 mph onwards. (The tachometer segments were amber throughout). When the results were analysed to take the colour changes into account there was little difference

between the error scores below 30 mph (green) and above 30 mph by more than 10 mph ie 40 mph and over (green and amber). Both error scores were higher than when the reading was above 30 mph but within 10 mph ie 30-40 mph. In this case the major part of the display would be green and only a maximum of five segments would be amber.

6. The data for the digital display were analysed in terms of the number of digits displayed, ie one or two; whether the digits included a '1'; and whether the digits included a '4'. This was because the digits 1 and 4 are considered to be more difficult to read with segmented displays due to their configuration (4) and spacing (1) (Radl-Koethe and Schubert 1971). Only one error was made when reading any of the digits. These ranged in inaccuracy from -21 to -1. The errors were all made by one person with poor eyesight but a driver.

4.5.8.4 Deciding whether the speed was within a speed limit

Table 4.3 indicates the number of errors made by subjects when deciding whether the speed was within a speed limit.

Table 4.3 The number of errors made when deciding whether the speed was within a speed limit

DISPLAY	ERROR		MISS		DON'T KNOW		TOTAL ERRORS		CORRECT	
	freq	%	freq	%	freq	%	freq	%	freq	%
ELECTROMECHANICAL DIAL (ORIGINAL)										
Speedometer	96	9	0	0	1	-	97	9	1028	91
Speedometer plus	64	6	23	2	5	-	92	8	1033	92
ELECTROMECHANICAL DIAL (REVISED)										
Speedometer	125	11	12	1	0	0	137	12	988	88
Speedometer plus	16	1	10	1	0	0	26	2	1099	98
ELECTRONIC DIAL										
Speedometer	30	3	11	1	1	-	42	4	1083	96
Speedometer plus	20	2	10	1	0	0	30	3	1095	97

Table 4.3 (continued)

DISPLAY	ERROR freq	ERROR %	MISS freq	MISS %	DON'T KNOW freq	DON'T KNOW %	TOTAL ERRORS freq	TOTAL ERRORS %	CORRECT freq	CORRECT %
ELECTRONIC CURVILINEAR										
Speedometer	14	1	5	-	1	-	20	2	1105	98
Speedometer plus	57	5	7	1	1	-	65	6	1060	94
ELECTRONIC DIGITAL										
Speedometer	22	2	1	-	1	-	24	2	1101	98
Speedometer plus	12	1	1	-	5	-	18	2	1107	98

Total number of responses per display = 1125
See Figure 4.4

It can be seen from Table 4.3 that:-

1. With the exception of the revised version of the electromechanical dial display there was no difference in error rates between the displays in the 'cluttered' and 'uncluttered' mode. The electronic curvilinear display performed slightly worse when additional instruments were presented.

2. With the exception of the electromechanical dial (revised) in the 'cluttered' mode the electronic display designs produced marginally less errors than the electromechanical display designs.

3. The number of errors made by subjects in this aspect of the test was very low (2%-12%) regardless of the display design.

4. Very few 'missed' or 'don't know' responses were made by subjects in this test, (maximum 2%).

4.5.8.5 The nature of the errors made when deciding whether the speed was within a speed limit

The nature of the errors made when deciding whether the speed was within a speed limit was expected to depend on the extent of the discrepancy between the speed indicated and the speed limit.

Table 4.4 indicates the number of errors made for each display with varying degrees of discrepancy from the speed limit.

Table 4.4 The numbers of errors made when deciding whether the speed was within a speed limit with varying degrees of discrepancy from the speed limit

DISPLAY	SPEED ON SPEED LIMIT		SPEED ABOVE WITHIN 10 mph		SPEED ABOVE MORE THAN 10 mph		SPEED BELOW WITHIN 10 mph		SPEED BELOW MORE THAN 10 mph	
	NUMBER OF ERRORS									
	freq	%	freq	%	freq	%	freq	%	freq	%
ELECTROMECHANICAL DIAL (ORIGINAL)										
Speedometer	3	4	1	1	1	1	1	1	1	1
Speedometer plus	19	25	5	7	2	3	2	3	1	1
ELECTROMECHANICAL DIAL (REVISED)										
Speedometer	4	5	9	12	2	3	2	3	3	4
Speedometer plus	3	4	1	1	1	1	0	0	1	1
ELECTRONIC DIAL										
Speedometer	5	7	2	3	0	0	2	3	1	1
Speedometer plus	2	3	0	0	1	1	0	0	0	0
ELECTRONIC CURVILINEAR										
Speedometer	1	1	1	1	2	3	1	1	1	1
Speedometer plus	6	8	7	9	1	1	1	1	1	1
ELECTRONIC DIGITAL										
Speedometer	2	3	2	3	2	3	1	1	3	4
Speedometer plus	no data		1	1	2	3	1	1	1	1

Total number of responses per display = 75

It can be seen from Table 4.4 that:-

1. The proportion of errors made for all display designs on this test was very small.

2. The greatest number of errors occurred when the speed shown was exactly equal to the speed limit. (The subjects were instructed that in this case the speed was within the speed limit). The error score probably indicates that, under the test conditions, the decision was difficult to make. This would probably not be the case when actually driving.

3. With the exception of the condition where the speed was actually equal to the speed limit, there was little difference between the number of errors made and the extent of the discrepancy from the speed limit.

4. There was little difference between display designs on the number of errors made when deciding whether the speed was within the speed limit, regardless of the discrepancy between the speed shown and the speed limit.

SUBJECTIVE MEASURES

The subjects were asked to state which of the five display designs they considered easiest and most difficult to read; to decide whether the speed was within a speed limit; the most and least attractive; and which they would choose and avoid for their own car. In addition, the subjects made comments about each display.

4.5.8.6 The display designs considered by the subjects to be easiest and most difficult to read the speed

Table 4.5 The display designs considered by the subjects to be the easiest and most difficult to read

DISPLAY	EASIEST TO READ		MOST DIFFICULT TO READ		RANK ORDER BY EASIEST
	freq	%	freq	%	
ELECTROMECHANICAL DIAL (ORIGINAL)	6	8	16	21	3
ELECTROMECHANICAL DIAL (REVISED)	13	17	3	4	2
ELECTRONIC DIAL	2	3	14	19	4
ELECTRONIC CURVILINEAR	2	3	41	55	4
ELECTRONIC DIGITAL	52	70	1	1	1
TOTAL	75	100	75	100	
	χ^2obs = 119.48 $p<0.05$		χ^2obs = 67.88 $p<0.05$		

See Figure 4.5

χ^2crit = 9.49

df = 4

It can be seen from Table 4.5 that:-

1. Only 17% and 8% of subjects thought the electromechanical designs (revised and original respectively) were easiest to read. 21% thought the electromechanical dial was most difficult to read.

2. The electronic digital display was considered easiest to read by 70% of the subjects compared with 17%, the highest score for any of the analogue displays (electromechanical dial revised).

3. The electromechanical dial designs were considered easiest to read by a larger proportion of subjects (17% and 8%) than the electronic dial design (3%).

4. The revised version of the electromechanical dial design was considered easiest to read by 17% of subjects compared with only 8% for the original version.

5. There was no clear difference between electronic and electromechanical display designs when subjects stated which designs they considered most difficult to read, the responses were very varied within display type.

6. The electronic digital display was considered most difficult to read by only one subject (1%).

7. The electromechanical dial (revised) was considered most difficult to read by only 4% of subjects whereas the original version was considered most difficult to read by 21% of subjects.

8. The electronic curvilinear design was considered most difficult to read by the largest group of subjects (55%).

4.5.8.7 The display designs considered by the subjects to be the easiest and most difficult to decide whether the speed was within a speed limit

Table 4.6 indicates the number of subjects who considered each display to be the easiest and most difficult to decide whether the speed was within a speed limit.

Table 4.6 The display designs considered by the subjects to be the easiest and most difficult to decide whether the speed was within a speed limit

DISPLAY	EASIEST TO DECIDE WHETHER WITHIN LIMIT		MOST DIFFICULT TO DECIDE WHETHER WITHIN LIMIT		RANK ORDER BY EASIEST
	freq	%	freq (1)	%	
ELECTROMECHANICAL DIAL (ORIGINAL)	5	7	23	31	5
ELECTROMECHANICAL DIAL (REVISED)	16	21	9	12	2
ELECTRONIC DIAL	8	11	9	12	4
ELECTRONIC CURVILINEAR	11	15	28	38	3
ELECTRONIC DIGITAL	35	47	5	7	1
TOTAL	75	100	75	100	

(1) 1 missing response
See Figure 4.6

$\chi^2 crit = 9.49$
$df = 4$

$\chi^2 obs = 37.75$
$p<0.05$

$\chi^2 obs = 27.34$
$p<0.05$

It can be seen from Table 4.6 that:-

1. Only 7% of subjects considered the electromechanical dial (original) easiest to decide whether the speed was within a speed limit, whereas 31% considered it the most difficult. 21% of subjects considered the revised version easiest for speed limit decisions. With the exception of the electronic digital display there is no clear difference between electromechanical and electronic display designs on this measure.

2. The electronic digital display was considered easiest for this task by nearly half (47%) the subjects.

3. The original electromechanical dial display performed worse (7% easiest 31% most difficult) than the other dial designs. The revised electromechanical dial design performed best (21% easiest 12% most difficult) of the dial displays.

4. The electronic curvilinear display was considered most difficult for this task by 38% of the subjects, even though the 'pointer' segments changed colour at 30 mph.

5. The electronic digital display was considered most difficult for this task by only 7% of subjects.

The subjects' comments on the curvilinear display indicate that they considered it easy to tell whether the speed was above or below 30 mph but at 50 mph and 70 mph speed limits it was considered difficult to use.

4.5.8.8 The display designs considered by the subjects to be the most and the least attractive

Table 4.7 indicates the number of subjects who considered each display to be the most and the least attractive.

Table 4.7 The display designs considered by the subjects to be the most and least attractive

DISPLAY	MOST ATTRACTIVE freq(1)	MOST ATTRACTIVE %	LEAST ATTRACTIVE freq(2)	LEAST ATTRACTIVE %	RANK ORDER BY MOST ATTRACTIVE
ELECTROMECHANICAL DIAL (ORIGINAL)	4	6	14	19	4
ELECTROMECHANICAL DIAL (REVISED)	20	27	11	15	3
ELECTRONIC DIAL	4	6	8	11	4
ELECTRONIC CURVILINEAR	22	30	30	41	2
ELECTRONIC DIGITAL	23	32	11	15	1
TOTAL	75	100	75	100	

(1) 2 missing responses
(2) 1 missing response
See Figure 4.7

$\chi^2_{obs} = 25.98$, $p < 0.05$ $\chi^2_{obs} = 20.73$, $p < 0.05$

$\chi^2_{crit} = 9.49$
$df = 4$

It can be seen from Table 4.7 that:-

1. Only 6% of subjects considered the original electromechanical dial display the most attractive design, whereas 27% of subjects considered the revised electromechanical dial display the most attractive. Only 6% of subjects considered the electronic dial display most attractive compared with the electronic curvilinear display (30%) and the electronic digital display (32%). Hence there is no discernable difference between the electromechanical and electronic displays as groups, on attractiveness.

2. The electronic digital display was considered the most attractive by the largest number of subjects (32%) closely followed by the electronic curvilinear display (27%). However the electronic curvilinear was considered the least attractive by the greatest number of subjects (41%).

3. The electronic dial display and the original electromechanical dial display were considered attractive by the smallest number of subjects (6%). The other display designs both electromechanical and electronic were considered attractive by approximately 30% of subjects.

4.5.8.9 The display designs which the subjects stated they would choose and would avoid for their own car

Table 4.8 indicates the number of subjects who stated they would choose and would avoid each of the display designs.

Table 4.8 The display designs considered by the subjects to be the ones which they would choose and would avoid for their own cars

DISPLAY	WOULD CHOOSE freq(1)	%	WOULD AVOID freq(2)	%	RANK ORDER BY WOULD CHOOSE
ELECTROMECHANICAL DIAL (ORIGINAL)	7	10	12	16	4
ELECTROMECHANICAL DIAL (REVISED)	18	25	6	8	2
ELECTRONIC DIAL	9	12	7	10	3
ELECTRONIC CURVILINEAR	6	8	43	59	5
ELECTRONIC DIGITAL	33	45	5	7	1
TOTAL	75	100	75	100	

(1) 2 missing responses $\chi^2 obs = 35.16$ $p < 0.05$ $\chi^2 obs = 71.03$ $p < 0.05$

(2) 2 missing responses

See Figure 4.8

$\chi^2 crit = 9.49$

$df = 4$

It can be seen from Table 4.8 that:-

1. There is no clear difference between electromechanical designs and electronic designs as groups. There is considerable variation within the groups. 10% to 25% of subjects would choose the electromechanical designs, and 8% to 45% of subjects would choose the electronic designs.

2. The largest group (45%) of subjects would choose the electronic digital display for their own car, followed by 25% who would choose the revised electromechanical design.

3. Of the dial designs the revised electromechanical display performed best in that 25% of subjects would choose it for their own car. Only 10% and 12% respectively would choose the other electromechanical and electronic dial displays.

4. Only 8% of subjects stated that they would choose the electronic curvilinear design whereas 59% stated that they would avoid that display for their own car.

5. The smallest number of drivers (7%) stated that they would avoid the electronic digital display for their own car.

Table 4.9 is a summary table indicating the relative scores of each display on both the objective and subjective measures.

Table 4.9 SUMMARY TABLE indicating how the displays scored on each of the tests

	ELECTROMECHANICAL		ELECTRONIC		
	ORIGINAL	REVISED	DIAL	CURVILINEAR	DIGITAL
OBJECTIVE MEASURES					
Reading the speed	● ●	●	● ● ● ●	● ● ●	● ● ● ● ●
Is the speed within a speed limit?	●	● ●	● ● ● ●	● ● ●	● ● ● ● ●
SUBJECTIVE MEASURES					
Easiest to read	● ● ●	● ● ● ●	● ●	● ●	● ● ● ● ●
Easiest for speed limits	●	● ● ● ●	● ●	● ● ●	● ● ● ● ●
Most attractive	● ●	● ● ●	● ●	● ● ● ●	● ● ● ● ●
Would choose for own car	● ●	● ● ● ●	● ● ●	●	● ● ● ● ●

The more dots the better. The scale is based on rank orders.
Only the positive side of the scale is shown in this table.

4.5.8.10 Characteristics of the sample

Seventy five subjects took part in the main study and they were selected to reflect the age and sex distribution of the general driving population.

Table 4.10 indicates the age and sex of the subjects included in the main study.

Table 4.10 Age and sex of the subjects

AGE (years)	SEX				TOTAL	
	Male freq	%	Female freq	%	freq(1)	%
17 - 30	19	26	10	16	29	39
31 - 50	15	20	9	12	24	32
51 and over	17	23	4	5	21	28
TOTAL	51	69	23	31	74	100

(1) 1 missing response

A comparison with the figures found by Sheppard (1971) indicates that the sample in the present study had slightly more females and a slightly lower proportion of people in the age group 31 - 50 years. This is probably due to the relative availability of subjects for daytime tests.

The subjects' eyesight was noted using the Snellen distance test and the Ishihari colour test. The majority of people in the sample performed satisfactorily on the Snellen distance test when tested under the same conditions as normal driving, ie wearing driving spectacles if appropriate. Two people had very poor distance vision, but were included as they did drive. Where the results are markedly affected this is noted.

The results of the Ishihari colour vision test indicated that 11 people (15%) had some form of defect in colour vision. All but one were male. None of these people reported any difficulty in seeing the photographic representations of the display designs. Forty people wore spectacles during the experiment. Of these, 10 people had bifocal lenses in their spectacles. The effects of bifocal lenses on the ability to read the displays was not apparent in this study because the displays were projected on to a screen at a distance of 2 m from the subjects, rather than at 750 mm as in a car. Bifocal lenses are focused to infinity for distance viewing and about 300 mm for close viewing.

The electromechanical dial display (original) used in the study is available in a number of Ford models and it was thought that familiarity with this type of display might bias the subjects' responses. Only eleven subjects had Ford cars. In addition, a large number of people allegedly recognised one or other of the electromechanical displays as one which was in their own car or had been in a previous car. Therefore, it proved impractical to obtain reliable data on the subjects' previous experience with the electromechanical dial display (original).

Table 4.11 indicates the number of years since the people in the sample had passed their driving test. These data give an approximate indication of driving experience and also can be compared with existing data (Sheppard 1971).

Table 4.11 The number of years since the subjects had passed their driving test

TIME SINCE TEST PASSED	freq	%
Less than 1 year	4	5
1 - 3 years	8	11
4 - 8 years	12	16
9 - 17 years	26	35
18 - 34 years	13	17
35 years or over	12	16
TOTAL	75	100

It can be seen from Table 4.11 that:-

1. The majority of people had been driving for 9 years or more (68%).

2. Only 5% had been driving for less than a year, and 11% had been driving for between 1 and 3 years.

A comparison of the data from the present study with that quoted by Sheppard (1971) indicates that the present sample contained less people who had been driving for 8 years or less and more people who had been driving for 9 years or more. This is surprising considering that the proportion of younger people, who would probably have been driving for a shorter time, was slightly greater in the present sample than in the study quoted by Sheppard.

4.5.8.11 The test results for each display design

In the preceding sections the test results have been presented in terms of the performance of each display on a particular criterion. In this section all the results for each display are presented.

The electromechanical dial display (original) test results

Table 4.12 Electromechanical dial display (original) - objective measures

OBJECTIVE MEASURES	SPEEDOMETER			SPEEDOMETER PLUS(1)		
	freq	%	Rank(2)	freq	%	Rank
Total no. of errors made when reading the speed	302	27	8	409	36	9
Nature of the errors made when reading the speed (3)						
Numbered graduation	5	7		8	11	
Unnumbered graduation	9	12		25	33	
Between graduations	51	68		57	76	
Total number of errors made when deciding whether the speed was within a speed limit	97	9	9	92	8	8
No. of errors made according to discrepancy from the speed limit						
Speed on speed limit	3	4		19	25	
Speed above, within 10 mph	1	1		5	7	
Speed above, over 10 mph	1	1		2	3	
Speed below, within 10 mph	1	1		2	3	
Speed below, over 10 mph	1	1		1	1	

(1) Speedometer plus = Speedometer, tachometer, odometer, fuel gauge

(2) Rank order 1 = best, 10 = worst

(3) See Table 4.13 for details

Table 4.13 Electromechanical dial display (original) - nature of the errors made when reading the speed

NATURE OF THE ERRORS (MPH)	SPEEDOMETER freq	%(2)	SPEEDOMETER PLUS(1) freq	%
NUMBERED GRADUATION				
- 28	-	-	1	1
- 15	-	-	1	1
- 5	-	-	1	1
- 2	1	1	1	1
- 1	-	-	1	1
Correct	70	93	67	89
+ 1	1	1	2	3
+ 2	1	1	-	-
+ 3	-	-	1	1
Missing response	2	3	-	-
TOTAL	75	100	75	100
UNNUMBERED GRADUATION				
- 20	-	-	1	1
- 15	-	-	1	1
- 10	-	-	1	1
- 9	-	-	1	1
- 5	1	1	1	1
- 3	-	-	3	4
- 2	-	-	2	3
- 1	-	-	5	7
Correct	66	88	50	67
+ 1	-	-	1	1
+ 2	3	4	-	-
+ 3	2	3	-	-
+ 5	-	-	3	4
+ 10	1	1	-	-
+ 14	-	-	1	1
+ 15	1	1	-	-
+ 18	-	-	1	1
Missing response	1	1	4	5
TOTAL	75	100	75	100

Table 4.13 (continued)

NATURE OF THE ERRORS (MPH)	SPEEDOMETER freq	%(2)	SPEEDOMETER PLUS(1) freq	%
BETWEEN GRADUATIONS				
- 27	-	-	1	1
- 12	-	-	3	4
- 10	1	1	1	1
- 7	1	1	1	1
- 6	2	3	1	1
- 5	2	3	-	-
- 3	-	-	1	1
- 2	3	4	5	7
- 1	30	40	21	28
Correct	24	32	18	24
+ 1	-	-	14	19
+ 2	1	1	3	4
+ 3	2	3	-	-
+ 4	4	5	-	-
+ 5	2	3	1	1
+ 7	-	-	1	1
+ 9	-	-	1	1
+ 13	1	1	-	-
Missing response	2	3	3	4
TOTAL	75	100	75	100

(1) Speedometer plus refers to the condition in which the speedometer, tachometer, odometer and fuel gauge were presented.

(2) Percentage figures have been rounded to the nearest unit and do not always sum to 100%.

Table 4.14 Electromechanical dial display (original) - subjective measures

SUBJECTIVE MEASURES	freq(2)	%	Rank(1)
Easiest to read	6	8	3
Most difficult to read	16	21	
Easiest to decide whether speed was within a speed limit	5	7	5
Most difficult to decide whether speed was within a speed limit	23	31	
Most attractive display	4	6	4
Least attractive display	14	19	
Would choose for own car	7	10	4
Would avoid for own car	12	16	

(1) Rank order 1 = best, 5 = worst

(2) Sample size = 75

The electromechanical dial display (original) - summary of results

The electromechanical dial display was included in the study to act as a bench mark against which the test results for the three electronic display designs could be assessed. There are a number of features about the display design which were indicated by the test results and in particular, by the drivers' comments. These are reported below.

1. The electromechanical dial display (original) performed poorly compared with the other display designs. In terms of accuracy of reading the speed, it ranked 8 (no clutter) and 9 (clutter) out of 10.

2. The electromechanical dial display (original) also performed poorly compared with other display designs when check reading the speed against a speed limit, it ranked 9 (no clutter) and 8 (clutter) out of 10.

3. The majority of speed reading errors occurred when the pointer indicated a speed reading between graduations. The second largest number of errors occurred when the speed reading was on an unnumbered graduation.

4. The electromechanical dial display (original) was considered easiest to read by only 8% of the subjects and most difficult to read by 21%. Subjects mentioned that the intervals marked only at 20, 40, 60... mph made the display more difficult to read compared with the revised version which had numbered graduations at each 10 mph.

5. The display was also considered most difficult to use for check reading the speed against a speed limit by 31% of the subjects and ranked 5 (out of 5). The most usual

speed limits in Britain are 30 mph, 50 mph and 70 mph. These speeds are not indicated on the scale markings, therefore the driver has to interpolate between wide scale markings when check reading the speed against speed limits.

6. The electromechanical dial display (original) was considered the most attractive display by only 4 subjects (6%). Subjects reported that the kph and the odometers positioned inside the scale made it look cluttered and unattractive.

7. Only 10% of drivers stated that they would choose this display for their own car although even fewer stated they would choose the electronic curvilinear display.

The electromechanical dial display (revised) test results

Table 4.15 Electromechanical dial display (revised) - objective measures

OBJECTIVE MEASURES	SPEEDOMETER			SPEEDOMETER PLUS		
	freq	%	Rank	freq	%	Rank
Total no. of errors made when reading the speed	432	38	10	298	27	7
Nature of the errors made when reading the speed (1)						
Numbered graduation	4	5		3	4	
Unnumbered graduation	10	13		9	12	
Between graduations	45	60		48	64	
Total no. of errors made when deciding whether the speed was within a certain speed limit	137	12	10	26	2	4
No. of errors made according to discrepancy from the speed limit						
Speed on speed limit	4	5		3	4	
Speed above, within 10 mph	9	12		1	1	
Speed above, over 10 mph	2	3		1	1	
Speed below, within 10 mph	2	3		0	0	
Speed below, over 10 mph	3	4		1	1	

(1) See Table 4.16 for details

Table 4.16 Electromechanical dial display (revised) - nature of the errors made when reading the speed

NATURE OF THE ERRORS (MPH)	SPEEDOMETER freq	%	SPEEDOMETER PLUS freq	%
NUMBERED GRADUATION				
- 10	-	-	1	1
- 3	1	1	-	-
Correct	71	95	72	96
+ 1	2	3	-	-
+ 5	-	-	1	1
+ 8	1	1	-	-
Missing response	-	-	1	1
TOTAL	75	100	75	100
UNNUMBERED GRADUATION				
- 16	-	-	1	1
- 10	1	1	1	1
- 4	2	3	1	1
- 2	-	-	1	1
- 1	-	-	2	3
Correct	65	87	66	88
+ 1	5	7	-	-
+ 2	1	1	1	1
+ 20	-	-	1	1
+ 25	1	1	-	-
Missing response	-	-	1	1
TOTAL	75	100	75	100
BETWEEN GRADUATIONS				
- 26	1	1	-	-
- 20	1	1	-	-
- 18	1	1	-	-
- 8	-	-	1	1
- 6	-	-	1	1
- 3	1	1	2	3
- 2	5	7	4	5
- 1	26	35	27	36
Correct	30	40	27	36
+ 1	7	9	11	15
+ 2	2	3	1	1
Missing response	1	1	1	1
TOTAL	75	100	75	100

Table 4.17 Electromechanical dial display (revised) - subjective measures

SUBJECTIVE MEASURES	freq	%	Rank
Easiest to read	13	17	2
Most difficult to read	3	4	
Easiest to decide whether speed was within a speed limit	16	21	2
Most difficult to decide whether speed was within a speed limit	9	12	
Most attractive display	20	27	3
Least attractive display	11	15	
Would choose for own car	18	25	2
Would avoid for own car	6	8	

The electromechanical dial display (revised) - summary of results

The electromechanical dial display (revised) was included to enable a more equal comparison between the electromechanical and electronic dial displays. The scale markings on the electromechanical dial (revised) and the electronic dial were the same. This display was not included in Studies 2 and 3.

1. When reading the speed the largest number of errors (38%) were made when reading the electromechanical dial (revised) speedometer only. Reading accuracy improved to 27% error when the speedometer was shown with other instruments. The majority of errors were made when subjects were reading speeds between graduations.

2. A similar pattern emerged for check reading the speed against a speed limit although the number of errors was much less.

3. The electromechanical dial display (revised) was considered easiest to read by 17% of subjects and ranked second only to the electronic digital display.

4. This display ranked second to the electronic digital display also for ease of check reading the speed against a speed limit.

5. Over a quarter (27%) of the subjects considered the electromechanical display (revised) to be the most attractive display and it ranked third.

6. A quarter of the subjects stated that they would choose this display for their own car, second only to the electronic digital display. Subjects reported that they liked the scale graduations at every 10 mph and they considered the pointer long and coloured for good legibility. Also the kph and odometers had been moved from the inner scale.

The electronic dial display test results

Table 4.18 Electronic dial display - objective measures

OBJECTIVE MEASURES	SPEEDOMETER			SPEEDOMETER PLUS		
	freq	%	Rank	freq	%	Rank
Total no. of errors made when reading the speed	153	14	4	139	12	3
Nature of the errors made when reading the speed(1)						
Numbered graduation	0	0		0	0	
Unnumbered graduation	22	29		15	20	
Between graduations(2)	Not possible by design					
Total number of errors made when deciding whether the speed was within a speed limit	42	4	6	30	3	5
No. of errors made according to discrepancy from the speed limit						
Speed on speed limit	5	7		2	3	
Speed above, within 10 mph	2	3		0	0	
Speed above, over 10 mph	0	0		1	1	
Speed below, within 10 mph	2	3		0	0	
Speed below, over 10 mph	1	1		0	0	

(1) See Table 4.19 for details

(2) The electronic dial display has been designed such that all the segments are aligned with graduation marks.

Table 4.19 Electronic dial display - nature of the errors made when reading the speed

NATURE OF THE ERRORS (MPH)	SPEEDOMETER freq	%	SPEEDOMETER PLUS freq	%
NUMBERED GRADUATION				
Correct	75	100	75	100
UNNUMBERED GRADUATION				
- 2	7	9	8	11
- 1	2	3	-	-
Correct	54	72	60	80
+ 1	3	4	1	1
+ 2	2	3	4	5
+ 10	1	1	-	-
+ 12	-	-	1	1
Missing response	6	8	1	1
TOTAL	75	100	75	100
BETWEEN GRADUATIONS	Not possible by design(1)			

(1) See note 2 Table 4.18

Table 4.20 Electronic dial display - subjective measures

SUBJECTIVE MEASURES	freq	%	Rank
Easiest to read	2	3	4
Most difficult to read	14	19	
Easiest to decide whether speed was within a speed limit	8	11	4
Most difficult to decide whether speed was within a speed limit	9	12	
Most attractive display	4	6	4
Least attractive display	8	11	
Would choose for own car	9	12	3
Would avoid for own car	7	10	

The electronic dial display - summary of results

1. When reading the speed shown on the electronic dial display only 14% (speedometer only) and 12% (speedometer and other instruments) errors were made. In this respect the display performed reasonably well being ranked 4 and 3 respectively.

2. No errors were made when subjects read the speed on a numbered graduation. All the errors occurred on unnumbered graduations as it was not possible for the display to show a reading between graduations.

3. Very few errors were made when check reading the speed against a speed limit.

4. Only 2 subjects considered this display the easiest to read and 20% considered it the most difficult.

5. This display was rank 4 (out of 5) for check reading the speed against a speed limit.

6. More subjects considered the electronic dial display to be the least attractive (8) than considered it the most attractive (4).

7. Only 9 subjects would choose this display for their own car, but no great negative response was found either as only 7 stated that they would avoid it. Subjects reported that the speedometer and tachometer were easily confused.

The electronic curvilinear display test results

Table 4.21 Electronic curvilinear display - objective measures

OBJECTIVE MEASURES	SPEEDOMETER			SPEEDOMETER PLUS		
	freq	%	Rank	freq	%	Rank
Total no. of errors made when reading the speed	283	25	6	263	23	5
Nature of the errors made when reading the speed(1)						
Numbered graduation	14	19		16	21	
Unnumbered graduation	no data(2)			11	15	
Between graduations	25	33		no data(2)		
Below 30 mph (green)	25	33		20	27	
Above 30 mph within 10 mph (green and amber)	16	21		10	13	
Above 30 mph over 10 mph (green and amber)	26	35		12	16	
Total number of errors made when deciding whether the speed was within a speed limit	20	2	2	65	6	7
No. of errors made according to discrepancy from the speed limit						
Speed on speed limit	1	1		6	8	
Speed above, within 10 mph	1	1		7	9	
Speed above, over 10 mph	2	3		1	1	
Speed below, within 10 mph	1	1		1	1	
Speed below, over 10 mph	1	1		1	1	

(1) See Table 4.22 for details

(2) These data points did not occur in the presentations

Table 4.22 Electronic curvilinear display - nature of the errors made when reading the speed

NATURE OF THE ERRORS (MPH)	SPEEDOMETER freq	SPEEDOMETER %	SPEEDOMETER PLUS freq	SPEEDOMETER PLUS %
NUMBERED GRADUATION				
- 10	-	-	1	1
- 4	1	1	2	3
- 2	9	12	10	13
Correct	61	81	59	79
+ 2	1	1	1	1
+ 5	1	1	-	-
Missing response	2	3	2	3
TOTAL	75	100	75	100
UNNUMBERED GRADUATION				
- 2			5	7
- 1			3	4
Correct	no data(1)		64	85
+ 14			1	1
Missing response			2	3
TOTAL			75	100
BETWEEN GRADUATIONS				
- 2	3	4		
Correct	50	67	no data(1)	
+ 1	6	8		
+ 2	11	15		
+ 4	2	3		
Missing response	3	4		
TOTAL	75	100		

Table 4.22 (continued)

NATURE OF THE ERRORS (MPH)	SPEEDOMETER freq	SPEEDOMETER %	SPEEDOMETER PLUS freq	SPEEDOMETER PLUS %
BELOW 30 MPH (green)				
- 10	-	-	1	1
- 8	-	-	1	1
- 6	3	4	1	1
- 5	-	-	2	3
- 4	3	4	-	-
- 2	3	4	6	8
- 1	7	9	-	-
Correct	50	67	55	73
+ 1	1	1	1	1
+ 2	4	5	2	3
+ 4	1	1	2	3
+ 10	1	1	-	-
Missing response	2	3	4	5
TOTAL	75	100	75	100
ABOVE 30 MPH, WITHIN 10 MPH (green and amber)				
- 11	1	1	-	-
- 2	2	3	3	4
- 1	6	8	2	3
Correct	59	79	65	87
+ 2	-	-	1	1
+ 6	2	3	-	-
+ 10	2	3	1	1
+ 12	-	-	1	1
+ 19	-	-	1	1
Missing response	3	4	1	1
TOTAL	75	100	75	100
ABOVE 30 MPH, OVER 10 MPH (green and amber)				
- 8	1	1	-	-
- 7	-	-	1	1
- 6	2	3	1	1
- 4	2	3	-	-
- 2	4	5	4	5
Correct	49	65	63	84
+ 1	5	7	-	-
+ 2	4	5	4	5
+ 4	2	3	-	-
Missing response	6	8	2	3
TOTAL	75	100	75	100

(1) These data points did not occur in the presentations

Table 4.23 Electronic curvilinear display - subjective measures

SUBJECTIVE MEASURES	freq	%	Rank
Easiest to read	2	3	4
Most difficult to read	41	55	
Easiest to decide whether speed was within a speed limit	11	15	3
Most difficult to decide whether speed was within a speed limit	28	38	
Most attractive display	22	30	2
Least attractive display	30	41	
Would choose for own car	6	8	5
Would avoid for own car	43	59	

The electronic curvilinear display - summary of results

1. About a quarter of the speed readings made were erroneous and no difference was found between the speedometer only condition and the speedometer with other instruments. The number of errors made was slightly less when the speed reading was within 10 mph of 30 mph where the segment colour changed from green to amber.

2. Very few errors were made when check reading the speed against the speed limit.

3. Only two subjects considered the electronic curvilinear display easiest to read, and a strong negative response was noted as over half (55%) the subjects considered this display the most difficult to read.

4. Although 15% of subjects considered that the electronic curvilinear display was easiest to use for check reading the speed against the speed limit, a greater number (38%) considered it to be the most difficult. Subjects' comments indicated that although the segment colour change at 30 mph made that speed limit easier the 50 mph and 70 mph were not enhanced.

5. Thirty per cent of the subjects considered the electronic curvilinear display to be the most attractive and it ranked 2. However, a larger number (41%) considered it to be the least attractive. Subjects remarked that the display was novel and colourful but some also considered that the variety of colours used seriously reduced the legibility of the displays.

6. Only 6 subjects stated that they would choose the electronic curvilinear display for their own car. A much larger number 43 (59%) stated that they would avoid that display. Subjects reported that the green segments below 30 mph were insufficiently bright, that the amber tachometer segments over the whole range of the scale were too bright and attracted attention from the speedometer.

The electronic digital display test results

Table 4.24 Electronic digital display - objective measures

OBJECTIVE MEASURES	SPEEDOMETER			SPEEDOMETER PLUS		
	freq	%	Rank	freq	%	Rank
Total no. of errors made when reading the speed	22	2	1	26	2	2
Nature of the errors made when reading the speed(1)						
Including digit '4'(2)	(45)1	1		(43)1	1	
Including digit '1'	(31)1	1		(61)1	1	
Single digit	(5) 1	1		(7) 1	1	
Two digits	(45)1	1		(43)1	1	
Total number of errors made when deciding whether the speed was within a speed limit	24	2	3	18	2	1
No. of errors made according to discrepancy from the speed limit						
Speed on speed limit	2	3		no data(3)		
Speed above, within 10 mph	2	3		1	1	
Speed above, over 10 mph	2	3		2	3	
Speed below, within 10 mph	1	1		1	1	
Speed below, over 10 mph	3	4		1	1	

(1) See Table 4.25 for details

(2) Actual digits shown in brackets

(3) These data points did not occur in the presentations

Table 4.25 Electronic digital display - nature of the errors made when reading the speed

NATURE OF THE ERRORS (MPH)	SPEEDOMETER freq	%	SPEEDOMETER PLUS freq	%
INCLUDING DIGIT '4'(1)	(45)		(43)	
- 9	1	1	-	-
- 1	-	-	1	1
Correct	74	99	74	99
TOTAL	75	100	75	100
INCLUDING DIGIT '1'	(31)		(61)	
- 21	1	1	-	-
- 17	-	-	1	1
Correct	74	99	74	99
TOTAL	75	100	75	100
SINGLE DIGIT	(5)		(7)	
- 1	-	-	1	1
Correct	74	99	74	99
Missing response	1	1	-	-
TOTAL	75	100	75	100
TWO DIGITS	(45)		(43)	
- 9	1	1	-	-
- 1	-	-	1	1
Correct	74	99	74	99
TOTAL	75	100	75	100

(1) Actual digits shown in brackets

Table 4.26 Electronic digital display - subjective measures

SUBJECTIVE MEASURES	freq	%	Rank
Easiest to read	52	70	1
Most difficult to read	1	1	
Easiest to decide whether speed was within a speed limit	35	47	1
Most difficult to decide whether speed was within a speed limit	5	7	
Most attractive display	23	32	1
Least attractive display	11	15	
Would choose for own car	33	45	1
Would avoid for own car	5	7	

The electronic digital display - summary of results

The electronic digital display was a 7-segment array with the digit '1' generated from the right hand segments.

1. When reading the speed only 2% of the readings were erroneous and most of these were made by one subject.

2. When check reading the speed against the speed limit only 2% of the responses were erroneous.

3. Seventy per cent of the subjects considered the electronic digital display easiest to read and it was rank 1.

4. Nearly half (47%) of the subjects considered the electronic digital display to be easiest for check reading the speed against the speed limit and was rank 1. Only five subjects considered it to be most difficult for this task.

5. About one third (32%) of the subjects considered this display to be the most attractive and again it was rank 1.

6. Nearly half (45%) of the subjects stated that they would choose this display for their own car, and again it was rank 1. Only five subjects stated that they would avoid this display. Subjects considered the digits large enough to be clear and easy to read. They also remarked that the colour coding of the speedometer (amber) and tachometer (blue) differentiated well between the two sets of digits and drew attention to the most important of the two instruments, the speedometer.

4.5.9 Main study - discussion

The discussion in this chapter will be concerned only with the main points of Study 1. Chapters 7, 8 and 9 discuss the whole programme in detail.

4.5.9.1 Discussion of the results

The objective measures of accuracy of reading the speed and accuracy of check reading against a speed limit indicate that the electronic digital display was read more accurately (98% correct) than any of the analogue displays. The majority of the errors on the digital display were made by one driver with poor eyesight. The high score was in accordance with expectations based on the literature, as in this test the digital display provided information in exactly the form required for an accurate response.

The data also indicate that the electromechanical analogue displays were more difficult to use for reading the speed shown on the speedometer. This may be due in part to the fact that the electromechanical displays could indicate an infinite variety of speedometer readings within the range 0 - 140 mph. The electronic digital display could only present unit readings; the electronic curvilinear display presented the speed readings in units of 2 mph; and the electronic dial display presented speed readings in units of 2½ mph. The opportunities to make an error are, therefore, very much greater with the electromechanical displays compared with the electronic displays, particularly the electronic analogue displays.

With the exception of the electromechanical dial (revised) display with additional instruments the electromechanical displays produced slightly more errors than the electronic displays, when deciding whether the speed shown on the speedometer was within a speed limit. There was no marked effect of discrepancy between the speed shown and the speed limit on any of the displays. The electronic displays scored equally low numbers of errors.

The electronic digital display performed equally well regardless of the number of digits presented (one or two), and the two digits '1' and '4' which were considered most difficult to read produced very few errors. Where the speed was on a numbered graduation the electronic dial display scored no errors compared with one error in every five presentations with the curvilinear display. However, when the speed was on an unnumbered graduation the error scores for both displays were relatively high. (This is not applicable to a digital display).

Theoretically, the digital displays should be more difficult to use when deciding whether the speed shown was within a speed limit. This is because a digital display requires a form of arithmetic calculation, whereas a analogue display, such as the dial or curvilinear display, only requires a comparison of 'pointer' position relative to a particular point. However, the digital display still scored the least number of errors (considerably reduced if one subject's scores are removed) compared with the curvilinear and dial displays. None of the electronic displays scored more than 5% errors.

The electronic curvilinear display segments changed colour from green to amber at 30 mph. This feature was designed to assist drivers when deciding whether the speed was within the 30 mph limit. Although the drivers considered this to be a useful feature the proportion of errors was still slightly higher than with the digital display when speeds limits of 50 mph and 70 mph were also taken into account. The effect of additional instruments was marked with the curvilinear display. The tachometer segments were amber throughout and appeared to distract the drivers attention from the speedometer. The colour coding of the tachometer was considered to be an artefact in the experiment and so the results for the curvilinear display cannot be accurately interpreted. The curvilinear display may perform better if the colour of the tachometer was changed.

On the basis of the objective measures the digital display performed better than the electronic dial or curvilinear display. This was most apparent when reading the speed shown on the speedometer. There was little to choose between the displays when deciding whether the speed was within a speed limit. The error scores for the digital display could be considerably reduced by removing the scores of one subject; and the curvilinear display may perform better if the colour of the tachometer was changed.

The subjective scores indicate a preference for the digital display on all topics. The digital and the curvilinear displays were considered to be the most attractive by an almost equal number of people (32% and 30% respectively). However, the curvilinear display was considered to be least attractive by a larger proportion (41%) of the subjects. With the exception of attractiveness the electronic digital display scored consistently higher than any of the analogue displays. The electronic curvilinear display scored consistently highest on the negative scales.

4.5.9.2 Discussion of the research method

The nature of the experiment may have influenced the results in favour of the digital display. The displays were presented for a fixed brief exposure time (450 m sec) which had been established as one at which subjects made errors which discriminated between display designs. However, the digital display could be read so rapidly that at 450 m secs very few errors were made but subjects could not cope with reading the analogue displays at a faster exposure time. In the pilot studies at exposure times of 200 m secs subjects were still reading the digital display accurately. (The tachistoscope became unreliable at faster than 200 m sec). Under normal driving conditions, where the driver can determine the time for which the displays are viewed the number of errors on the analogue displays may decrease. However, the driver would probably take his/her eyes off the road for a longer period of time than that required to read a digital display accurately.

The tachistoscope presentation method did not attempt to simulate driving conditions. It was an attempt to obtain an overview of the ease of use of different display designs. At first the notion of simulating glances from driving to read the instruments was contemplated but the literature indicated that 'eyes off road' time while driving was so varied and in many cases very lengthy that this proved an unsatisfactory approach. At average 'eyes off road' times drivers did not make any errors when reading the speedometer. When driving the driver wishes to obtain an accurate reading of the speedometer hence he/she adjusts the reading time accordingly. As the purpose of this study was to discriminate between designs the 'eyes off road' time had to be abandoned and a fixed rapid exposure time introduced.

There were a number of other factors which could have produced a higher accuracy score than would be found in driving. Unlike driving, the only task the subject had to carry out was reading the speedometer (and noting down the speed). There was no other tasks to hold the driver's attention. All the tests were conducted under night time lighting conditions when each of the displays was of equal brightness and contrast. (They were all projected slides). In driving the displays would be viewed in a variety of lighting conditions and they would also be at different brightness. The displays were static and did not change as they would do in normal driving. This was considered particularly important as the ease of reading of the digital display may be related to digit update rate. The subjects did not have to refocus from infinity to read the speed at facia distance.

Some features of the experiment may have produced a higher error score than would be found in driving. The main feature was that there was no auditory or visual feedback from a vehicle to indicate to the subject what band of speed reading may be appropriate. This was important for the analogue displays and the curvilinear display in particular because this meant that the whole scale had to be scanned to identify the correct reading. In driving, the driver would have an idea from vehicle and road data what range of speed was likely and hence where to aim a glance on the scale.

The advantages of using this method of simulation were that it was possible to conduct trials with large numbers of people relatively easily as they could be tested in groups. The projection tachistoscope equipment was inexpensive and readily available. The displays were produced as artwork and then as slides. This was a time consuming activity as 400 slides were required. However, it was very cheap and quick compared with the development of prototype dynamic displays. This method clearly can be used to obtain objective data concerning the accuracy of use of different display designs. The usefulness of this method for obtaining subjective preference data was not so clear. However, the subjects were able to respond to questions concerning perceived ease of use, attractiveness of the design and choice for own car (if the displays were real instrument panels).

The major disadvantage is that the displays were static and hence no information on ease of use and preference in dynamic conditions could be obtained. This was a particular disadvantage for the electronic displays where the update rate of the leading segments or the digits was of great interest.

4.5.9.3 Discussion of the display designs

In this study all the display designs were produced as photographic representations. There was no difference, except in style between the 'electromechanical' and 'electronic' displays. Hence it can be considered that this simple tachistoscope presentation in which many features of the displays including illumination, information content and viewing times could be controlled reflects a true difference in ease of use between display designs.

The two electromechanical designs were continuous scale/pointer designs which means that a reading could be given at any point on the scale. The two electronic analogue displays were discrete and hence a reading could only be made at the ends of the lit segments namely every 2 mph for the curvilinear display and every 2½ mph for the dial display. The digital display only gave readings in whole units with a maximum of 3 digits and a usual range of 2.

The display colours (except for the electronic curvilinear display) were specified by Ford Motor Company but could be controlled in the experiment such that for example the speedometer was always the same colour across designs. The electromechanical designs were blue-green with amber pointers; the electronic dial was amber for both speedometer and tachometer with amber odometers and green fuel gauge; the electronic curvilinear design contained four colours, green scale and segments 0-30 mph, amber segments 30-130 mph on the speedometer, blue scale and amber segments on the tachometer, blue surround and symbol and red indicator on the fuel gauge, green and blue odometers; the electronic digital display had amber speedometer and odometers, blue tachometer and green fuel gauge. The use of colours clearly influenced subjects' objective and subjective responses to the displays. This was most apparent with the curvilinear display where the amber tachometer segments clearly attracted the driver's eyes to the tachometer rather than the speedometer. The brightness of the amber also made it difficult to read the green and blue segments and scales. The amber speedometer on the digital display with blue tachometer was considered an advantage because the speedometer was brighter and hence attracted the eyes more than the tachometer. The electronic dial display which had both dials amber was considered unsatisfactory because the driver could not readily discriminate between the speedometer and tachometer particularly as both were the same style. The amber pointer on the electromechanical designs was considered clear and easy to read and produced a useful colour contrast.

The display designs contained three styles of analogue dial, an analogue curvilinear design and a digital design. Some comparisons can be made between the results for these designs. The results are very design specific however. They would not apply to all digital speedometer designs or all curvilinear designs. Under static conditions the objective measures indicated that the digital display can be read most accurately (98% correct). The electronic dial next most accurately (87% av.) and the electronic curvilinear next (76% av.). There is the possibility that these results reflect not the ease of reading but the probability of error. For example the electromechanical designs can be read to any accuracy because they are continuous, the electronic dial can only be read to an accuracy of 2½ mph. Hence if the figures were weighted the results may be more evenly distributed. However, this does not reflect the relative ease or difficulty of the decision making process in that for example the subject knows that when reading the speed on the electronic dial the response can only be 2½, 5, 7½, 10 mph etc.

The literature indicates that linear displays are more difficult to read than dial or digital diplays (Sleight 1948, Graham 1956). This is mainly because of the increased scanning time required to locate the pointer on the scale. In this experiment the curvilinear design performed marginally better than the two electromechanical dials (if the results for the clutter and no clutter conditions are taken together). This may be because the scale markings are much clearer on the curvilinear design.

There was very little difference between display designs when deciding whether the speed was within a speed limit, all were accurate to within 10%. The curvilinear design segments changed colour at 30 mph from green to amber. Although the subjects considered that this feature made the display easier for check reading at a 30 mph speed limit this was not corroborated by the objective data. Subjects did not make fewer errors when check reading for 30 mph speed limit. There was no advantage at 50 mph and 70 mph.

The design of the scales with numbered and unnumbered graduations at 5 and 10 and 20 mph intervals made a difference to the accuracy of reading the displays. The level of accuracy decreased from readings on numbered graduations (range of errors 0%-21%) to unnumbered graduations (range of errors 12%-33%), to readings between graduations (range of errors 33%-76%). The original electromechanical dial only had scale markings at 0, 20, 40, 60 mph ...., the revised version, the electronic dial and the electronic curvilinear displays had scale markings at 0, 10, 20, 30 mph .... The unnumbered graduations were at every 5 mph (and 10 mph for the original electromechanical design). However, the curvilinear design segments were in 2 mph units hence they did not correspond with the 5 mph scale markings, giving 4 or 6 mph readings only. This variation in scale marking design makes the direct comparison of display styles more complex and it is difficult to draw conclusions based only on one aspect of the overall design. The small number of errors made when reading the digital display were analysed in terms of whether the digits '1' or '4' appeared, as the literature (Van Nes and Bouma 1978) indicates that these digits tend to cause most problems. Only two errors were recorded with the digit '1' and two with the digit '4'. The errors appear to be random and not related to the digits themselves. The results were also analysed as to the nature of the errors made when one or two digits were presented. Again there appears to be no pattern to the errors relating to the digits presented, and only four errors were made. (The errors were all made by one person with poor eyesight but a driver).

The question which appeared to synthesise the subjects' preferences for the display designs was 'which display design would you choose for your own car?'. This was intended as a question to bring out the balance between ease of use and aesthetic appeal. 45% of drivers would choose the digital display for their own car and 59% would avoid the curvilinear display.

4.5.10 Main Study - conclusions

The first stage of the research programme to investigate driver responses to electronic instrument panel designs addressed itself to two main questions. These were concerned with whether electronic instrument panels have advantages from an ergonomics point of view over electromechanical instrument panels, and also the comparative merits of the different electronic display designs. The main conclusions from the first stage of the research programme are presented in this section.

4.5.10.1 Are electronic displays preferable to electromechanical displays from an ergonomics point of view?

The speed shown on the speedometer was read more accurately from the electronic displays than from the electromechanical displays.

The subjective measures did not clearly discriminate between the electronic displays and the electromechanical displays. However, the electromechanical dial (original) was less well liked than the electronic displays.

From an ergonomics point of view the electronic displays have advantages over the electromechanical displays under these test conditions.

4.5.10.2 Which of the electronic displays performed most satisfactorily, from an ergonomics point of view?

Subjects made least errors when reading the speed shown on a digital speedometer.

When deciding whether the speed shown on the speedometer was within a given speed limit, subjects made slightly fewer errors with the digital display.

The majority of subjects (70%) considered it was easiest to decide whether the speed was within a given speed limit using a digital display. Thirty eight per cent of the subjects considered that the curvilinear display was most difficult for this task and 31% thought the electromechanical dial (original) was the most difficult.

The digital display was considered most attractive by the largest number of drivers (32%). However, it was closely followed by the curvilinear display (30%) and the electromechanical dial (revised) (27%). Although 30% of the drivers thought the curvilinear display the most attractive, 41% considered it to be the least attractive.

The digital display was the display which the largest number of the drivers (45%) stated they would choose for their car. Fifty nine per cent of the drivers stated that they would avoid choosing the curvilinear display for their car.

The digital display performed better than the other two electronic displays on the objective measures, particularly when reading the speed. There was little to choose between the electronic displays when deciding whether the speed was within a speed limit. The subjective scores indicated a preference for the digital display on all the topics investigated in the study.

CHAPTER 5 STUDY 2 DRIVER RESPONSES TO FOUR DESIGNS OF INSTRUMENT PANEL TESTED IN A VEHICLE SIMULATOR

SUMMARY

In the second stage of an investigation of drivers' responses to electronic instrument panel designs, tests on the ease of reading and using four designs in simulated driving conditions were carried out. Dynamic models of the designs were installed in a computer controlled vehicle simulator. The designs comprised an electromechanical dial display, an electronic dial display, an electronic curvilinear display and electronic digital display. The speedometer and tachometer responded to the vehicle simulator controls. One hundred drivers tested the displays and measures were taken of the accuracy of reading the speed and of check reading against a speed limit. Drivers also gave their opinions about the ease of use of the displays and made comments on the designs.

CONCLUSIONS

- The electronic digital display performed considerably better than the other displays on accuracy of reading the speed and deciding whether the speed was within a speed limit.

- The majority of drivers considered that it was easiest to use to read the speed; to decide whether the speed was within a speed limit; and to keep a speed target using the electronic digital display.

- The electromechanical dial display was considered the least distracting of the displays when driving.

- The electronic curvilinear display was considered most attractive by the largest number of people. However, about a third of the drivers thought it was the least attractive and a further third thought the electronic digital display was the least attractive.

- The electronic digital display was the one which most drivers stated they would choose for their own car. About a third of the drivers said they would avoid choosing the electronic curvilinear display.

5.1 Introduction

The results of Study 1 showed that the electronic display designs could be considered to have advantages over the electromechanical designs tested. However, the results for the three electronic designs indicated that the choice of electronic design was not clear. Within Ford Motor Company there was a strong preference for the curvilinear design and a reluctance to accept the possibility of adopting a digital display. The performance of the electronic displays in dynamic conditions was also unknown. Hence all three electronic designs, slightly amended, were included in the test programme.

In the second stage of the research, user trials were conducted in a purpose built vehicle simulator. One electromechanical dial display and three electronic displays were built as dynamic models and tested by drivers under more realistic conditions than pertained in Study 1.

5.2 Aims of Study 2

Under simulated driving conditions:-

1. To compare the driving performance of subjects using three electronic displays with their performance using an electromechanical dial display.

2. To measure the error rate of reading the instruments whether to gauge the current speed or to decide if a speed limit was being exceeded.

3. To obtain drivers' preferences and opinions about the instrument panel designs.

5.3 Pilot studies

Prior to the commencement of the main experiment, the following brief pilot studies were conducted; the aims of which were:-

1. To establish the optimum duration of each task and the task related practices.

2. To determine the length of driving practice time required for the subjects to become familiar with the vehicle simulator and to establish the level of competence with the simulator needed to complete the experiment.

3. To assess the questionnaire design and the method of presentation and response.

4. To test the experimental method; the illumination levels; timing and duration of the experiment; the sampling procedures; the eyesight tests; the inter-experimenter variability in response time.

Sixteen subjects took part in the pilot studies. All the subjects were drivers who had driven within the last year.

The results of the pilot studies were used to design the main experiments.

5.4 Experimental design

The instrument panel designs used in the study were:-

Electromechanical dial display
Electronic dial display
Electronic curvilinear display
Electronic digital display

The instruments included on the display designs were a speedometer, tachometer, odometers and a fuel gauge. The speedometer and tachometer responded to the vehicle controls, the odometers and fuel gauge were static. The instruments were specified by Ford Motor Company Limited.

A complete block design was used such that:

1. All subjects drove the vehicle simulator with all four display designs.

2. Each display occurred first, second, third or fourth in order of presentation an equal number of times.

The main task as far as the subjects were aware was driving the vehicle simulator. While driving, each subject carried out three other tasks. These were commenced at a stimulus noise from the computer.

Task A - state the speed shown on the speedometer as quickly and as accurately as possible (10 readings per driver).

Task B - state whether the vehicle's speed was within a speed limit shown on the TV monitor, as quickly and as accurately as possible (10 readings per driver).

Task C - adjust the vehicle's speed to remain as close as possible to a speed target shown on the TV monitor, and rate the ease or difficulty of the task with each display.

The tasks were repeated in the same order with each of the four displays. Each 3 minute task was controlled by a computer program which at specified intervals activated a stimulus signal, displayed and changed speed limits, recorded responses via the keyboard, and recorded performance readings from the vehicle controls.

The speed limits shown on the screen in Task B were 30 mph, 50 mph and 70 mph. The speed targets shown in Task C were 30 mph, 40 mph, 50 mph and 70 mph (specifications of the tasks are given in Figure 5.1).

The experiments were conducted under night time lighting conditions (approximately 100 lux). The lighting was not controlled.

The following measures were taken during each experiment:

Time from the start of each task
Actual speedometer reading
Actual tachometer reading
Stimulus time
Subject's response (speed reading (Task A), Yes/No (Task B))
Response time
Driving error (whether the subject had driven off the road during the time sampled)
Speed limit (Task B)
Speed target (Task C).

Readings were taken automatically by the computer at 1 second intervals throughout the experiment, with the exception of the subjects' responses which were typed in by the experimenter via the computer keyboard.

5.5 Subjects

100 subjects took part in the main study. They were all drivers who had driven within the last year. Subjects who took part in Study 1 were excluded from Study 2, as their previous experience with the display designs may have influenced their opinions.

Equal numbers of men and women attended and there were also equal numbers in each of 3 age groups: 17-30 years, 31-50 years, 51 years and over.

The subjects were tested singly and the experiment lasted 1½-2 hours.

5.6 Equipment

5.6.1 Computer based simulator

An Apple II computer controlling the simulator was responsible for the following functions:-

1. The production of a dynamic picture of a road as viewed from inside a vehicle moving along that road.

2. The interpretation of signals produced by the vehicle's controls and the modification of the road picture accordingly.

3. The production of random deviations in the vehicle's apparent path, to simulate buffeting by the wind, so that steering actions were needed to compensate.

4. The sending of signals to the speedometers and tachometers, so that they behaved realistically and in response to the vehicle's controls.

5. The control of the experimental tasks.

6. The collection of data on the subject's performance and the storing of data in a suitable form for subsequent analysis.

To improve the speed at which programs were interpreted and to reduce storage space occupied by the programs, it was necessary to program the computer in the Assembler code of Apple II.

5.6.2 Vehicle simulator

The subject was seated in the vehicle simulator based on a Ford Granada bodyshell. The simulator was fitted with the usual controls and these controls operated as they would in an ordinary car. The controls were connected to transducers as follows:-

steering wheel	- potentiometer reading angle
accelerator	- potentiometer reading position
brake	- pressure transducer
clutch	- position switch
gear lever	- four position switches (no reverse gear)

The transducers were connected to the computer via electronic circuitry introducing lags, scaling the signals appropriately and enabling the dynamic properties of the simulator to be varied to match the performance of a real vehicle. Subjects heard a simulated engine noise which varied in tone according to engine speed and gear selection.

5.6.3 Collimating lens

The computer produced the road picture on a standard monochrome TV monitor. Since the monitor was of limited size, it had to be placed fairly close to the subject. However, in such a position, the subject saw the 'road' and the displays at approximately the same distance from the eyes and had no need to refocus when moving between them. A 500 mm diameter focal length aspheric collimating lens was placed in front of the monitor. This had the effect of projecting the road picture to infinity. A stand was designed and built to support the lens at the correct angle.

The vehicle simulator and road picture are shown in Appendix 5, Figure 5.2.

5.6.4 Instrument panel designs

Four instrument panels were built and tested in the experiment. The three electronic designs were prototypes and were built from drawings provided by Ford Motor Company Limited. The instruments included in the designs were a speedometer, a tachometer, odometers and a fuel gauge. The speedometer and tachometer were dynamic and the odometers and fuel gauge were static.

The electromechanical dial display was based on an R-module design and the speedometer and tachometer were activated using continuous motors.

The electronic dial display and the electronic curvilinear display were produced by silk screen printing the scales, segments, odometers and fuel gauge patterns on to polarised plastic face plates. LEDs were built up into patterns to correspond to the segment arrangements of the instrument panel signs. The segments were fastened to the face plates and activated via specially designed electronic circuits. The display components were coloured as shown in the photographs in Appendix 2. The scales, fuel gauge and odometers were back lit by specially designed light packs.

The electronic digital display panel was produced in a similar fashion to the electronic dial and curvilinear displays by back lighting a screen printed face plate. Two sets of two 25 mm tungsten filament digits were inset into the face plate. The digits formed a speedometer and a tachometer, and were activated directly by the computer. The rate of change of the display digits varied according to the rate of acceleration or deceleration based on a sampling rate of four samples per second.

The lighting packs and the LED arrays were powered by a 12 volt battery.

5.6.5 Questionnaire

A questionnaire was designed to collect demographic details about the subjects, such as age, sex, driving experience, and to collect data on the subjects' preferences and opinions regarding the four instrument panel designs. Subjects were asked to rate which of the designs was best and worst on criteria such as ease of reading and attractiveness. They were also asked to give their comments about the designs based on their experience while using the displays during the experiment. A pilot study had assessed the possibility of completing parts of the questionnaire via the computer, but this was found to be unsatisfactory.

The questionnaire is shown in Appendix 3.

5.6.6 Other equipment

MAVIS Master Vision Screener
ISIHARA colour vision test
Anthropometer to measure sitting eye height
Stopwatch
Recording schedule for hearing test and Task C (see Appendix 3)
Recording schedules for MAVIS and the Ishihara test (see Appendix 3).

5.7 Procedure

The project was described to each subject emphasising the driving aspect of the project rather than the instrument panel designs. The following measurements were then taken:

- near and distance vision, and stereopsis using the MAVIS Master Vision Screener
- colour vision using the Ishihara test.

The results were noted on the recording schedule shown in Appendix 3.

A test was also carried out to ensure that the subject could hear the sound effects used in the experiment. These were:-

engine noise
beep - stimulus
buzz - vehicle off the road.

After instruction in the use of the vehicle simulator, each subject practised driving the simulator for a 5 minute period. Most subjects were competent after this practice, but some drivers were given a second practice of 3 minutes duration. Those subjects who could not master the vehicle simulator after two practices were not tested further.

The subject drove the vehicle simulator with each of the four display designs in turn, carrying out Tasks A, B and C for each display. The driving part of the experiment took between 45 minutes and one hour to complete. The subject then completed the questionnaire refering to a flash-card containing photographs of the designs.

5.8 Data handling and analysis

Data on the subjects' preferences and opinions, and demographic data collected by questionnaire were analysed by hand.

Data on the subjects' performance were collected and stored automatically on floppy disc by the computer during the experiments.

The performance data analyses comprised:-

Task A - mean of actual speed and actual engine rev.s between stimulus and response

- direction and extent of speed reading errors

- number of 'kerb hits' (time off road) between stimulus and response

- response time

Task B - mean of actual speed and actual engine rev.s between stimulus and reponse

- response error

- number of 'kerb hits' between stimulus and response

- response time

Task C - mean of actual speed and actual engine rev.s in 10 second sampling blocks for each speed target

- 'kerb hits' within the sampling blocks.

These data were analysed for each instrument panel design for each subject. The data were then amalgamated to provide data for each design.

Drivers' comments on the display designs were recorded and classified.

5.9 Results

5.9.1 Introduction

The second stage of the programme of research to evaluate driver responses to electronic instrument panel designs consisted of experiments conducted under controlled laboratory conditions, in a vehicle simulator. The limitations of such experiments are outlined below, in order to put the main findings into context.

Unlike normal driving, the vehicle simulator presented few distractions to the subjects, and was less demanding of their attention. Therefore, the subjects could direct more attention to the displays than in normal driving. However, there were also fewer cues as to the speed of the vehicle so the subjects were more reliant on the instruments.

The electronic displays used in the experiment were models produced using techniques different from those which would be employed in the 'production' instrument panel designs. The electronic dial and curvilinear displays were produced using LED segments with backlit scales. The electronic digital display used 25 mm tungsten filament digits. In the production displays, Ford Motor Company Limited intended to use LCD technology. The technical and visual properties of the displays used in the tests were not representative of LCD technology. However, as far as the subjects were concerned, the displays looked 'electronic'.

The display designs differed in the amount of information presented to the subject. The electromechanical dial display pointer could indicate any speed on the scale; the electronic digital display showed the speed in units of 1 mph; the electronic curvilinear display segments lit up in units of 2 mph; and the electronic dial display segments lit up in units of 2½ mph. Therefore, the opportunities for making errors were reduced by a factor of 2 for the curvilinear display and 2½ for the dial display compared with the digital display.

5.9.2 Objective measures

5.9.2.1 Reading the speed

Table 5.1 indicates the accuracy with which subjects were able to read the speed for each display design.

Table 5.1 Accuracy of reading the speed

DISPLAY	ACCURACY SCORE (1)								MEAN (2) RESPONSE TIME (secs)
	± 2 mph		± 3 to 5 mph		± over 5 mph		MISSING RESPONSE		
	freq	%(3)	freq	%	freq	%	freq	%	
ELECTROMECHANICAL DIAL	467	47	331	33	185	19	17	2	1.64
ELECTRONIC DIAL	231	23	601	60	159	16	9	1	1.63
ELECTRONIC CURVILINEAR	33	3	319	32	637	64	11	1	1.69
ELECTRONIC DIGITAL	969	97	5	1	13	1	13	1	1.19

Total number of responses per display = 1000

See Figure 5.3

Footnote

(1) The score was calculated from the subjects' response and the mean of the speed readings between the stimulus and the response.

(2) Mean response time was calculated as time from the stimulus to the experimenter pressing a single known response key on the keyboard. It, therefore, includes subject response time, reading time, and experimenter reaction time. The purpose was to take a relative measure which may discriminate between designs rather than an absolute measure.

(3) Percentages are rounded to the nearest unit.
Percentages below 1 are shown as -.

It can be seen from Table 5.1 that:-

1. The electronic digital display was read correctly (to within ± 2 mph) in 97% of readings. The vast majority of readings were exactly correct.

2. The electromechanical dial display was read accurately (± 2 mph) by a larger proportion of subjects (47%) than the two electronic analogue displays (dial 23%, curvilinear 3%). However the electronic digital display was read more accurately, hence there is no clear difference between the electromechanical and electronic displays.

3. Of the analogue displays the electromechanical display was read most accurately (47% ± 2 mph).

4. If an accuracy of within ± 5 mph is considered acceptable then there is very little difference between the two dial displays (80% electromechanical, 83% electronic). The majority of the electronic dial display readings were inaccurate by ± 3-5 mph (60%).

5. The electronic curvilinear display performed very poorly on this task with only 3% of readings within ± 2 mph. The majority (64%) were inaccurate by over ± 5 mph. There was a marked tendency for the speed to be underread by approximately 6-8 mph (the equipment and the calibrations were thoroughly checked and no explanation could be found from that source). The reading errors were evenly distributed across the scale.

6. The electronic digital display was read more quickly (1.19 secs) than the analogue displays (1.63-1.69 secs).

7. Compared with the results obtained in Study 1 the electronic digital display performed equally well (98% accurate Study 1, 97% accurate to $\pm$ 2 mph Study 2). For all the analogue displays the accuracy score decreased under dynamic test conditions if an accuracy level of $\pm$ 2 mph in Study 2 is observed. The analogue curvilinear design scores were markedly lower in Study 2.

5.9.2.2 The nature and extent of the errors made when reading the speed

In Study 1 the displays were presented to subjects as photographic representations and hence were static; the display readings did not change while being viewed. Hence it was possible to obtain accuracy scores for reading which were correct or incorrect when a comparison between the actual speed and the subject's response was made. Also in Study 1 accuracy of readings at numbered graduations, unnumbered graduations and between graduations could be compared. In Study 2, the displays were dynamic, hence the accuracy scores could only be based on an estimate of the speed shown on the display at the time the subject looked at the speedometer. This was taken as the average speed shown between the time of the stimulus to the time of the response. Hence it was not possible to know excactly where the 'pointers' were positioned, and therefore readings related to particular 'pointer' positions are not possible.

5.9.2.3 Deciding whether the speed was within a speed limit

Table 5.2 indicates the number of errors made by subjects for each display when deciding whether the speed shown on the speedometer was within a speed limit.

Table 5.2 The number of errors made when deciding whether the speed was within a speed limit

DISPLAY	ERROR freq	ERROR %	MISS freq	MISS %	TOTAL ERRORS freq	TOTAL ERRORS %	CORRECT freq	CORRECT %	MEAN RESPONSE TIME (secs)
ELECTROMECHANICAL DIAL	298	29	22	2	320	32	680	68	1.65
ELECTRONIC DIAL	303	30	25	3	328	33	672	67	1.22
ELECTRONIC CURVILINEAR (1)	518	52	29	3	547	55	453	45	1.61
ELECTRONIC DIGITAL	60	6	7	1	67	7	933	93	1.39

Total number of responses per display = 1000

(1) See Table 5.17.1 and 5.17.2 for further details

See Figure 5.4

It can be seen from Table 5.2 that:

1. The electronic digital display produced only 7% errors out of 1000 readings when deciding whether the speed was within a speed limit.

2. The electromechanical and electronic dial display designs produced a similar percentage of errors (32% and 33% respectively). This was considerably higher than the errors recorded for the electronic digital display.

3. The analogue curvilinear design produced the greatest percentage of errors (55%) compared with the analogue dial displays (32% and 33%).

4. The electronic dial display had the shortest mean response time (1.22 secs) which was faster than the time for the electronic digital display (1.39 secs) for check reading. The electromechanical dial display produced marginally the longest response time on this test (1.65 secs).

5. When comparing the accuracy of deciding whether the speed was within a speed limit in Study 1 to Study 2 it is clear that the percentage of errors increases under dynamic conditions. This is even marginally so for the electronic digital display (98% accurate Study 1, 93% accurate Study 2). The most marked effect was for the electronic curvilinear display, which reduced in accuracy from 98/94% (clutter/no clutter) in the static conditions of Study 1 to 45% in the dynamic conditions of Study 2.

5.9.3 Subjective measures

The drivers were asked to state which of the four display designs they considered easiest and most difficult to read; easiest and most difficult to decide whether the speed was within a speed limit; the easiest and most difficult to use to keep to a speed target; the least and most distracting while driving; the most and least attractive; and which they would choose and avoid for their own car. In addition, drivers made comments about each display.

5.9.3.1 The display designs considered by the subjects to be the easiest and most difficult to read the speed

Table 5.3 The displays considered by the subjects to be the easiest and most difficult to read

DISPLAY	EASIEST TO READ %	MOST DIFFICULT TO READ %	RANK ORDER BY EASIEST
ELECTROMECHANICAL DIAL	11	34	4
ELECTRONIC DIAL	15	20	2
ELECTRONIC CURVILINEAR	12	29	3
ELECTRONIC DIGITAL	62	9	1
NO ONE DISPLAY	0	8	
TOTAL (n = 100)	100	100	

See Figure 5.5

A χ^2crit (based on all responses) = 9.49 df = 4

B χ^2crit (excluding 'no one display') = 7.82 df = 3

A χ obs = 116.70 B χ obs = 73.36 $p < 0.05$

A χ^2 obs = 27.10 B χ^2 obs = 15.75 $p < 0.05$

It can be seen from Table 5.3 that:-

1. The electronic digital display was considered easiest to read by the majority of drivers (62%). Only 9% of drivers considered the digital display the most difficult to read.

2. The electromechanical dial display was considered easiest to read by approximately the same numbers of subjects (11%) as the analogue electronic dial (15%) and the curvilinear display (12%). All three performed much worse than the electronic digital display (62%).

3. The electromechanical dial display and the electronic curvilinear display were considered most difficult to read by about a third of the drivers (34% and 29% respectively).

4. Eight subjects felt that no one display was more difficult to read than another.

5. A greater proportion of subjects considered that the electronic digital display was easiest to read in the dynamic conditions of Study 2 (62%) compared with the static conditions of Study 1 (52%).

6. The electromechanical dial display was considered the most difficult to read in Study 2 (34%) whereas the electronic curvilinear design was considered most difficult in Study 1 (41%).

5.9.3.2 The display designs considered by the subjects to be the easiest and most difficult to decide whether the speed was within a speed limit

Table 5.4 The displays considered by the subjects to be the easiest and most difficult to decide whether the speed was within a speed limit

DISPLAY	EASIEST TO DECIDE WHETHER WITHIN LIMIT %	MOST DIFFICULT TO DECIDE WHETHER WITHIN LIMIT %	RANK ORDER BY EASIEST
ELECTROMECHANICAL DIAL	13	29	3
ELECTRONIC DIAL	13	20	3
ELECTRONIC CURVILINEAR	19	22	2
ELECTRONIC DIGITAL	51	13	1
NO ONE DISPLAY	4	16	
TOTAL (n = 100)	100	100	

See Figure 5.6

A χ^2obs = 65.8   A χ^2obs = 7.5 NS
B χ^2obs = 41.5   B χ^2obs = 8.0 ($p < 0.05$)
$p < 0.05$

A χ^2crit (based on all responses) = 9.49 df = 4
B χ^2crit (excluding 'no one display') = 7.82 df = 3

It can be seen from Table 5.4 that:

1. The electronic digital display was considered easiest to decide whether the speed was within the speed limit by the majority of drivers (51%).

2. The electromechanical dial display was considered easiest for check reading by approximately the same number of subjects (13%) as the analogue electronic

dial 13%) and the curvilinear display (19%). All three performed much worse than the electronic digital display (51%).

3. The analogue displays were each considered most difficult for check reading by approximately a fifth of the subjects. Thirteen percent of subjects considered the electronic digital display to be most difficult and 16% felt that no one display was more difficult for check reading than another.

4. A greater proportion of subjects considered that the electronic digital display was easiest for check reading in the dynamic conditions of Study 2 (51%) compared with the static conditions of Study 1 (35%).

5. The electromechanical dial display was considered most difficult for check reading in Study 2 (29%) whereas the electronic curvilinear design was considered most difficult in Study 1 (38%).

5.9.3.3 The display designs considered by the subjects to be the easiest and most difficult to use to keep to a speed target

Table 5.5 The ease or difficulty of using the speedometer to keep to a speed target

DISPLAY	VERY EASY %	EASY %	NEITHER EASY NOR DIFFICULT %	DIFFICULT %	VERY DIFFICULT %	TOTAL (n=100)
ELECTROMECHANICAL DIAL	10	36	36	18	0	100
ELECTRONIC DIAL	8	45	27	16	4	100
ELECTRONIC CURVILINEAR	12	31	32	21	4	100
ELECTRONIC DIGITAL	35	32	12	17	4	100

See Figure 5.7

It can be seen from Table 5.5 that:-

1. The electronic digital display was considered easy or very easy to use to keep to a speed target by over two thirds of the subjects (67%).

2. The electromechanical dial display was considered easy or very easy by approximately the same number of subjects (46%) as the other two analogue displays (53% dial and 43% curvilinear). All three performed worse than the electronic digital display (67%).

3. The electromechanical dial display was considered difficult or very difficult by the smallest number of subjects (18%). The electronic curvilinear display performed worst (25% of subjects considered it worst).

4. Approximately a third of the subjects considered that each of the analogue display designs was neither easy nor difficult to use to keep to a speed target. The electronic digital display clearly was perceived as easy to use as only 12% considered it neither easy nor difficult and 67% considered it easy or very easy.

5. This task was not possible in the static test conditions of Study 1 hence no comparison can be made between the results in the two studies.

5.9.3.4 The display designs considered by the subjects to be the least and the most distracting while driving

Table 5.6 The displays considered by the subjects to be the least and the most distracting while driving

DISPLAY	LEAST DISTRACTING %	MOST DISTRACTING %	RANK ORDER BY LEAST DISTRACTING
ELECTROMECHANICAL DIAL	43	10	1
ELECTRONIC DIAL	9	13	4
ELECTRONIC CURVILINEAR	15	20	3
ELECTRONIC DIGITAL	22	38	2
NO ONE DISPLAY	11	19	
TOTAL (n = 100)	100	100	

See Figure 5.8

A χ^2crit (based on all responses) = 9.49
df = 4
B χ^2crit (excluding 'no one display') = 7.82
df = 3

A χ^2obs = 35.0
B χ^2obs = 29.58
$p<0.05$

A χ^2obs = 23.70
B χ^2obs = 23.35
$p<0.05$

It can be seen from Table 5.6 that:

1. The electromechanical dial display was considered to be least distracting by 43% of the subjects. Only 10% found it to be the most distracting.

2. The electronic digital display was considered to be most distracting by 38% of the subjects, but it ranked second to the electromechanical dial display on the basis of least distracting as 22% of the subjects considered it to be least distracting.

3. The electromechanical dial display performed better than any of the electronic displays on this factor as the largest group of subjects (43%) considered it least distracting and the smallest group (10%) considered it most distracting.

4. Of the analogue displays the electromechanical dial display was clearly considered least distracting (43% of subjects) and the electronic curvilinear most distracting (20% of subjects).

5. The electromechanical dial display was considered the least distracting of the dial displays (43% compared with 9%) but there was little difference between the dial designs when considering the most distracting (10% and 13% respectively).

5. Almost one subject in five (19%) responded that no one display design could be considered most distracting and one in ten (11%) felt that no one display could be considered least distracting.

6. This aspect of the display designs could not be tested in Study 1 as it was the behaviour of the display designs under dynamic conditions which was considered to contribute substantially to distraction.

5.9.3.5 The display designs considered by the subjects to be the most and the least attractive

Table 5.7 The displays considered by the subjects to be the most and the least attractive

DISPLAY	MOST ATTRACTIVE %	LEAST ATTRACTIVE %	RANK ORDER BY MOST ATTRACTIVE
ELECTROMECHANICAL DIAL	15	25	4
ELECTRONIC DIAL	24	11	2
ELECTRONIC CURVILINEAR	39	30	1
ELECTRONIC DIGITAL	19	30	3
NO ONE DISPLAY	3	4	
TOTAL (n = 100)	100	100	

A χ^2obs = 34.60 B χ^2obs = 13.61 $p < 0.05$

A χ^2obs = 28.10 B χ^2obs = 10.08 $p < 0.05$

See Figure 5.9

A χ^2crit (based on all responses) = 9.49 df = 4

B χ^2crit (excluding 'no one display') = 7.82 df = 3

It can be seen from Table 5.7 that:

1. The electronic curvilinear display was considered to be the most attractive by 39% of subjects, however 30% of the subjects considered it to be the least attractive design.

2. The electromechanical dial display was considered to be the most attractive by the smallest group of subjects (15%) compared with the electronic display designs.

3. Of the analogue designs the electromechanical dial display was clearly considered most attractive by the smallest group of subjects (15%) and considered least attractive by the second largest group (25%). The curvilinear design was considered to be the most attractive and the least attracive by the largest number of subjects (39% and 30% respectively).

4. The electronic digital display was considered most attractive by only 19% of the subjects (rank third) and least attractive by the largest group of subjects (30% ranked equal first).

5. More subjects felt able to make choices about the display designs on the dimension of attractiveness, only a small number (3–4%) considered that no one display was more or less attractive than the others.

6. In Study 1 the electronic digital display was considered most attractive by the largest group of people (32%). In the dynamic conditions of Study 2 only 19% of subjects considered it most attractive and a much higher number (30% compared with 15% in Study 1) considered it least attractive.

7. The electronic curvilinear design was considered most attractive by the largest group of subjects (39%) in Study 2. In Study 1 the curvilinear design was second to the electronic digital display with 30% of subjects considering it most attractive. However, the diversity of view was present in both studies in that high proportions of subjects considered it to most and least attractive (30% and 41% respectively Study 1, 39% and 30% in Study 2).

5.9.3.6 The display designs which the subjects stated they would choose and would avoid for their own cars

Table 5.8 The displays considered by the subjects to be the ones which they would choose and would avoid for their own cars

DISPLAY	WOULD CHOOSE %	WOULD AVOID % (1)	RANK ORDER BY WOULD CHOOSE
ELECTROMECHANICAL DIAL	21	21	2
ELECTRONIC DIAL	18	17	4
ELECTRONIC CURVILINEAR	20	32	3
ELECTRONIC DIGITAL	39	26	1
NO ONE DISPLAY	2	4	
TOTAL (n = 100)	100	100	

(1) one missing response
See Figure 5.10

A χ^2obs = 34.50   A χ^2obs = 9.5
B χ^2obs = 11.63   B χ^2obs = 5.26 NS
A χ^2crit (based on all responses) = 9.49 $p < 0.05$ $p < 0.05$
df = 4
B χ^2crit (excluding 'no one display') = 7.82
df = 3

It can be seen from Table 5.8 that:

1. 39% of the subjects stated that they would choose the electronic digital display for their own car, about twice the number who would choose any of the other displays.

2. The electromechanical dial display scored about the same as the electronic display designs with the exception of the electronic digital display which more subjects (39%) considered they would choose for their own car.

3. Similar numbers of subjects (18% 20% 21%) stated that they would choose the analogue display designs. However a third (32%) stated that they would avoid the electronic curvilinear display.

4. There was no difference between subjects' responses to the electromechanical and electronic dial displays.

5. Although 39% of subjects stated that they would choose the electronic digital display for their car, a quarter (26%) stated that they would avoid choosing it.

6. As was found in Study 1 the electronic digital display would be chosen by the largest group of subjects (45% Study 1 and 39% Study 2). However, a larger number of subjects (26%) would avoid the electronic digital display after having experienced it in dynamic conditions than reported they would do so in Study 1 (7%).

7. The electronic curvilinear design results improved in Study 2 in that 20% of subjects stated that they would choose the curvilinear design compared with only 8% in Study 1. This was also shown in the avoidance figures in that 59% of subjects stated they would avoid the electronic curvilinear display in Study 1 . This was reduced to 32% in Study 2. It was however, in both studies the design which the largest group of subjects stated they would avoid.

Table 5.9 is a summary table indicating the relative scores for each display design on both the drivers' preferences and the performance measures. The results obtained in Study 1 are alo presented for comparison.

Table 5.9 SUMMARY TABLE indicating how the display designs scored on each of the measures in Studies 1 and 2

OBJECTIVE MEASURES	ELECTROMECHANICAL DIAL	E L E C T R O N I C		
		DIAL	CURVILINEAR	DIGITAL
Reading the speed	○ ● ● ●	○ ○ ○ ● ●	○ ○ ●	○ ○ ○ ○ ● ● ● ●
Is the speed within a speed limit?	○ ● ● ●	○ ○ ○ ● ●	○ ○ ●	○ ○ ○ ○ ● ● ● ●
SUBJECTIVE MEASURES (1)				
Easiest to read	○ ○ ○ ●	○ ○ ● ● ●	○ ○ ● ●	○ ○ ○ ○ ● ● ● ●
Easiest for speed limits	○ ● ●	○ ○ ● ●	○ ○ ○ ● ● ●	○ ○ ○ ○ ● ● ● ●
Very easy/easy for keeping to a speed target	Not measured in Study 1 ● ●	● ● ●	●	● ● ● ●
Least distracting	Not measured in Study 1 ● ● ● ●	●	● ●	● ● ●
Most attractive	○ ○ ●	○ ○ ● ●	○ ○ ○ ● ● ● ●	○ ○ ○ ○ ● ● ●
Would choose for own car	○ ○ ● ● ●	○ ○ ○ ●	○ ● ●	○ ○ ○ ○ ● ● ● ●

(1) Only the positive side of the scale is shown in this table

○ Study 1

● Study 2

The more dots the better. The scale is based on rank orders

5.9.2 Characteristics of the sample

The sample was chosen to provide approximately equal numbers of subjects of both sexes and in 3 age groups.

Table 5.10 indicates the age and sex of the subjects included in the main study

Table 5.10 Age and sex of the subjects

AGE (years)	SEX		TOTAL
	MALE %	FEMALE %	%
17-30	19	16	35
31-50	15	20	35
51 and over	18	12	30
TOTAL (n = 100)	52	48	100

The slight variation in numbers between cells indicates the relative availability of subjects. For example, there are few female drivers over 50 years in the general driving population, hence they are more difficult to recruit. More females than males in the 31-50 years age group are able to attend during the available test times. Experiments were conducted in the evenings but less experimentation time is available in the evening because only one 1½ hour test can be conducted whereas four can be carried out during the day. More women than men in the 31-50 years age group are able to attend during the day.

The MAVIS Master Vision Screener was used to test subjects' eyesight. All the tests were carried out with the subject wearing driving spectacles if they were usually worn. The Ishihara test for colour vision was also carried out.

Table 5.11 summarises the results of the eyesight tests.

Table 5.11 Subjects' eyesight test results

VISION TESTS	% (n = 100)
ISHIHARA TEST	
COLOUR VISION:	
Normal	98
Red/green deficiency	2
Total deficiency	0
MAVIS TEST	
DISTANCE ACUITY GOOD	47
NEAR ACUITY GOOD	74
DISTANCE STEREOPSIS (1)	
Good	29
Moderate	39
Poor	32
NEAR STEREOPSIS (2)	
Good	73
Moderate	0
Poor	27
OBSERVATION	
BIFOCALS WORN WHEN DRIVING	15

(1) Good = 50 seconds of arc stereo-acuity
Moderate = 400 seconds of arc stereo-acuity
Poor = 500 seconds of arc, or over, stereo-acuity

(2) Good = 50 seconds of arc stereo-acuity
Moderate = 75 seconds of arc stereo-acuity
Poor = 195 seconds of arc, or over, stereo-acuity

(from The Interpretation of Master Vision Screener Records)

It can be seen from Table 5.11 that:-

1. Only 2% of the sample had any problem with colour vision. This is much less than the 15% found in the previous study, and also less than the percentage in the general population (approximately 10% of the male population, less than 1% of the female population).

2. Only 47% of the sample had what the MAVIS test interprets as good distance acuity, in spite of the fact that this test was carried out with subjects wearing spectacles if they normally did so to drive.

3. 74% of the sample had good near acuity, in spite of the fact that this test was carried out with subjects wearing distance corrected spectacles if they normally wore them for driving.

4. 15% of the sample wore bifocal spectacles while driving.

Early studies of drivers' eyesight have indicated that a high proportion of drivers had defects of vision even when wearing their normal driving spectacles (Gahan and Marshall 1973). However, Davison and Irving (1980) have subsequently reported better visual acuity and cast doubts on the appropriateness of some of the earlier studies.

When given a hearing test all the subjects could hear the stimulus BEEP (high frequency noise) and the kerb hit BUZZ (low frequency noise) against a background of simulated engine noise.

Table 5.12 indicates the number of years since the people in the sample had passed their driving test. These data give an approximate indication of driving experience.

Table 5.12 The number of years since the subjects had passed their driving test

TIME SINCE TEST PASSED	%
Less than 1 year	5
1-3 years	9
4-8 years	15
9-17 years	27
18-34 years	29
35 years or over	8
No test taken	7
TOTAL (n = 100)	100

It can be seen from Table 5.12 that:

1. The majority of subjects had been driving for 9 years or more (71%). This is to be expected as there was a bias towards people in the older age group compared with the general driving population.

2. Only 5% had been driving for less than a year and 9% had been driving for between one and 3 years.

Two subjects were unable to master the vehicle simulator driving technique. This manifested itself mainly in the inability to steer without continually driving off the road. These two subjects were not included in the sample.

About one driver in 20 required a second practice in order to master the vehicle simulator driving technique. All others managed satisfactorily after one practice.

5.9.5 The test results for each display design

In the preceding sections the test results have been presented in terms of the performance of each display on a particular criterion. In this section all the results for each display are presented.

The drivers' preferences and opinions were recorded in two forms. These were drivers' opinions about which of the displays was best and worst on a number of criteria such as ease of reading, attractiveness and so on; and also drivers' comments about the displays expressed in his/her own words. These comments are summarised for each display in this section.

The performance measures, ie the errors made when reading the speed and when deciding whether the speed was within a speed limit, were recorded automatically by the computer during the experiment, and then tabulated. The number of times the subjects steered off the road while reading the speedometer was also recorded but the incidence were so small as to be negligible and are not reported in the tables.

5.9.5.1 The electromechanical dial display test results

Table 5.13 The electromechanical dial display test results - objective measures

OBJECTIVE MEASURES	ACCURACY SCORE freq (n=1000)	%	Rank(1)
<u>Reading the speed</u>			
Response correct to:			
Within $\pm$ 2 mph	467	47	2
$\mp$ 3-5 mph	331	33	
$\mp$ over 5 mph	185	19	
Missing responses	17	2	
Mean response time	1.64 secs		3
<u>Deciding whether speed was within a speed limit</u>			
Correct responses	680	68	2
Incorrect responses	298	29	
Missing responses	22	2	
Total errors	320	32	
Mean response time	1.65 secs		4

(1) Rank order 1 = best, 4 = worst

Table 5.14 The electromechanical dial display test results - subjective measures

SUBJECTIVE MEASURES	% (n = 100)	Rank
Easiest to read	11	4
Most difficult to read	34	
Easiest to decide whether speed was within a speed limit	13	3
Most difficult to decide whether speed was within a speed limit	29	
Easy or very easy to keep to a speed target	46	3
Difficult or very difficult to keep to a speed target	18	
Least distracting display	43	1
Most distracting display	10	
Most attractive display	15	4
Least attractive display	25	
Would choose for own car	21	2
Would avoid for own car	21	

The electromechanical dial display - summary of results

The electromechanical dial display was included in the study to act as a bench mark against which the test results for the three electronic display designs could be assessed. There are a number of features about the display design which were indicated by the test results and, in particular, by the drivers' comments. These are reported below.

1. In spite of the adverse comments made about the display design by the subjects, the electromechanical dial design was second only to the electronic digital display in terms of accuracy of reading the speed. Just under half the subjects (47%) read the speed accurately to within ± 2 mph and a further third (33%) to within ± 5 mph. Although second after the digital display this latter design scored considerably better with 97% of responses accurate to ± 2 mph.

2. Apart from the electronic digital display, the electromechanical dial display scored least errors when subjects check read the speed against a speed limit (68% correct). The score was similar to that obtained for the electronic dial display (67%) but much less than that obtained for the electronic digital display (93%).

3. The mean response time for reading the speed and for check reading against a speed limit was very similar (1.64 sec and 1.65 secs respectively). These response times were generally slower than for other designs.

4. The electromechanical dial display was scored as most difficult to read and most difficult to use for check reading against a speed limit by the largest groups of subjects (34% and 29% respectively). The results were consistent in that the smallest groups of subjects (11%

and 13% respectively) scored the design as easiest on the two measures.

5. The electromechanical dial display was considered to be easy or very easy to keep to a speed target by the second smallest number of people (46%), but also difficult or very difficult by the least number of people (18%). One problem mentioned by the drivers was that the speed targets were 30, 50, 70 mph, the normal British speed limits. These speeds were only unnumbered graduations on the scale and hence were more difficult to locate.

6. When considering distraction while driving, the electromechanical display was clearly considered less distracting than the other designs as 43% of subjects scored it as least distracting and only 10% as most distracting. Nearly twice as many people thought the electromechanical dial display was least distracting than its nearest rival, the electronic digital display (22%). Some drivers considered that this could be due to familiarity with the design, others considered that the even lighting helped to reduce distraction.

7. The electromechanical dial display was considered most attractive by only 15 subjects and least attractive by 25. The display scored the worst of the four designs on attractiveness.

8. One driver in 5 (21%) stated that they would choose the electromechanical dial display for their own car. The same number (21%) stated they would avoid choosing it. This was a similar score to that received by the other analogue designs on choice for own car. Only the digital display was outstanding (39% would choose it).

9. The electromechanical dial display was read less accurately under dynamic test conditions compared with the static conditions in Study 1. In Study 1 64% of the readings were exactly correct (with 'clutter') whereas in Study 2 47% were accurate to ± 2 mph. A reduction in accuracy of check reading also occurred under dynamic conditions with 68% of the check readings correct in Study 2 compared with 92% (with clutter) in Study 1.

10. On the measures of driver preference the electromechanical dial display ranked 3 in Study 1 and 4 in Study 2. On ease of check reading it ranked worst in both studies (5 in Study 1 and equal 3 in Study 2). The design also ranked worst in both studies on attractiveness but did improve in Study 2 in that it ranked 2 on choice for own car compared with 4 in Study 1.

5.9.5.2 The electronic dial display test results

Table 5.15 The electronic dial display test results - objective measures

OBJECTIVE MEASURES	ACCURACY SCORE freq (n=1000)	%	Rank
Reading the speed Response correct to:			
Within ± 2 mph	231	23	3
± 3-5 mph	601	60	
± over 5 mph	159	16	
Missing responses	9	1	
Mean response time	1.63 secs		2
Deciding whether speed was within a speed limit			
Correct responses	672	67	3
Incorrect responses	303	30	
Missing responses	25	3	
Total errors	328	33	
Mean response time	1.22 secs		1

Table 5.16 The electronic dial display test results - subjective measures

SUBJECTIVE MEASURES	% (n = 100)	Rank
Easiest to read	15	2
Most difficult to read	20	
Easiest to decide whether speed was within a speed limit	13	3
Most difficult to decide whether speed was within a speed limit	20	
Easy or very easy to keep to a speed target	53	2
Difficult or very difficult to keep to a speed target	20	
Least distracting display	9	4
Most distracting display	13	
Most attractive display	24	2
Least attractive display	11	
Would choose for own car	18	4
Would avoid for own car	17	

The electronic dial display - summary of results

The electronic dial display was similar to the electromechanical dial display and to many other speedometer designs in that it was an analogue dial display. It was the least novel of the three electronic display designs and as such may have been afforded less attention by the subjects than the other designs. This could have been aggravated to some extent by the experimental design whereby drivers rated the worst and best displays only, on a number of criteria. It would seem that the relatively unimpressive performance of the electronic dial display on subjective measures when compared with the other display designs is in some way alleviated by the generally positive nature of the drivers' comments about the design.

1. When reading the speed shown on the electronic dial display less than one reading in 4 (23%) was accurate to within $\pm$ 2 mph*. The largest number of readings were within $\pm$ 5 mph of the correct reading (60%). The majority of errors were under-reading of the speed. The electronic dial display segments were in units of 2.5 mph hence subjects were under reading the speed by approximately two segments. The electronic dial display was read less accurately (23% $\pm$ 2 mph) than the design most similar to it, the electromechanical dial display (47% $\pm$ 2 mph).

2. The accuracy of check reading against a speed limit for the electronic dial display was very similar to that for the electromechanical dial display (67% and 68% correct respectively).

3. The mean response time for reading the speed was very

* The accuracy $\pm$ 2 mph includes readings from +2.9 to -2.9 mph and hence includes the 2.5 mph segment units.

similar to that for the other analogue displays (1.64 sec). However, the mean response time for check reading against a speed limit was considerably faster than for any of the other display designs (1.22 secs).

4. Of the analogue display designs the electronic dial display was considered easiest to read by the largest group of subjects (15%). However this was a considerably smaller number of subjects than those who considered the electronic digital display easiest to read (62%). In addition, more subjects (20%) considered it the most difficult to read.

5. The electronic dial display was considered easiest to use for check reading against a speed limit by the smallest group of subjects (13%), equal to the electromechanical dial display. More subjects (20%) considered that it was the most difficult to use for check reading, but only the electronic digital display scored less (13%) on this factor.

6. A large number of subjects (53%) considered that the electronic dial display was easy or very easy to use to keep to a speed target. It was second only to the electronic digital display (67%). Drivers' comments indicate that the display was easier to use for keeping to a speed target because a change of 2½ mph was required before the segments changed status.

7. Only 9% of subjects considered that the electronic dial display was least distracting. However only 13% considered it most distracting. This result may well be an example of this design being overshadowed by the strong response to other designs. For example 43% of subjects considered the electromechanical dial display to be least distracting and 38% considered the electronic digital to be most distracting.

8. One quarter of the subjects (24%) considered the electronic dial display to be most attractive, second only to the curvilinear display (39%).

9. The electronic dial display was rank 4 for choice for own car with only 18% of drivers who stated that they would choose it for their own car. However only 17% said that they would avoid it. The other electronic display designs were clearly more outstanding to subjects in this respect.

10. The electronic dial display was read less accurately under dynamic test conditions compared with the static conditions of Study 1. This was the case with all of the analogue display designs. In Study 1 88% of the readings were exactly correct (with 'clutter') whereas in Study 2 23% were correct to within $\pm$ 2 mph. A reduction in accuracy of check reading also occurred in Study 2 (67% correct) as compared with Study 1 (97% correct with 'clutter'). This was also the case for all the analogue display designs.

11. On the measures of driver preference the electronic dial display improved in the dynamic conditions of Study 2. It was rank 4 in Study 1 and rank 2 in Study 2. It also improved on ease of check reading from rank 4 in Study 1 to rank 3 in Study 2, on attractiveness from rank 4 in Study 1 to rank 2 in Study 2. Although a larger percentage of subjects stated they would choose the display for their own car in Study 2 (18%) compared with Study 1 (12%) the rank went down from 3 to 4 in Study 2.

5.9.5.3 The electronic curvilinear display - test results

Table 5.17 The electronic curvilinear display test results - objective measures

OBJECTIVE MEASURES	ACCURACY SCORE freq (n=1000)	%	Rank
Reading the speed Response correct to:			
Within ± 2 mph	33	3	4
∓ 3-5 mph	319	32	
∓ over 5 mph (1)	637	64	
Missing responses	11	1	
Mean response time	1.69 secs		4
Deciding whether speed was within a speed limit			
Correct responses	453	45	4
Incorrect responses(2)	518	52	
Missing responses	29	3	
Total errors	547	55	
Mean response time	1.61 secs		3

(1) Under-reading error scores

Percentage of subjects inaccurate by more than 5 mph

Table 5.17.1

Speed (mph)	% Subjects
30 - 39	20
40 - 49	15
50 - 59	64
60 - 69	63
70 - 79	60
80 - 89	50

(2) Check reading against speed limit error scores.

Percentage of subjects giving incorrect responses

Table 5.17.2

Speed (mph) limit	% Subjects
30	49
50	57
70	34

Table 5.18 The electronic curvilinear display test results - subjective measures

SUBJECTIVE MEASURES	% (n = 100)	Rank
Easiest to read	12	3
Most difficult to read	29	
Easiest to decide whether speed was within a speed limit	19	2
Most difficult to decide whether speed was within a speed limit	22	
Easy or very easy to keep to a speed target	43	4
Difficult or very difficult to keep to a speed target	25	
Least distracting display	15	3
Most distracting display	20	
Most attractive display	39	1
Least attractive display	30	
Would choose for own car	20	3
Would avoid for own car	32	

The electronic curvilinear display - summary of results

The electronic curvilinear display was novel in design in that the scale formed a curved line rather than a dial. In addition, the speedometer segments changed colour from green to amber at 30 mph and upwards. The curvilinear design caused much interest among the drivers and opinion was strong although not in a unified direction. Opinion was divided on a number of criteria.

1. When reading the speed shown on the electronic curvilinear display subjects performed very badly and only 3% of readings were accurate to $\pm$ 2 mph. The vast majority of readings (64%) were inaccurate by an underreading of over 6 mph. (The display calibration was checked for accuracy and no fault could be found). The underreading error was greatest with speeds over 50 mph. It is at 50-60 mph that the upward direction of the scale curves to produce the horizontal direction for speeds over 60 mph.

2. The accuracy of check reading against a speed limit was also poor with the electronic curvilinear display (45% correct) but clearly better than actual speed reading. A further analysis of the results indicates that the errors occurred most frequently at a speed limit of 50 mph (57% errors). At a speed limit of 70 mph drivers were more accurate (34% errors) in deciding whether the speed was within the speed limit. No particular advantage was indicated at the 30 mph speed limit where the segments changed colour from green to amber (57% correct).

3. The mean response time for reading the speed was very similar to that for the other analogue displays (1.69 sec) although it is the slowest of the times. The mean response time for check reading the speed against a

speed limit (1.61 sec) was similar to that for the electromechancial dial display. Subjects were not taking noticeably longer to read or check read the curvilinear display. It is clearly the accuracy rather than the reading time which is compromised.

4. The electronic curvilinear display was considered easiest to read by only 12% of subjects. A similar response was obtained for each of the analogue displays. However 29% of subjects considered it to be the most difficult to read second only to the electromechanical dial display (34% most difficult).

5. The electronic curvilinear display was considered easiest for check reading by 19% of subjects. Although this gave it a rank of 2 it was considerably less than the 51% of subjects who considered the electronic digital display to be easiest for check reading. 22% of subjects considered it most difficult for check reading. Drivers comments suggested that the segment change at 30 mph from green to amber was helpful for check reading at 30 mph speed limits, but did not provide any advantage for 50 and 70 mph speed limits. Hence the slightly higher score than for the electronic and electromechanical dial displays.

6. The electronic curvilinear display scored slightly worse than the other display designs (43% easy or very easy) on ease of keeping to a speed target. The segment colour change at 30 mph should have assisted with this task but after having gained experience with the display in the tests the subjects appeared to find that overall the advantage was outweighed by other factors including difficulty in reading the speed accurately.

7. Fifteen percent of subjects considered the electronic curvilinear display to be least distracting while driving, whereas a greater number (20%) considered it most distracting. Drivers' comments indicated that they found the flashing end segment distracting and the display generally rather bright.

8. The electronic curvilinear display was considered most attractive by 39% of the subjects and ranked 1. Certainly it was the most colourful of the designs. However just under a third of the subjects (30%) thought it was the least attractive.

9. The largest group of subjects (32%) stated that they would avoid the electronic curvilinear display for their own car, but 20% stated that they would choose it for their own car.

10. The electronic curvilinear display performed considerably worse under dynamic test conditions than it did in the static test conditions of Study 1. The accuracy of speed reading fell from 77% exactly correct (with 'clutter') in Study 1 to only 3% correct to within $\pm$ 2 mph in Study 2. Similarly the accuracy of check reading against a speed limit fell from 94% correct in Study 1 to 45% correct in Study 2. All the analogue designs performed less well under dynamic test conditions but the extent of the degradation was not so great.

11. The preference measures showed improvement in Study 2 compared with Study 1. The electronic curvilinear display was rank 3 rather than 4 for ease of reading, rank 1 rather than rank 2 for attractiveness, and rank 3 rather than rank 5 for choice for own car.

5.9.5.4 The electronic digital display - test results

Table 5.19 The electronic digital display test results - objective measures

OBJECTIVE MEASURES	ACCURACY SCORE freq (n=1000)	%	Rank
Reading the speed Response correct to:			
Within $\pm$ 2 mph	969	97	1
$\mp$ 3-5 mph	5	1	
$\mp$ over 5 mph	13	1	
Missing responses	13	1	
Mean response time	1.19 secs		1
Deciding whether speed was within a speed limit			
Correct responses	933	93	1
Incorrect responses	60	6	
Missing responses	7	1	
Total errors	67	7	
Mean response time	1.39 secs		2

Table 5.20 The electronic digital display test results - subjective measures

SUBJECTIVE MEASURES	% (n = 100)	Rank
Easiest to read	62	1
Most difficult to read	9	
Easiest to decide whether speed was within a speed limit	51	1
Most difficult to decide whether speed was within a speed limit	13	
Easy or very easy to keep to a speed target	67	1
Difficult or very difficult to keep to a speed target	21	
Least distracting display	22	2
Most distracting display	38	
Most attractive display	19	3
Least attractive display	30	
Would choose for own car	39	1
Would avoid for own car	26	

The electronic digital display - summary of results

The electronic digital display was probably the most novel of the three electronic instrument panel designs and drivers' overall opinions about the display were clearly divided. The results of the performance tests were, however, unequivocal, the subjects' performance when using the digital display was far superior to any of the other displays.

1. Nearly all the 100 drivers read the speed shown on the electronic digital display accurately to within $\pm$ 2 mph. It was not possible to establish what proportion of the responses were exactly correct as the digit reading may have changed during the time from stimulus to response, particularly if the brakes or accelerator were being applied.

2. The electronic digital display scored very well when drivers used the display to check read against a speed limit. Only 67 errors were recorded out of 1000 readings compared with 320 errors for the next best display (electromechanical dial display).

3. The mean response time for reading the speed with the electronic digital display was considerably quicker (1.19 secs) than for any of the analogue displays. The response time for the electronic dial display was faster (1.22 secs) than the electronic digital display (1.39 secs) for check reading against a speed limit.

4. The electronic digital display was considered easiest to read and easiest for check reading against a speed limit by the greatest number of subjects (62% and 51% respectively). The results are also confirmed by the small numbers of subjects who considered the digital display to be the most difficult for these tasks (9% and 13% respectively).

The latter result is interesting as analogue displays are traditionally considered easier to use for tasks such as these. Subjects' opinion on use is borne out by the results of the performance tests where subjects made very few errors.

5. The majority of subjects (67%) considered the electronic digital display very easy or easy to use to keep to a speed target. However, some of the subjects who found it difficult or very difficult to use mentioned that compared with the other electronic displays which light up in segments, the digital display indicated every speed change to 1 mph accuracy. This made it more difficult to keep exactly to a speed target, but the target was achieved with greater accuracy.

6. The electronic digital display was considered most distracting by the largest group of subjects (38%). However, one driver in 5 (22%) considered it least distracting and the display was rank 2 after the electromechanical dial display. The rate of change of the display digits varied according to the rate of acceleration or deceleration based on a sampling rate of four samples per second.

7. The electronic digital display was considered least attractive by 30% of the subjects equal with the electronic curvilinear display (30%). Only 19% of subjects considered it most attractive and it was rank 3 on attractiveness. This result may have been influenced by the way the dynamic model was produced. The other two electronic displays were produced by attaching LEDs behind a printed face plate. The tungsten filament digits and filters stood slightly proud of the face plate and the overall effect was not as aesthetically pleasing as the other two electronic displays. (See Appendix 2).

8. Nearly twice the number of people (39%) stated that they would choose the electronic digital display for their own car than would choose any of the other three displays. However, just over a quarter of the subjects (26%) stated that they would avoid the electronic digital display for their own car.

9. Of the drivers in the over 50 years age group half stated that they would choose the digital display for their own car. In addition, of all the people who said that they would choose the electronic digital display the largest number were in the over 50 years age group.

10. The electronic digital display scored best on all the measures taken in Study 1. The only measures on which it failed to do so in Study 2 were attractiveness and distraction while driving (not measured in Study 1). However, it still scored second best on those measures. Even under dynamic test conditions the electronic digital display continued to be outstanding. However, for the two measures on which it scored less well, although rated second, the results were poor. The distraction effects are clearly important not only from an aesthetic point of view, but also with regard to safety.

5.10 Discussion

The discussion in this chapter is concerned only with the main points of Study 2. Chapters 7, 8 and 9 discuss the whole programme in detail.

5.10.1 Discussion of the results

The objective measures of accuracy of reading the speed and of check reading against a speed limit indicate that the electronic digital display was read more accurately (97%

within ± 2 mph) and more quickly (1.19 secs) and used for check reading more accurately (93% correct) than any of the analogue designs. These results were also obtained in the static conditions of Study 1 as would be expected from the literature. However, the subjects using the electronic digital display maintained a high accuracy score under the dynamic conditions of Study 2. The electronic digital display was designed such that the rate of change of the digit varied according to the rate of acceleration or deceleration based on a sampling rate of four samples per second. The rate of change of digits is critical to the ease of use of the digital display because if the rate of change is too rapid the driver would not be able to focus on the digits fast enough to read them while they are updating. If the rate of change is too slow the speed reading will not be accurate and may also produce large jumps in readings on the 'scale' during acceleration or deceleration of the vehicle. Drivers' clearly did not experience any difficulty with the update rate used in the experiment. (The update rate was determined by Ford Motor Company).

Of the analogue display designs the electromechanical dial display was read most accurately (47% within ± 2 mph). The two electronic analogue designs were read less accurately (23% dial and 3% curvilinear within ± 2 mph). The majority of errors were underreadings in the case of all the analogue display designs. The analogue displays performed considerably worse under the dynamic test conditions as would be expected, even though the criterion for a correct response allowed a greater number of responses to be considered correct. In Study 1 the response had to be exactly correct whereas in Study 2 the response could be within 2 mph either side of the correct response to satisfy the criterion. This also took account of the fact that it was not possible to know at exactly what point between the stimulus and response the subject had looked at the speedometer. The mean of the speedometer readings between the stimulus and the response time was considered the correct response. As the mean response time for each display was less than 2 secs the change in speedometer readings was not usually very great in that period. The electronic analogue displays indicated the speed by the end of the last lit segment. The segments were in units of 2 mph (curvilinear display) and 2½ mph (dial display). The 'pointer' (the end of the last lit segment) would not indicate speed changes of less than one unit, hence the number of segment changes in the stimulus to response period was not usually very great. It was not common for subjects to brake or accelerate the simulator very rapidly. It is not likely therefore that the rapid rate of change in the segments is a full explanation for why the electronic analogue displays were read with such poor accuracy. The electronic curvilinear display was not read with equal accuracy throughout the scale. The speed readings above 50 mph were much more likely to be inaccurate than those below 50 mph. It is at 50 mph that the upward curve changes to a horizontal line, and the maximum number of errors occurs with speeds along the horizontal line. Subjects' comments indicated that the display was too long and 'stretched out over a longer distance'. They also indicated that the 2 mph segments were more difficult to use particularly as they did not align with the 5 mph graduation marks. Hence the useful reference points were reduced once the segment colour change at 30 mph had been exceeded. The evidence from the literature also indicates that linear displays are more difficult to read and take longer to scan to identify the correct reading (Sleight 1948, Graham 1956).

The subjects' performance when using the display designs for check reading against a speed limit was also less accurate than in Study 1 with the exception of the electronic digital display. However, the two analogue dial displays were check read accurately on over two thirds of occasions. The electronic curvilinear display did not perform so well with less than half the responses (45%) accurate. This could be partly a function of the poor accuracy of speed reading. However, the check reading was not carried out with equal accuracy for each of the speed limits. At 30 mph the segments were all green and above 30 mph amber segments illuminate to indicate the speed. Although subjects considered this colour change to be an advantage it is clear that subjects were still inaccurate in check reading on over half the occasions at the speed limit 30 mph. At 50 mph speed limit the accuracy was further reduced to only 43% correct. However, at 70 mph speed limit the accuracy improved to two thirds. Only a very small section of the scale is illuminated when a speed of 30 mph is shown and this is in the far left of the display. In addition a number of drivers reported that the lower part of the scale was hidden by the left hand on the steering wheel and that readings below 50 mph were out of the drivers' field of vision when looking ahead. The improvement in check reading accuracy at 70 mph also supports the theory that the lower speed limits were more difficult to use for check reading as 70 mph is in the centre of the scale and in the drivers' line of vision when casting eyes straight down from the road.

In terms of drivers' preferences, the electronic digital display maintained its superiority in Study 2. However, there were some criteria which could not be measured in the static conditions of Study 1, which were particularly important for the electronic displays. These were the drivers' responses to the dynamic characteristics of the displays, segments lighting up or digits changing to indicate speed and rate of change. These criteria were assessed in terms of distraction while driving and ease of driving to a speed target. None of the electronic display designs performed very well in terms of distraction while driving. The electromechanical dial display was considered most distracting by the largest group of subjects (38%). The effect of novelty does enter into the argument, however. The subjects were all drivers and were well used to the standard electromechanical dial displays. At the time of the experiments the incidence of more novel instrument panel designs on the market was very low and none of the drivers who took part in the experiment had any experience of electronic instrument panels in cars. Hence it is very likely that the novelty of the display designs could be a distraction to drivers. A review of drivers' comments on the designs does not indicate that this is a major factor for the electronic dial display. It was not considered very different from the electromechanical dial but did have some better features. The electronic digital display was considered distracting because the numerals were large, 25 mm, and they changed shape rather than changed by a rotating drum as is the case with electromechanical digital displays. The amber colour of the speedometer was also considered distracting and some subjects suggested a less bright colour such as green. The electronic curvilinear display was the most novel of the electronic designs and was also considered the most distracting. Subjects' comments in Study 1 had indicated that the amber scales for both the speedometer and tachometer, the amber segments on the tachometer and for over 30 mph on the speedometer were very distracting. Subjects reported that their attention was drawn to the bright amber tachometer rather than to the speedometer. In Study 2 the colours on the scales had been changed to green and only the segments above 30 mph on the speedometer were amber. Although no question was asked directly about distraction in Study 1 because of the static nature of the tests, it is likely that the colour changes on the display did assist in reducing distraction. However, it was still considered the most distracting. This could be because the segments indicate in units of 2 mph and hence change more frequently than those of the electronic dial display which indicates units of 2½ mph. Drivers' comments mention the changing segments frequently as a source of disatisfaction. The length of the scale was also considered to be distracting in that more time was needed to scan the display to locate the 'pointer' and this distracted attention from the road. This also applied to the difficulty drivers experienced in reading the speed accurately.

The changing segments from lit to unlit on the pointer was also of interest in terms of distraction and hence subjects used the instrument panels to drive to a speed target as if cruising on a motorway at a set speed, for example. The electromechanical display was considered easy or very easy for this task by over two thirds of the subjects, the other displays by about half the subjects. The electromechanical dial display was considered difficult to use to keep to a speed target because the speed targets in the experiment were 30, 50, 70 mph, the usual British speed limits. However these speeds were only unnumbered bold graduations on the scale with unnumbered fine graduations at 5 mph intervals. Hence there were four graduations between 40 mph and 60 mph and the subjects were expected to keep to a speed target of 50 mph as accurately as possible. In addition, unlike the electronic displays the pointer had a continuous movement whereas the electronic displays were discrete. In order to keep the electronic analogue displays to a speed target the subject had to adjust the speed to ensure that a particular segment, the 'pointer' segment, remained lit and that the next segment did not light up. It was common for the 'pointer' segment to flash on and off as the subjects attempted to drive to a speed target. The curvilinear design pointer flashed more frequently than the dial design because it indicated speed changes of 2 mph rather than 2½ mph. This may account for the difference in results for the two electronic analogue displays. Drivers considered that the flashing 'pointer' segment was distracting to some extent, but other drivers considered that the displays were easier to use for this task because of the discrete nature of the speed change indicator.

The electronic digital display indicated speed change by changing the shape of the digits to indicate exact speed in units of one. This change of digit when keeping to a speed target was also of interest. Two thirds of the drivers considered the electronic digital display to be easy or very easy to use for this task. The main reason appears to be because the information is given to the driver accurately and in a form which is extremely easy to use. However, some of the subjects who found it difficult or very difficult to use, mentioned that compared to the other electronic displays the digital display indicated every speed change. This made it more difficult to keep exactly to a speed target but the target was achieved with greater accuracy.

In Study 1 the electronic digital display was considered most attractive by a slightly larger number of subjects. In Study 2 this display ranked 3 on attractiveness. This result may have been influenced by the way the dynamic model was produced. The other two electronic displays were produced by attaching LEDs behind a printed face plate. The tungsten filament digits and filters stood slightly proud of the face plate and the overall effect was not as aesthetically pleasing as the other two electronic displays.

The concept of choice for own car was used as a synthesis of all the drivers' experience with the display designs. The electronic digital display was still the one which the largest group of drivers would choose for their own car after having experienced the design in dynamic test conditions. Without the option of choosing the revised electromechanical dial display from Study 1 more subjects than in Study 1 stated that they would choose the electromechanical or electronic dial displays. However, a smaller percentage of drivers stated that they would avoid choosing the electronic curvilinear display. The change of scale and tachometer colour may have improved the designs acceptability in Study 2.

5.10.2 Discussion of the research method

In Study 1 the display designs were presented to drivers as photographic representations. In Study 2 working models of the display designs were made and installed in a vehicle simulator. Subjects then gained experience of the behaviour of the designs under dynamic test conditions which was more like driving on the road. Although the electronic technology used in these dynamic simulations was not the same as that which would be used in production designs, many features of the designs could be assessed and drivers' preferences and opinions obtained under controlled conditions. The electromechanical dial was a standard production display operated by continuous motors. The electronic analogue designs were made using LED segments and backlit screen printed scales and other instruments (eg fuel gauge and odometers). The electronic digital display was made by inserting tungsten filament digits into the screen printed face plate and as such did not have quite the professional appearance of the other two electronic displays. It was, however, acceptable for the purposes of the test. As far as the subjects were concerned it was clear from their comments and responses that the designs looked 'electronic'.

In Study 1 the displays presented to the drivers did not fluctuate as they would do in normal driving. It was anticipated, however, that when the displays were tested under conditions more like normal driving where the display readings fluctuated in response to the driving controls and where the driver could adjust his/her own display reading time, within the constraints of driving the simulator and not driving off the road, the performance of the displays would alter relative to each other. As in Study 1 the subject was not able to choose the time at which he/she used the instruments. The stimulus to read or check read was initiated by the computer according to a time schedule. Hence the subjects could not prepare themselves for the task.

However, there were similarities with normal driving which make the tests a reasonable indication of performance in road conditions. The displays were dynamic and responded to the use of the controls by the driver, hence the driver had some knowledge of the likely state of the displays. In addition the road scene responded directly to the drivers' use of the controls and speeded up or slowed down according to control movements. Hence the driver received visual cues from the road scene as to likely speed. The vehicle simulator included simulated engine noise which was sensitive not only to speed and acceleration but also to the gear selected. Hence the driver also received auditory information about the likely speed. (It is interesting to note that subjects found it extremely difficult to drive the vehicle simulator successfully in some pilot trials in which the engine noise was not present). The road scene was produced on a monochrome monitor placed about 1750 mm away from the driver. Between the driver and the monitor was placed an aspheric collimating lens which projected the road scene to infinity. Drivers, therefore, had to refocus from the road scene, infinity, to approximately 750 mm to read the instruments. Unlike normal driving there was no serious consequence if the subject took his/her eyes off the road for too long. There was a consequence, however, which was that if the vehicle was steered off the road an unpleasant buzz sounded until the vehicle was back on the road.

As in Study 1 all the tests were conducted under night time lighting conditions and each of the displays was at an equal brightness. In normal driving the displays would be viewed in a variety of lighting conditions. Because the designs were not produced using the same technology as would be present in production displays it was not considered worthwhile testing the performance of LEDs in different lighting conditions when LCDs would be used in production. Different lighting conditions were tested in Study 3 when the designs were produced in LCD.

The main advantage of using this research method in the second study was that drivers' response to the dynamic properties of the electronic designs could be tested in conditions more like real driving. It was most important that the display models responded as they would do as production designs with the same sizes, the same rates of change or update and so on. In addition the drivers were able to gain information from their own control use and from visual and auditory cues which would normally be used in interpreting the display readings.

In the vehicle simulator the amount of control over the experimental design, and the experimental conditions was much greater then could be expected in road trials. Each driver was able to experience all the display designs in a single experiment because the number of variables to control was manageable compared with road trials (see Study 3). Each driver experienced the designs under exactly similar conditions because the driving task was generated and controlled by the computer. In addition any hazard associated with using the designs was eliminated, particularly as very little was known at that time about the distracting effects the electronic designs may have had on the driver.

The main disadvantage of the research method was that the technology used to produce the displays was not that which would be used in production. The cost of producing prototype LCD designs at that time was very high whereas LED designs could be produced relatively cheaply. Even at the time of the road trials (Study 3) it was not possible to produce 25 mm LCD digits and so the tungsten filament displays were used for both studies.

The computer control of the vehicle simulator also meant that readings from the instrument panels could be taken directly. The computer recorded the speed and the tachometer reading in one second intervals throughout the experiment, and also indicated when the stimulus was initiated, when the response was recorded and whether the vehicle was on or off the road. In addition the computer calculated the mean speed readings between stimulus and response time and the accuracy of the subject's response. This level of instrumentation was not feasible at the time in road vehicles.

This method can be used to obtain reliable objective data on subjects' performance with the display designs. However, the reliability is not as great as was possible in Study 1 because the displays were dynamic and the readings may change during the time from the stimulus to the response. Hence it is not possible to know exactly what speed was being shown at the time the subject was looking at it. As the response time was usually very short, less than 2 seconds, however, it is not likely that the display readings changed markedly in that time. A review of a sample of the computer record indicates that this is a reasonable assumption.

This method was more appropriate than Study 1 for obtaining subjective responses to the display designs because the subject had the opportunity to use the designs for a variety of tasks when the displays were behaving dynamically as they would in real driving. This was particularly important because very little was known about driver response to these novel display designs.

5.10.3 Discussion of the display designs

None of the designs were changed markedly from Study 1 to Study 2. Only the electromechanical dial (revised) was omitted. However the colours used on the electronic curvilinear design were changed as driver response was so strong. The blue scale and amber segments on the tachometer were changed to green throughout as drivers had reported that the amber segments were too bright and attracted attention away from the speedometer. The size of the numerals on the odometers of the electronic digital display were also reduced, as they were considered too large and caused some confusion as to their function.

The main difference between the displays was their dynamic behaviour in that the electromechanical dial display had a pointer operated by continuous motors, the two analogue electronic displays had discrete segments which lit up around the scale and the 'pointer' was the end of the last lit segment. The curvilinear design had segments of 2 mph and the dial design had segments of 2½ mph. The digital design had two blue digits indicating engine speed and three amber digits (two normally visible) indicating road speed. The digits changed shape to form numbers as the speed changed. The digits were 7-segment design. Each display also showed an odometer, trip odometer and fuel gauge. These instruments were static.

The electromechanical dial display was the design with which subjects were most familiar. However, in the tests of accuracy of reading only 47% of the responses were correct to within ± 2 mph, and only 68% of the check readings against a speed limit were correct. This may reflect the normal accuracy of reading this design of speedometer as there was no reason to suppose that these experimental conditions were sufficiently unlike real driving to influence the response accuracy. The electronic digital design was clearly read most accurately and the accuracy had not decreased under the dynamic conditions of Study 2. However, the accuracy of check reading was also maintained, a result which would not have been expected from the literature as analogue designs are reputed to be more appropriate for check reading (Bailey 1982, McCormick 1976).

In terms of drivers' opinions the greatest number of drivers (34%) considered the electromechanical dial to be most difficult to read, in spite of the familiarity of the design. The scale markings were much less satisfactory than those on the other two analogue designs as only speeds of 0, 20, 40, 60, 80 .... mph were indicated whereas the other designs had every 10 mph indicated. All three analogue designs had unnumbered graduations for 5 mph intervals. This may also account for the large number (29%) of drivers who considered the electromechanical dial the most difficult to use for check reading. The usual British speed limits of 30, 50, 70 mph are not marked as numbered graduations on the scale. The electronic digital display was considered to be the easiest to read by the majority of subjects (62%) as was found in Study 1 even though the display was dynamic in Study 2, a feature which could have made it less easy to read. The majority (51%) of subjects also considered the electronic digital display to be easiest for check reading against a speed limit. This result is interesting because although check reading was clearly carried out more accurately using the digital design subjects may well have considered it to be a more difficult task than check reading using an analogue design.

The distraction of drivers' attention was a matter of great concern when the electronic designs were being considered. This aspect could not be tested in the static conditions of Study 1, it was the effect of the dynamic properties of the designs on drivers which was not known. As has been mentioned earlier, a balance must be reached between accuracy of reporting road speed or engine speed and the rate at which the display readings are updated. The display update rates were determined by Ford Motor Company. Some adverse comments were reported about the flashing on and off of the leading segment, the 'pointer' segment, when cruising at a constant speed. There are a number of ways of dealing with this problem, one is to increase the damping in the system so that the segments flash less readily, another is to increase the size of the segments to 5 mph for example. However, this latter is not acceptable as it may not meet the current construction and use regulations for speedometer accuracy.

The colours of the electronic displays may also have affected distraction compared with the white scale on black background, orange pointer and blue-green lighting of the electromechanical dial design with which subjects were familiar. It was not possible to conduct tests in which the colours were standardised or absent to test out this theory. However the experiment reported by Galer and Simmonds (1985) indicates that colour, even of electromechanical designs can have a marked effect on driver preference, though not on performance.

The most novel design, the electronic curvilinear display was considered most attractive by the largest group of subjects (39%). This may be because of its novelty, or because the colours, mainly green with some amber were more acceptable than the mainly amber colours of the electronic dial design. Drivers' comments indicate that the electronic digital display may be too simple and functional to be considered attractive. However, the use of two colours and brightness to distinguish the speedometer and tachometer was well received. The use of red for the fuel gauge on the curvilinear display was not generally acceptable. The red colour was associated with warning, and yet a large amount of red was present when the fuel tank was full, not a warning condition. The amount of red reduced as the fuel level went down.

The question on choice for own car, as in Study 1 was used to synthesise the subjects' response to the designs, and was intended as a question to bring out the balance between ease of use and aesthetic appeal. In spite of its poor scores on distraction and attractiveness the greatest number of subjects (39%) stated they would choose the electronic digital display for their own car. However, a quarter stated that they would avoid that design. A third of drivers stated thay they would avoid the electronic curvilinear design even though it was considered attractive by the largest group of subjects.

5.11 Conclusions

The second stage of the research programme to investigate driver responses to electronic instrument panel designs continued to address two main questions. These were whether electronic instrument panel designs have advantages from an ergonomics point of view over electromechanical designs, and also the comparative merits of the different electronic display designs.

The main conclusions from the second stage of the research programme are presented in this section.

5.11.1 Are electronic displays preferable to electromechanical displays from an ergonomics point of view?

The electromechanical dial, the electronic dial and the electronic curvilinear display results tended to group together particularly for:-

- ease of reading

- ease of deciding whether the speed was within a speed limit

- ease of keeping to a speed target

- choice of display for own car

The electromechanical dial display performed better than the others on:-

- accuracy of reading speed (except for the digital display)

- accuracy of deciding whether the speed was within speed limits (except for the digital display)

- distraction while driving

The electromechanical dial display performed worst on:-

- attractiveness

5.11.2 Which of the electronic displays performed most satisfactorily from an ergonomics point of view?

The electronic digital display performed best on:-

- accuracy of reading

- accuracy of deciding whether the speed was within a speed limit

- ease of reading

- ease of deciding whether the speed was within a speed limit

- ease of keeping to a speed target

- choice of display for own car

38% of drivers considered the digital display most distracting, but of the three electronic displays, it was also the one which the greatest number of people (22%) thought least distracting.

The electronic curvilinear display was considered most attractive (39%) but 30% thought it was least attractive and a further 30% thought the digital display was least attractive.

CHAPTER 6 STUDY 3 DRIVER RESPONSES TO FOUR DESIGNS OF INSTRUMENT PANEL TESTED IN VEHICLES DURING ROAD TRIALS

SUMMARY

In the third stage of an investigation of drivers' responses to electronic instrument panel design, tests were carried out on the ease of reading and use of four instrument panel designs under normal driving conditions. Pre-production LCD prototypes of three electronic instrument panel designs and an electromechanical dial design were installed into Ford Granada cars. In three sets of road trials drivers compared either an electronic dial display, an electronic curvilinear display or an electronic digital display with an electromechanical dial display. The electromechanical dial display acted as the benchmark against which each of the electronic designs were tested. In these tests, unlike Studies 1 and 2, each driver only saw one electronic design and the electromechanical design. All the displays responded as in normal driving. The display designs were tested by a total of 204 drivers under day and night lighting conditions. Measures were taken of the accuracy of reading the speed and check reading against a speed limit. Drivers also gave their opinions about the ease of use of the displays and made comments on the designs.

CONCLUSIONS

- The electronic digital display performed better and was preferred by drivers on all measures when tested in both daylight and night-time trials, compared with the electromechanical dial display.

- The electronic dial display performed better and was preferred by drivers in the night-time tests. The electromechanical dial display performed better and was preferred by drivers in the daytime tests.

- The electronic curvilinear display was preferred on some of the measures when tested in daylight. There was little difference between results for the electronic curvilinear display and the electromechanical dial display in the night-time trials.

6.1 Introduction

The results of the laboratory tests carried out in Studies 1 and 2 showed that the electronic display designs could have advantages over the electromechanical designs tested. However, Study 2 showed that distraction of drivers attention while driving may be a problem with the electronic designs. It was not possible in Study 2 to use the LCD technology for the displays, which would be used in vehicles, hence the performance of the display designs in LCD in the different lighting conditions found in normal driving was not known. There was still a reluctance on the company's part to accept the results obtained for the electronic digital display in terms of accuracy of use and driver preference. Hence, road trials were conducted as the display designs became available.

In the third stage of the research programme user trials were conducted in vehicles on a test route including a variety of traffic and lighting conditions. Each of the three electronic displays were compared with an electromechanical dial display.

6.2 Aims of Study 3

1. To compare the performance of drivers using three electronic instrument panel designs with their performance using an electromechanical dial display under normal driving conditions.

2. To measure the accuracy of reading the instruments either to obtain the current speed or to decide if a speed limit is being exceeded.

3. To obtain drivers' preferences and opinions about the display designs.

4. To assess the performance of the electronic displays under different lighting conditions.

6.3 Pilot studies

Prior to the commencement of the main experiments the following pilot studies were conducted:

1. To establish optimum routes for the road trials, and notate the routes on a response sheet.

2. To determine the optimum duration of each trial, and the length of driving practice time required for the subjects to become familiar with the particular type of vehicle used - a European Ford Granada with automatic transmission.

3. To assess the response format and the questionnaire design, including the use of the Apple computer in the vehicles.

4. To test the experimental method; the illumination levels; timing and duration of the experiment; the sampling procedures and the eyesight tests.

Twenty subjects took part in the pilot studies. All the subjects were drivers who had driven within the last year. The results of the pilot studies were used to design the main experiments.

6.4 Experimental design

The instrument panel designs used in the study were:-

TRIAL 1 Electronic dial display - Electromechanical dial display

TRIAL 2 Electronic digital display - Electromechanical dial display

TRIAL 3 Electronic curvilinear display - Electromechanical dial dial display

Full instrument clusters including a speedometer, a tachometer, odometers, fuel gauge etc., were supplied by Ford Motor Company Ltd.

(See Appendix 2).

The experimental design was such that:

- a minimum of 60 subjects tested one electronic instrument panel design compared with an electromechanical dial display.

- each display design was tested first or second by an equal number of people.

- each display design was tested under day and night lighting conditions.

The main task as far as the driver was concerned was driving along the test route. While driving each subject carried out two other tasks. These were, at a request from the experimenter:

Task A - state the speed shown on the speedometer as quickly and as accurately as possible. (10 readings per subject per display).

Task B - state whether the speed was within the current speed limit, as quickly and as accurately as possible. (15 readings per subject per display).

The tasks were repeated in a specified order for each trial on the outward journey and in reverse order for the return journey. The order of task presentation was determined by the type of road, current speed limits, and street lighting conditions. (The response sheets are shown in Appendix 3). The speed limits tested on the route were 30 mph, 60 mph and

70 mph. Speed limits of 40 mph and 50 mph were represented on the route but not included in the test schedule.

The experiments were conducted during day and night lighting conditions. Times during the day when the light changed during the test period such as at dusk, were avoided in the experimental schedule, as were peak traffic hours.

The following measures were taken during each experiment:-

Actual speedometer reading

Subject's response - Speed reading (Task A)
- Yes/No (Task B).

Ambient light levels

The measures were taken by the experimenter at specified points on the test route, and responses noted on the sheets shown in Appendix 3.

6.5 Subjects

A total of 204 subjects took part in the road trials. This comprised:-

TRIAL 1 Electronic dial display test - 69 subjects

TRIAL 2 Electronic digital display test - 70 subjects

TRIAL 3 Electronic curvilinear display test - 65 subjects

The subjects were all drivers who had driven within the last year and who conformed to the following vehicle insurance requirements:-

21 years of age or over

full driving licence for one year or more

no more than one speeding conviction

otherwise clean driving licence.

The subjects were obtained by local advertisement. Subjects who took part in Studies 1 and 2 of the research programme were excluded from Study 3 as their previous experience with the displays may have influenced their opinions.

Approximately equal numbers of men and women attended and there were also approximately equal numbers in each of the three age groups: 21 - 30 years, 31 - 50 years, 51 years and over. The subjects were tested singly but two independent experiments were conducted simultaneously. Each experiment lasted 1½ - 2 hours per subject.

Between 40 - 50 subjects tested each of the instrument panel designs in day time conditions and 20 - 30 subjects tested them in night time conditions.

6.6 Equipment

6.6.1 Vehicles

Each test employed two vehicles. The vehicle containing the electromechanical dial display was the same throughout the experiments, a 1978 European Ford Granada GL 2.8 litre. The vehicle containing the electronic dial display was a 1976 European Ford Granada Ghia 3 litre, and the vehicle containing the electronic digital and curvilinear displays was a 1980 2.8 litre European Ford Granada Ghia. All three vehicles had automatic transmission. The vehicles were provided by Ford Motor Company Ltd.

6.6.2 Instrument panel designs

Three electronic instrument panels and an electromechanical dial display were provided and fitted in the vehicles by the Ford Motor Company Ltd. The electronic dial display was a 1978 liquid crystal display. The electronic curvilinear display was a 1980 liquid crystal display. The electronic digital display was produced using tungsten filaments. The tungsten filaments were filtered to look like LCDs. The instrument panel was fully functional and all the instruments and ancilliary displays functioned as they would do in a normal vehicle. Photographs of the instrument panel designs are shown in Appendix 2.

6.6.3 Instrumentation

The vehicles were instrumented by Ford Motor Company Ltd., such that an LED digital readout of the vehicle speed shown on the speedometer was provided in the rear passenger seat. Attempts to use the Apple computer in the vehicle to record responses was abandoned after the pilot studies indicated that constant power could not be provided.

6.6.4 Light measurement

The light coming in through the windscreen, and also the light falling on the instrument panel was measured by two detector/filter combinations fixed to the windscreen and to the dashboards. The detector/filters produce a spectral response which duplicates the human eye (C.I.E. standard photopic curve).

6.6.5 Questionnaire and response sheets

A questionnaire was designed to collect demographic details about the subjects, e.g. age, sex, driving experience; and to record drivers' preferences and opinions regarding the display designs. Unlike Studies 1 and 2 in which drivers stated which display design was best and worst on a particular criterion, in Study 3 drivers stated which of the two display designs they had tested were better on particular criteria such as ease of reading and attractiveness. Each driver, therefore, compared an electronic design with the electromechanical display. Subjects also gave their comments on the designs based on their experience while using them during the road trials. The questionnaire was completed by the subjects at the end of the road trials. The questionnaire is shown in Appendix 3.

The response sheets were designed to record information during the road trials, and included information on street lighting, speed limits and land marks along the test route. The experimenter noted on the response sheets the illuminance, the actual vehicle speed (from the LED digital speed readout) and the drivers' responses (a speed reading or whether the speed was above or below the speed limit).

Additional questions concerning the effects of light from the sun and from headlights on the visibility of the instrument panel display were also included on the response sheets.

6.6.6. Other equipment

MAVIS Master Vision Screener

ISHIHARA colour vision test

Recording schedules for MAVIS and the Ishihara test (see Appendix 3).

6.6.7 Test route

A 40 km (25 mile) test route was devised local to Loughborough which included the following features:-

Roads	motorway
	dual carriageway
	single carriageway main roads
	residential roads
	country lanes
Lighting	lit streets in a town and city with shop lighting
	lit streets without other lighting
	unlit streets
Speed limits	30 m.p.h.
	40 m.p.h.
	50 m.p.h.
	60 m.p.h.
	70 m.p.h.

The route also included the city of Leicester, the town of Loughborough and urban and rural driving conditions.

A diagram of the test route is shown in Appendix 6.

6.7 Procedure

The project was described briefly to each subject and the test route described using a map. The following measurements were then taken:

near and distance vision, and stereopsis using the MAVIS Master Vision Screener

colour vision using the Ishihara test.

The results were noted on the recording schedule.

Two subjects failed to reach the Department of Transport minimum eyesight standard and were rejected from the sample for safety reasons.

Two subjects were tested at a time. Each subject drove one of the cars in one direction on the test route and returned in the other car. The order in which each subject saw each car was devised such that each vehicle was seen first or second an equal number of times. At the beginning of each trial the subjects were shown the principles of driving an automatic transmission car and were familiarised with the position of the controls and displays by an expert driver. The subjects were given practice in driving the vehicles and in making the appropriate responses to the two experimental tasks. When the expert drivers were satisfied that the subject was driving normally the experiment commenced. One subject who could not satisfactorily master the vehicle controls and whose driving was considered unsafe was not tested further. Route guidance was also given by the expert driver. The subjects drove the vehicle along the test route and at specific points along the route they were required by the experimenter to state:

A - the speed shown on the speedometer (10 readings per driver per display)

or B - whether the speed was above the current speed limit (15 readings per driver per display, 5 at 30 m.p.h., 5 at 60 m.p.h. and 5 at 70 m.p.h.)

In task B the experimenter told the subject what was the current speed limit to ensure that incorrect responses were due to incorrect reading of the instruments rather than ignorance of the current speed limit.

The experimenter recorded the subjects' responses and the actual vehicle speed shown on the LED digital speed readout provided for the experimenter in the back of the car.

At appropriate points in the experiment, depending on weather conditions and lighting conditions, the subject was asked questions about the instrument panel designs.

The subjects exchanged vehicles at a halfway point along the route and retraced the route in the other vehicle. The experimental procedure was repeated on the return journey. Thus each subject drove a vehicle containing an electronic display and one containing a standard electromechanical display along the same route, in the same lighting conditions.

The subject then completed the questionnaire with reference to a flash card containing photographs of the instrument panel designs.

The experiment took 1½ - 2 hours to complete.

Appendix 6 shows the experiment in progress.

6.8 Data handling and analysis

Data on drivers' preferences and opinions, demographic data and the performance measures were analysed by hand. In each of the three tests the electromechanical dial display acted as the control. The results are, therefore, in a different form to those reported in Studies 1 and 2 of the research programme. Whereas, in the earlier studies all the subjects compared all of the display designs, in Study 3 one third of the subjects compared each of the three electronic instrument panel designs with the standard electromechanical dial display.

The performance data analyses comprised:

Task A - direction and extent of speed reading errors.

Task B - response error.

These data were analysed for each instrument panel design for each subject. The data were then amalgamated to provide data for each design. Drivers' comments on the display designs were also recorded.

6.9 Results

6.9.1 Introduction

In this study each driver compared only one electronic display design with an electromechanical display design. In Studies 1 and 2 drivers compared all the display designs.

Studies 1 and 2 were also conducted under controlled laboratory conditions using photographic representations or dynamic models in a vehicle simulator. Study 3 was conducted in road conditions in standard vehicles. Although some of the limitations of laboratory tests are overcome in road trials there are other factors which should be borne in mind when interpreting the results. The most obvious feature is that in road trials the main task is clearly driving and all other aspects of the experiment must be subsumed to the safety of the vehicle occupants and other road users. Hence it was not always possible to carry out all the tasks or at exactly the same locations on the test route for all subjects. There was considerable variation in traffic conditions for different trials even though attempts were made to remedy this by avoiding certain times when the traffic was known to be heavy such as at rush hour. The lighting conditions were controlled in as much as experiments were not conducted at times when the light would vary markedly during the experiment such as at dusk. However, during the trials as the seasons and weather conditions changed the light experienced by the drivers varied greatly, but only as it would do in normal driving. The weather conditions varied through the trials from snow and fog in winter to very bright sunlight in summer. The driving characteristics of the subjects also made a difference to their experience of the designs. Some subjects were very slow, cautious drivers who did not often experience the rapid rate of change of display readings which the more enthusiastic, fast drivers did. The characteristics of the electronic displays were not exactly the same because the electronic dial display represented the best LCD technology available in 1978, whereas the electronic curvilinear display represented the best LCD technology available in 1980. As no LCD technology was available in 1981 with which to produce the 25 mm digits for the digital display tungsten filament digits had to be employed. The amount of control which can be exerted over an experiment reduces as the experiment approaches reality, hence in road trials not all the conditions were controllable.

In the tables which follow, the results for the electromechanical dial display are presented separately for each of the electronic display designs.

6.9.2 Objective measures

6.9.2.1 Reading the speed

Table 6.1 indicates the accuracy with which subjects were able to read the speed for each display design.

Table 6.1 Accuracy of reading the speed

DISPLAY	ACCURACY SCORE (1)					
DAY	± 2 mph freq.	%	± 3 to 5 mph freq.	%	± over 5 mph freq.	%
Electronic dial	285	68	122	29	13	3
E-M(2) dial (n=420)	370	88	50	12	0	0
Electronic Curvilinear	349	85	53	13	8	2
E-M dial (n=410)	369	90	33	8	8	2
Electronic Digital	500	100	0	0	0	0
E-M dial (n=500)	475	95	20	4	5	1
NIGHT						
Electronic dial	200	74	65	24	5	2
E-M dial (n=270)	141	52	113	42	16	6
Electronic Curvilinear	196	85	32	14	2	1
E-M dial (n=230)	182	79	46	20	2	1
Electronic Digital	200	100	0	0	0	0
E-M dial (n=200)	190	95	10	5	0	0

See Figures 6.1 and 6.2

(1) The score was calculated from the drivers' response and the actual vehicle speed shown on the LED digital readout.

(2) E-M dial = Electromechanical dial display.

It can be seen from Table 6.1 that:

1. All of the speed readings in both day and night conditions were correct to within $\pm$ 2 mph with the electronic digital display.

2. Under daytime conditions the electromechanical dial display was read more accurately than the two electronic analogue displays. However, at night time this trend was reversed and the electromechanical dial display was read less accurately than the electronic analogue displays.

3. Of the two electronic analogue displays in both day and night conditions the electronic curvilinear display was read more accurately than the electronic dial display (85% (day and night) within $\pm$ 2 mph curvilinear, 68% (day) and 74% (night) dial).

4. The electronic dial display performed worst of the three electronic displays in both day and night conditions.

5. The electronic curvilinear and digital displays did not show any change in accuracy of reading in day and night conditions. However, the electronic dial display performance improved slightly in the night trials and the electromechanical dial display performed less well in the night trials with the electronic dial display.

6. The performance of the electronic curvilinear display was most noteworthy when comparing the results of Study 3 with Study 2. In the road trials the electronic curvilinear performed extremely well with 85% of responses correct to within $\pm$ 2 mph in both trials. The digital display maintained a very high level of accuracy and in both day and night conditions. All the display designs were read more accurately in the road trials than they were in the vehicle simulator trials.

6.9.2.2 Deciding whether the speed was within a speed limit.

Table 6.2. The number of errors made when deciding whether the speed was within a speed limit.

Table 6.2 The number of errors made when deciding whether the speed was within a speed limit

DISPLAY	ERROR		CORRECT	
DAY	freq	%	freq	%
Electronic dial	13	2	617	98
E-M dial	0	0	630	100
(n=630)				
Electronic Curvilinear	12	2	603	98
E-M dial	6	1	609	99
(n=615)				
Electronic Digital	0	0	750	100
E-M dial	0	0	750	100
(n=750)				
NIGHT				
Electronic dial	4	1	401	99
E-M dial	8	2	397	98
(n=405)				
Electronic Curvilinear	10	3	335	97
E-M dial	3	1	342	99
(n=345)				
Electronic Digital	6	2	294	98
E-M dial	6	2	294	98
(n=300)				

It can be seen from Table 6.2 that the number of errors made by the drivers was very small when checkreading the speed against the current speed limit. There was no difference in scores between any of the electronic displays and the electromechanical dial display in either day or night time conditions.

6.9.3 Subjective measures

Drivers were asked to state which of the two displays they considered easier to read; easier to decide whether the speed was within a speed limit; less distracting while driving; more attractive; which they would choose for their own car and which they prefered overall. In addition drivers made comments about the displays.

6.9.3.1 The display designs considered by the subjects to be the easier to read the speed

Table 6.3 The displays considered by the subjects to be the easier to read

DISPLAY	EASIER TO READ				ELECTRONIC DISPLAYS RANK ORDER EASIER	
	DAY		NIGHT			
	freq.	%	freq.	%	Day	Night
ELECTRONIC DIAL	9	21	16	59		
ELECTROMECHANICAL DIAL	32	76	6	22	3	2
NEITHER (Day n = 42) (Night n = 27)	1	3	5	19		
ELECTRONIC CURVILINEAR	16	38	10	43		
ELECTROMECHANICAL DIAL	20	48	11	48	2	3
NEITHER (Day n = 41) (Night n = 23)	5	14	2	9		
ELECTRONIC DIGITAL	44	88	19	95		
ELECTROMECHANICAL DIAL	6	12	1	5	1	1
NEITHER (Day n = 50) (Night n = 20)	0	0	0	0		

See Figures 6.3 and 6.4

χ^2crit = 3.84
df = 1
excluding 'neither'

A χ^2 = 12.9
p < 0.05
B χ^2 = 0.44 NS
C χ^2 = 28.88
p < 0.05

A χ^2 = 4.54
p < 0.05
B χ^2 = 0.04 NS
C χ^2 = 16.2
p < 0.05

It can be seen from Table 6.3 that:

1. The electronic digital display was considered easier to read than the electromechanical dial display by the vast majority of subjects who took part in the day (88%) and the night time (95%) tests.

2. With the exception of the night trials with the electronic dial display, the electromechanical dial display was considered easier to read than the electronic analogue displays.

3. Of the electronic analogue displays the electronic curvilinear display was considered easier to read by the greater percentage of subjects in the day time tests, but the electronic dial display was considered easier by the greater percentage of subjects in the night time tests.

4. Of the two analogue dial displays the electromechanical design was considered easier to read in the day and the electronic design easier to read in the night trials.

5. When compared with the electronic digital display the electromechanical dial display performed very badly on ease of reading (12% and 5%).

6. Only the electronic and electromechanical dial display results altered in the different lighting conditions of day and night trials. The positions were reversed from day when the electromechanical was preferred to the night when the electronic dial was preferred for ease of reading. The results for the other displays did not alter.

7. The electronic digital display was still considered easiest to read by the larger group of subjects even in the road trials of Study 3 compared with Study 2.

6.9.3.2 The display designs considered by the subjects to be the easier to decide whether the speed was within a speed limit

Table 6.4 The displays considered by the subjects to be easier to decide whether the speed was within a speed limit

DISPLAY	EASIER TO DECIDE WHETHER WITHIN SPEED LIMITS				ELECTRONIC DISPLAYS RANK ORDER EASIER	
	DAY		NIGHT			
	freq.	%	freq.	%	Day	Night
ELECTRONIC DIAL	7	17	17	63		
ELECTROMECHANICAL DIAL	28	66	A 7	26	3	2
NEITHER (Day n = 42) (Night n = 27)	7	17	3	11		
ELECTRONIC CURVILINEAR	18	43	13	56		
ELECTROMECHANICAL DIAL	15	36	B 9	39	2	3
NEITHER (Day n = 41) (Night n = 23)	8	21	1	5		
ELECTRONIC DIGITAL	33	66	14	70		
ELECTROMECHANICAL DIAL	10	20	C 4	20	1	1
NEITHER (Day n = 50) (Night n = 20)	7	14	2	10		

See Figures 6.5 and 6.6 A $\chi^2 = 12.6$ $p < 0.05$ B $\chi^2 = 0.28$ NS C $\chi^2 = 12.30$ $p < 0.05$ A $\chi^2 = 4.16$ $p < 0.05$ B $\chi^2 = 0.81$ NS C $\chi^2 = 5.56$ $p < 0.05$

$\chi^2_{crit} = 3.84$
df = 1
excluding 'neither'

It can be seen from Table 6.4 that:-

1. The electronic digital display was judged to be the easier to use when checking the speed against a speed limit by the majority of drivers in both day and night trials.

2. With the exception of the daytime trials with the electronic dial display the electromechanical dial display always performed worse than the electronic displays on ease of check reading against a speed limit.

3. Of the electronic analogue designs the curvilinear display performed better than the dial in day time trials. The position was reversed in night time trials with a slightly greater percentage of subjects considering the dial display easier.

4. Of the two analogue dial displays the electromechanical design was considered easier for check reading the speed against a speed limit in the day and the electronic design easier in the night time trials.

5. It is interesting to note that only 43% (day) and 56% (night) of subjects considered the electronic curvilinear design easier for check reading even though on this design the segments changed from green to amber above 30 mph. In fact 21% (day) of subjects felt that neither of the two designs in that trial were easier for check reading against a speed limit.

6. When compared with the electronic digital display the electromechanical dial display performed poorly on ease of check reading (20% in both day and night trials).

7. As with ease of reading the speed, only the electronic and electromechanical dial display results were different in the day and night trials. In the day time trials the electromechanical dial scored higher (66%) and in the night trials the electronic dial scored higher (63%).

8. When comparing the results in Study 3 with Study 2 it is clear that the electronic digital display maintained its position as the easiest display to use for check reading speeds in the road trials.

6.9.3.3 The display design considered by the subjects to distract attention while driving

Table 6.5 The displays considered by the subjects to distract attention while driving

DISPLAY	CAUSES DISTRACTION WHILE DRIVING				ELECTRONIC DISPLAYS* RANK ORDER LEAST DISTRACTING	
	DAY		NIGHT			
	freq.	%	freq.	%	Day	Night
ELECTRONIC DIAL	13	31	7	26		
ELECTROMECHANICAL DIAL	1	2	A 3	11	3	2
NEITHER (Day n = 42) (Night n = 27)	28	67	17	63		
ELECTRONIC CURVILINEAR	10	24	11	48		
ELECTROMECHANICAL DIAL	1	2	B 1	4	2	1
NEITHER (Day n = 41) (Night n = 23)	30	74	11	48		
ELECTRONIC DIGITAL	7	14	5	25		
ELECTROMECHANICAL DIAL	0	0	C 2	10	1	3
NEITHER (Day n = 50) (Night n = 20)	43	86	13	65		

* The majority of subjects considered NEITHER display distracting

A $\chi^2 = 26.14$ $p < 0.05$ A $\chi^2 = 11.55$ $p < 0.05$

See Figures 6.7 and 6.8   B $\chi^2 = 32.19$ $p < 0.05$ B $\chi^2 = 8.7$ $p < 0.05$

$\chi^2_{crit} = 5.99$

df = 2 including 'neither'   C $\chi^2 = 63.87$ $p < 0.05$ C $\chi^2 = 8.7$ $p < 0.05$

It can be seen from Table 6.5 that:-

1. The majority of drivers in all the test conditions, except the night trials with the electronic curvilinear display, considered that neither the electronic nor the electromechanical display distracted attention while driving.

2. In all the trials the electronic displays were considered to distract attention by a greater percentage of the subjects than the electromechanical dial display.

3. In the day time trials, of the electronic analogue designs, the curvilinear display performed better than the dial display. This was reversed in the night trials with nearly half the subjects reporting that the curvilinear design was distracting.

4. Of the two analogue dial displays the electronic design was considered distracting by the greatest percentage of subjects in both day and night trials.

5. When comparing the electronic designs it is interesting to note that the smallest percentage of drivers considered the electronic digital display to be distracting (14% (day) and 25% (night)).

6. The electronic curvilinear display in night time conditions performed least well of the display designs. Nearly half the subjects considered it to be distracting.

7. Both the electronic digital display and the electronic curvilinear display were considered distracting by a larger percentage of subjects in the night trials as compared with the day time trials.

8. The electromechanical dial display was considered least distracting in Study 2 and this was clearly maintained in Study 3. Of the electronic designs in Study 2 the digital display was considered least distracting (22%) and most distracting (38%) by the largest group of subjects. In Study 3 the smallest percentage of subjects considered the digital display distracting although the proportion increased from 14% in the day trials to 25% in the night trials. (Study 2 was conducted in night time conditions).

6.9.3.4 The display designs considered by the subjects to be the more attractive

Table 6.6 The displays considered by the subjects to be the more attractive

DISPLAY	ATTRACTIVE				ELECTRONIC DISPLAYS RANK ORDER ATTRACTIVE	
	DAY		NIGHT			
	freq.	%	freq.	%	Day	Night
ELECTRONIC DIAL	22	52	20	74		
ELECTROMECHANICAL DIAL	15	36	6	22	3	1
NEITHER (Day n = 42) (Night n = 27)	5	12	1	4		
ELECTRONIC CURVILINEAR	27	67	12	52		
ELECTROMECHANICAL DIAL	8	19	9	39	1	3
NEITHER (Day n = 41) (Night n = 23)	6	14	2	9		
ELECTRONIC DIGITAL	31	62	13	65		
ELECTROMECHANICAL DIAL	13	26	4	20	2	2
NEITHER (Day n = 50) (Night n = 20)	6	12	3	15		

See Figures 6.9 and 6.10

χ^2 crit = 3.84
df = 1 excluding 'neither'

A χ^2 = 1.32 NS
B χ^2 = 10.32
$p < 0.05$
C χ^2 = 7.36
$p < 0.05$

A χ^2 = 7.54
$p < 0.05$
B χ^2 = 0.42 NS
C χ^2 = 4.78
$p < 0.05$

It can be seen from Table 6.6 that:-

1. The majority of subjects in both the day and night conditions considered the electronic displays to be more attractive than the electromechanical display.

2. Of the electronic analogue designs the dial display was preferred by a greater percentage (74%) of subjects at night and the curvilinear display was preferred by a greater percentage (67%) of subjects in day time conditions.

3. Comparing the two analogue dial designs the electronic display was preferred to the electromechanical display in both day and night conditions. The preference was more marked in the night trials.

4. The curvilinear design was considered attractive by slightly more (67%) subjects in the day time trials than the digital display (62%). However, in the night trials the digital display was considered more attractive by a larger percentage (65%) of subjects than the curvilinear display (52%).

5. The electronic dial and digital displays were considered attractive by a larger percentage of subjects in the night trials. The electronic curvilinear display was considered attractive by the larger percentage of subjects in the day time trials.

6. The electronic curvilinear design was considered most attractive in Study 2 (39%) although a large percentage of subjects (30%) considered it least attractive. Study 2 took place in night conditions and used a different display technology. In Study 3 in day light the electronic curvilinear was considered attractive by the largest percentage of subjects (67%). However in the night conditions of Study 3 the electronic dial display was considered attractive by the largest percentage of subjects (74%) and the curvilinear design by the smallest percentage of subjects (52%).

6.9.3.5 The display designs which the subjects stated they would choose for their own cars

Table 6.7 The displays considered by the subjects to be the ones which they would choose for their own cars

DISPLAY	CHOICE FOR OWN CAR				ELECTRONIC DISPLAYS RANK ORDER CHOICE	
	DAY freq.	DAY %	NIGHT freq.	NIGHT %	Day	Night
ELECTRONIC DIAL	9	22	12	44		
ELECTROMECHANICAL DIAL	27	64	8	30	3	3
NEITHER (Day n = 42) (Night n = 27)	6	14	7	26		
ELECTRONIC CURVILINEAR	18	45	11	48		
ELECTROMECHANICAL DIAL	15	36	10	44	2	2
NEITHER (Day n = 41) (Night n = 23)	8	19	2	8		
ELECTRONIC DIGITAL	37	74	15	75		
ELECTROMECHANICAL DIAL	7	14	3	15	1	1
NEITHER (Day n = 50) (Night n = 20)	6	12	2	10		

See Figures 6.11 and 6.12

χ^2crit = 3.84
df = 1
excluding 'neither'

A χ^2 = 9.0 $p < 0.05$
B χ^2 = 0.28NS
C χ^2 = 20.46 $p < 0.05$

A χ^2 = 0.8NS
B χ^2 = 0.04NS
C χ^2 = 8.0 $p < 0.05$

It can be seen from Table 6.7 that:-

1. Three quarters (74% and 75%) of subjects in the day and night trials with the electronic digital display stated that they would choose it for their own car.

Only 14% (day) and 15% (night) stated that they would choose the electromechanical dial display.

2. With the exception of the daytime trials with the electronic dial display, the electronic designs were preferred by the greater percentage of subjects compared with the electromechanical dial display.

3. Of the electronic analogue designs the curvilinear display was preferred by a slightly higher percentage of drivers in the day and night tests compared with the electronic dial display. The electronic dial display performed poorly in the daytime trials.

4. Of the analogue dial designs the electromechanical dial would be chosen for their own car by a greater percentage (64%) of drivers in the daytime trials and the electronic dial in the night time trials (44%).

5. Less than a quarter of subjects would choose the electronic dial display, in the daytime trials. Compared with the electronic digital design only 14% (day) and 15% (night) of subjects would choose the electromechanical dial display for their own car.

6. The electronic dial display performed considerably better under night time conditions than daytime conditions. The other two electronic displays did not change in peformance between day and night trials.

7. The electronic digital display maintained its position in Study 3 as the design which the largest percentage of drivers would choose for their own car. Three quarters of the drivers who tested it in comparison with the electromechanical dial display stated that they would choose it for their own car.

6.9.3.6 The display designs which the subjects stated they preferred overall

Table 6.8 The displays which drivers stated they preferred overall

DISPLAY	GENERAL PREFERENCE DAY freq.	%		NIGHT freq.	%	ELECTRONIC DISPLAYS RANK ORDER PREFERENCE Day	Night
ELECTRONIC DIAL	9	22		15	55		
ELECTROMECHANICAL DIAL	31	71	A	11	41	3	2
NEITHER (Day n = 42) (Night n = 27)	3	7		1	4		
ELECTRONIC CURVILINEAR	17	42		11	48		
ELECTROMECHANICAL DIAL	18	43	B	11	48	2	3
NEITHER (Day n = 41) (Night n = 23)	6	15		1	4		
ELECTRONIC DIGITAL	36	72		16	80		
ELECTROMECHANICAL DIAL	9	18	C	4	20	1	1
NEITHER (Day n = 50) (Night n = 20)	5	10		0	0		

See Figures 6.13 and 6.14

χ^2crit = 3.84
df = 1
excluding 'neither'

A $\chi^2 = 12.10$
$p < 0.05$
B $\chi^2 = 0.28$ NS
C $\chi^2 = 16.2$
$p < 0.05$

A $\chi^2 = 0.62$ NS
B $\chi^2 = 0$
C $\chi^2 = 7.2$
$p < 0.05$

It can be seen from Table 6.8 that:-

1. The electronic digital display was clearly preferred by a large percentage (72% and 80%) of the drivers, in both day and night trials. The electromechanical dial display was also preferred by a high percentage (71%) of drivers in the day time trials with the electronic dial display.

2. There was no consistent preference for or against the electromechanical dial display in the trials. It was preferred in the daytime trials with the electronic dial display but not in the night trials. There was no difference between the preferences for either the electromechanical dial display or the electronic curvilinear display in the day or night trials. The electronic digital display was clearly preferred to the electromechanical dial display in both day and night trials.

3. The only outstanding feature, when comparing the electronic analogue designs was the very small percentage (22%) of drivers who preferred the electronic dial display in the day time trials. In the other trials there was little difference between preferences for the designs.

4. Of the analogue dial designs the electromechanical dial was preferred by a large percentage of drivers (71%) in the day time trials, but there was little difference between the dial designs in the night trials.

5. Less than a quarter of drivers preferred the electronic dial display in the day time trials. Only 18% and 20% of drivers preferred the electromechanical dial display when compared with the electronic digital display in both the day and night trials.

6. The percentage of subjects who preferred the electronic dial display increased from 22% in the day time trials to 55% in the night time trials. The percentage of drivers who preferred the electromechanical dial display dropped from 71% in the day time trials to 41% in the night trials. Otherwise the percentage of subjects preferring each design did not change substantially between the day and night trials.

7. General preference was not included in Study 2 hence no comparison can be made between the findings.

Table 6.9 is a summary table indicating the relative scores for each display design on both the drivers' preferences and the performance measures. The results for Studies 1 and 2 cannot be compared directly because in the earlier studies each subject compared five (Study 1) or four (Study 2) designs whereas in Study 3 each subject only compared an electronic design with the electromechanical design.

Table 6.9 SUMMARY TABLE indicating how the displays scored on each of the measures in Study 3

	DAY					
OBJECTIVE MEASURES	ELECTRONIC DIAL	E-M(3) DIAL	ELECTRONIC CURVILINEAR	E-M DIAL	ELECTRONIC DIGITAL	E-M DIAL
Reading the speed		●(2)		●	●	
Is the speed within a speed limit?	no difference		no difference		no difference	
SUBJECTIVE MEASURES(1)						
Easier to read		●		●	●	
Easier for speed limits		●	●		●	
Causes distraction	neither		neither		neither	
More attractive	●		●		●	
Would choose		●	●		●	
General preference		●	no difference		●	
OBJECTIVE MEASURES	NIGHT					
Reading the speed	●		●		●	
Is the speed within a speed limit?	no difference		no difference		no difference	
SUBJECTIVE MEASURES						
Easier to read	●			●	●	
Easier for speed limits	●		●		●	
Causes distraction	neither		● or neither		neither	
More attractive	●		●		●	
Would choose	●		●		●	
General preference	●		no difference		●	

(1) Only the positive side of the scale is shown

(2) ● indicates which display performed better on each measure except 'Causes distraction'. A ● on this measure indicates which design was considered to cause distraction while driving

(3) E-M = Electromechanical dial display

6.9.4 Characteristics of the sample

The samples for each test were chosen to provide approximately equal numbers of subjects of both sexes and in three age groups.

Table 6.10 indicates the age and sex of the subjects included in the study.

Table 6.10 Age and sex of the subjects

AGE (years)	SEX		TOTAL %
	MALE %	FEMALE %	
21 - 30	22	14	36
31 - 50	22	20	42
51 and over	14	8	22
TOTAL (n=204)	58	42	100

As was found in Study 2 the variation in numbers between cells indicates the relative availability of drivers. This was exacerbated by the fact that in Study 3 road trials were undertaken. This meant that subjects had to exhibit their driving skills. Some subjects were only too willing to show how 'well' they could drive but others were less willing and did not agree to take part. This latter attitude was most common among women drivers particularly the older and younger age group. The women drivers, especially in the oldest age group were unwilling to take part in the night trials as many of them normally avoided driving at night.

The MAVIS Master Vision Screener was used to test subjects' eyesight. All the tests were carried out with the subject wearing driving spectacles if they were usually worn. The Ishihara test for colour vision was also carried out. A minimum standard comparable to the Department of Transport requirements was demanded. Two subjects failed to reach this standard.

Table 6.11 summarises the results of the eyesight tests.

Table 6.11 Subjects' eyesight test results

VISION TESTS	% (n = 204)
ISHIHARA TEST	
COLOUR VISION	
Normal	96
Red/green deficiency	4
Total deficiency	0
MAVIS TEST	
DISTANCE ACUITY GOOD	79
NEAR ACUITY GOOD	69
DISTANCE STEREOPSIS (1)	
Good	29
Moderate	39
Poor	32
NEAR STEREOPSIS (2)	
Good	84
Moderate	0
Poor	16
OBSERVATION	
SPECTACLES WORN WHEN DRIVING (not bifocal)	31
BIFOCALS WORN WHEN DRIVING	6

(1) Good = 50 seconds of arc stereo-acuity
Moderate = 400 seconds of arc stereo-acuity
Poor = 500 seconds of arc, or over, stereo acuity

(2) Good = 50 seconds of arc stereo-acuity
Moderate = 75 seconds of arc stereo-acuity
Poor = 195 seconds of arc, or over, stereo-acuity

(from the Interpretation of master Vision Screener Records)

It can be seen from Table 6.11 that:-

1. Only 4% of the sample had any problem with colour vision, slightly less than the percentage in the general population.

2. 79% of the sample had what the MAVIS test interprets as good distance acuity.

3. 69% of the sample had good near acuity, in spite of the fact that this test was carried out with subjects wearing distance corrected spectacles if they normally wore them for driving.

4. 31% of the sample wore spectacles while driving and 6% wore bifocal lens spectacles.

A review of drivers' visual acuity is given in Davison and Irving (1980), see also Section 5.9.2.

Table 6.12 indicates the number of years since the people in the sample had passed their driving test. These data give an approximate indication of driving experience.

Table 6.12 The number of years since the subjects had passed their driving test

TIME SINCE TEST PASSED	%
Less than 1 year	1
1 - 3 years	6
4 - 8 years	22
9 - 17 years	37
18 - 34 years	26
35 years or over	5
No test taken	2
TOTAL (n = 204)	100

It can be seen from Table 6.12 that:-

1. The majority (70%) of subjects had been driving for 9 years or more.

2. Only 1% had been driving for less than one year and 6% for between one and three years which is to be expected with the minimum age of 21 years for inclusion in the sample for insurance reasons.

6.9.5 The test results for each display design

In the preceding sections the test results have been presented in terms of the performance of each electronic display when compared with the electromechanical dial display, on a particular criterion. In this section all the results for each display are presented.

The drivers' preferences and opinions were recorded in two forms. These were drivers' opinions about which of the two display designs was better on a number of criteria such as ease of reading, attractiveness and so on; and also drivers' comments about the displays expressed in his/her own words. The comments are summarised for each display in this section.

6.9.5.1 The electromechanical dial display test results

The electromechanical dial display was used as the comparison design throughout the trials. Therefore the results are presented separately for each of the comparison trials.

Table 6.13 The electromechanical dial display test results - objective measures

Table 6.13.1 Comparison with the electronic dial display

OBJECTIVE MEASURES	ELECTROMECHANICAL DIAL/ ELECTRONIC DIAL ACCURACY SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
<u>Reading the speed</u>						
Response correct to:						
± 2 mph	370	88	141	52	511	74
± 3 to 5 mph	50	12	113	42	163	24
± over 5 mph	0	0	16	6	16	2
<u>Deciding whether speed was within a speed limit</u>						
Correct responses	630	100	397	98	1027	99
Incorrect responses	0	0	8	2	8	1

Number of responses:

Reading speed	Day	= 420
	Night	= 270
	Total	= 690
Within speed limit	Day	= 630
	Night	= 405
	Total	= 1035

Table 6.13.2 Comparison with the electronic curvilinear display

OBJECTIVE MEASURES	ELECTROMECHANICAL DIAL/ ELECTRONIC CURVILINEAR ACCURACY SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Reading the speed						
Response correct to:						
± 2 mph	369	90	182	79	551	86
± 3 to 5 mph	33	8	46	20	79	12
± over 5 mph	8	2	2	1	10	2
Deciding whether speed was within a speed limit						
Correct responses	609	99	342	99	951	99
Incorrect responses	6	1	3	1	9	1

Number of responses:

Reading speed	Day	= 410
	Night	= 230
	Total	= 640
Within speed limit	Day	= 615
	Night	= 345
	Total	= 960

Table 6.13.3 Comparison with the electronic digital display

OBJECTIVE MEASURES	ELECTROMECHANICAL DIAL/ ELECTRONIC DIGITAL ACCURACY SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
<u>Reading the speed</u>						
Response correct to:						
± 2 mph	475	95	190	95	665	95
± 3 to 5 mph	20	4	10	5	30	4
± over 5 mph	5	1	0	0	5	1
<u>Deciding whether speed was within a speed limit</u>						
Correct responses	750	100	294	98	1044	99
Incorrect responses	0	0	6	2	6	1

Number of responses:

Reading speed	Day	= 500
	Night	= 200
	Total	= 700
Within speed limit	Day	= 750
	Night	= 300
	Total	= 1050

Table 6.14 The electromechanical dial display test results - subjective measures

Table 6.14.1 Comparison with the electronic dial display

SUBJECTIVE MEASURES	ELECTROMECHANICAL DIAL/ ELECTRONIC DIAL PREFERENCE SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Easier to read	32	76	6	22	38	55
Easier to decide whether within speed limits	28	66	7	26	35	51
Causes distraction while driving	1	2	3	11	4	6
More attractive	15	36	6	22	21	30
Would choose for own car	27	64	8	30	35	51
General preference	31	71	11	41	42	61

Sample size Day = 42
Night = 27
Total = 69

Table 6.14.2 Comparison with the electronic curvilinear display

SUBJECTIVE MEASURES	ELECTROMECHANICAL DIAL/ ELECTRONIC CURVILINEAR PREFERENCE SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Easier to read	20	48	11	48	31	48
Easier to decide whether within speed limits	15	36	9	39	24	38
Causes distraction while driving	1	2	1	4	2	3
More attractive	8	19	9	39	17	27
Would choose for own car	15	36	10	44	25	39
General preference	18	43	11	48	29	45

Sample size Day = 41
Night = 23
Total = 64

Table 6.14.3 Comparison with the electronic digital display

SUBJECTIVE MEASURES	ELECTROMECHANICAL DIAL/ ELECTRONIC DIGITAL PREFERENCE SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Easier to read	6	12	1	5	7	10
Easier to decide whether within speed limits	10	20	4	20	14	20
Causes distraction while driving	0	0	2	10	2	3
More attractive	13	26	4	20	17	24
Would choose for own car	7	14	3	15	10	14
General preference	9	18	4	20	13	19

Sample size Day = 50
Night = 20
Total = 70

The electromechanical dial display - summary of results

The electromechanical dial display was included to act as a bench mark against which the test results for the three electronic displays could be assessed. Each driver compared an electronic display design directly with the electromechanical display design. Drivers' responses to the electromechanical dial display will reflect their response to the electronic display design with which it was being compared. Therefore, it is not alway possible to draw general conclusions about the performance of the electromechanical dial display. However, there were a number of features about the display design which are indicated by the test results and in particular, by the drivers' comments. These are reported below.

1. Under daytime lighting conditions the electromechanical dial display was read accurately (within $\pm$ 2 mph) by a greater number of drivers than either of the electronic analogue display designs. This trend was reversed in the night trials. Drivers' comments indicate that the electromechanical dial display was seen more clearly in the day time because unlike the LCD designs there was no washout effect. However, at night the electromechanical dial display appeared dimly lit compared with the LCD electronic displays.

2. All the display designs including the electromechanical dial were accurately check read against the current speed limit.

3. With the exception of the night trials with the electronic dial display the electromechanical dial display was considered easier to read than the electronic analogue designs. Drivers' comments on the relative brightness of the displays in day and night lighting also influences the perceived ease of reading, although the electromechanical dial display was still considered easier to read in the night trials compared with the electronic curvilinear design.

4. With the exception of the daytime trials with the electronic dial display the electromechanical dial display always performed worse than the electronic displays on ease of check reading against a speed limit.

5. The majority of subjects in all the test conditions except the night trials with the electronic curvilinear display considered that neither the electromechanical nor the electronic displays distracted attention while driving. In all the trials the electromechanical dial display was considered to distract attention by a smaller percentage of the subjects than the electronic display designs.

6. In both the day and night trials only a minority of subjects considered the electromechanical dial display to be more attractive than the electronic display with which it was compared.

7. The majority of subjects (64%) stated they would choose the electromechanical dial display for their own car in the day time tests with the electronic dial display. In all the other tests the electronic designs were preferred on choice for own car.

8. There was no consistent general preference for or against the electromechanical dial display in the road trials. It was preferred in the day time trials with the electronic dial display but not in the night trials. There was no difference between the preferences for either the electromechanical dial or the electronic curvilinear display in the day or night trials. The electronic digital display was clearly preferred to the electromechanical dial display in both day and night trials.

9. In terms of accuracy of using the electromechanical dial display in road trials, there was a marked improvement in accuracy of reading the speed in the day time trials (88% with within $\pm$ 2 mph) compared with Study 2. However, in the night time trials which were more like the lighting conditions in Studies 1 and 2, there was no real change in accuracy (64% Study 1, 47% Study 2, 52% Study 3). All the display designs were used accurately to check read against speed limits in the road trials and a marked improvement was shown when compared with the results of Study 2 (68% correct Study 2, 99% correct Study 3). The design was also used accurately for check reading in Study 1 (92% correct).

10. The performance of the electromechanical dial display on preference measures was much influenced by the drivers' responses to the electronic comparison display, and by the lighting conditions (day or night trials). The relative brightness of the designs influenced a number of the preference measures. The electromechanical dial display was not affected by washout which reduced the brightness of the LCD displays in bright daylight. At night, when the electronic displays were bright the electromechanical dial display appeared dimly lit. Hence no clear pattern emerges for the electromechanical dial display throughout the trials which can be compared with the earlier studies. The electromechanical dial display was responded to more positively by drivers in the dynamic test conditions of the vehicle simulator trials (Study 2) compared with the tachistoscopic tests of Study 1. However in the road trials the advantages which the electromechanical dial display exhibited in terms of drivers' familiarity with the general style of the display were often overshadowed by the novelty or exceptionally high performance of the electronic displays. This is apparent in the day/night reversal of driver opinion when tested with the electronic dial display. The electronic dial display was a very clear, bright display at night. It is also most apparent when compared with the outstanding performance of the electronic digital display.

Electromechanical dial display - summary of drivers' comments

- In general drivers considered the electromechanical dial display to be rather ordinary, fussy, and confusing.

- The dials were considered to be too far apart for easy scanning.

- Many drivers remarked on the obscuration of the dials, particularly the speedometer, by the steering wheel and drivers' hands.

- The most frequently occurring complaint concerned the lighting of the display at night. The lighting was considered too dim and unevenly distributed around the dial faces.

- Drivers liked the clarity of the printed numbers and scale on the dial faces.

- The use of a pointer to indicate speed was also felt to be a more satisfactory method than lit segments.

- Drivers also liked the familiarity and conventional appearance of the display.

- It was suggested that the scale numbers and the pointer could be lit more brightly than the other figures to enhance the reading of the display.

- To overcome the problems of obscuration by the steering wheel and drivers' hands, it was suggested that the dials be moved closer to the centre of the display, or that the speedometer be centralised and the tachometer reduced in size or removed.

6.9.5.2 The electronic dial display test results

Table 6.15 The electronic dial display test results - objective measures

OBJECTIVE MEASURES	ELECTRONIC DIAL ACCURACY SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Reading the speed Response correct to:						
± 2 mph	285	68	200	74	485	70
± 3 to 5 mph	122	29	65	24	187	27
± over 5 mph	13	3	5	2	18	3
Deciding whether speed was within a speed limit						
Correct responses	617	98	401	99	1018	98
Incorrect responses	13	2	4	1	17	2

Number of responses:

Reading speed	Day	= 420
	Night	= 270
	Total	= 690
Within speed limit	Day	= 630
	Night	= 405
	Total	= 1035

Table 6.16 The electronic dial display test results - subjective measures

SUBJECTIVE MEASURES	ELECTRONIC DIAL PREFERENCE SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Easier to read	9	21	16	59	25	36
Easier to decide whether within speed limits	7	17	17	63	24	35
Causes distraction while driving	13	31	7	26	20	29
More attractive	22	52	20	74	42	61
Would choose for own car	9	22	12	44	21	30
General preference	9	22	15	55	24	35

Sample size Day = 42
Night = 27
Total = 69

The electronic dial display - summary of results

The electronic dial display was similar to the electromechanical dial display and to most other instrument panel designs current in 1981, in that it was an analogue dial design. It was produced using liquid crystal technology which was older and less sophisticated than that used in the electronic curvilinear design. The major problem was in the daytime brightness in that washout occurred in bright sunlight, making the display more difficult to read. This was particularly marked when sunlight came in through the drivers' side window. The display occassionally also appeared very dim to the drivers when they were driving into bright sunshine ahead.

1. The electronic dial display was read accurately by less subjects than the other electronic displays in both the day (68% within $\pm$ 2 mph) and night trials (74% within $\pm$ 2 mph). The accuracy of reading was maintained in the day and night trials.

2. All the display designs including the electronic dial display were accurately check read against the current speed limit.

3. Only one driver in five (21%) considered the electronic dial display easier to read than the electromechanical dial display in the day time trials. In the night trials 59% of the drivers considered that the electronic dial display was easier to read. Drivers commented that the contrast of the display was poor in daylight but that as they could still see the outline of the display this was

not considered a serious problem. It was also mentioned that the amber colour was helpful in the night trials when reading the display against oncoming white headlights.

4. Only 17% of drivers considered that the electronic dial display was easier to use for check reading against a speed limit in the day time trials. However, in the night trials nearly two thirds (63%) considered it easier than the electromechanical dial display.

5. The majority of subjects in all the test conditions, except the night trials with the electronic curvilinear display, considered that neither the electronic nor the electromechanical designs distracted attention while driving. However, of the electronic designs in daylight trials the largest percentage of subjects (31%) considered the electronic dial design to be distracting.

6. The electronic dial display was considered more attractive than the electromechanical dial display in both the day and night trials. Of the electronic display designs the dial was considered attractive by the smallest percentage of drivers (52%) in the day time trials and the largest percentage of drivers (74%) in the night trials.

7. Only 22% of drivers in the day time trials stated that they would choose the electronic dial display rather than the electromechanical dial display for their own car. In the night trials the greatest percentage of drivers (44%) stated they would choose

the electronic dial display although a quarter (26%) stated they would choose neither.

8. The electronic dial display came a poor second to the electromechanical dial display on general preference in the day time trials. This position was reversed in the night trials although the difference between the percentages of subjects preferring each design were not very great.

9. In terms of accuracy of reading the electronic dial display in road trials there was a marked improvement in the percentage of readings accurate to within $\pm$ 2 mph from 23% in Study 2 to 68% (day) and 74% (night) in Study 3. The precentage correct in Study 3 was not quite as high as in Study 1 (88%). All the display designs were check read accurately against speed limits in Study 3. The results for Study 2 (67%) were clearly improved upon, whereas the results for Study 1 (97%) were maintained.

10. On the measures of driver preference with the electronic dial display drivers were clearly influenced by the lighting conditions in Study 3. These had been controlled as night time conditions in Studies 1 and 2. The electronic dial display was considered better than the electromechanical dial display in all the preference measures except distraction while driving. As night time lighting conditions were those pertaining in Studies 1 and 2 it is interesting to note that the electronic dial display maintained a favourable position. In the day time conditions of Study 3, however, the electromechanical dial display performed better on the measures of drivers' preference.

Electronic dial display - summary of drivers' comments

- Drivers disliked the reflections from the instrument panel of the car interior during daylight.

- The movement of the brightly lit segments was considered distracting. The tendency for the leading segment to flash on and off in response to minor speed fluctuations was considered particularly unsatisfactory.

- The speedometer and tachometer were considered to be too similar in design, leading to confusion of function.

- The scale design, in particular the 2½ mph segments was considered unsatisfactory.

- The contrast was considered to be poor in daylight, but drivers also mentioned that as they could still see the basic outline of the display this was not a serious problem.

- The speedometer and tachometer were considered too far apart.

- Drivers often complained about the obscuration of the speedometer by the steering wheel and drivers' hands.

- The reflection of the display onto the windscreen was remarked on by drivers in the night time tests.

- Drivers disliked the digital clock in the central position.

- The display was considered easy to read.

- The layout was considered clear, clean and efficient.

- The style of the display was complimented.

- Drivers in the night trials mentioned that the amber colour of the display was particularly helpful when reading it against oncoming white headlights.

- The dimmer control for night driving was considered essential.

- Some drivers suggested that the scales and segments should be visually separated by, for example, having different colours or different brightness.

- Drivers who disliked the segment movement suggested an electronic form of pointer, or a continuous band rather than segments.

6.9.5.3 The electronic curvilinear display test results

Table 6.17 The electronic curvilinear display test results - objective measures

OBJECTIVE MEASURES	ELECTRONIC CURVILINEAR ACCURACY SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
<u>Reading the speed</u>						
Response correct to:						
± 2 mph	335	85	185	85	520	85
± 3 to 5 mph	51	13	31	14	80	13
± over 5 mph	8	2	2	2	12	2
<u>Deciding whether speed was within a speed limit</u>						
Correct responses	583	98	317	97	904	98
Incorrect responses	12	2	10	3	18	2

Number of responses:

Reading speed	Day =	394
	Night =	218
	Total =	612
Within speed limit	Day =	595
	Night =	327
	Total =	922

Table 6.18 The electronic curvilinear display test results - subjective measures

SUBJECTIVE MEASURES	ELECTRONIC CURVILINEAR PREFERENCE SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Easier to read	16	38	10	43	26	39
Easier to decide whether within speed limits	18	43	13	56	31	47
Causes distraction while driving	10	24	11	48	21	33
More attractive	28	67	12	52	40	61
Would choose for own car	19	45	11	48	30	45
General preference	18	42	11	48	29	44

Sample size Day = 42
Night = 23
Total = 65

The electronic curvilinear display - summary of results

The electronic curvilinear display was novel in design in that the scale formed a curved line rather than a dial. In addition the speedometer segments changed colour from green to amber above 30 mph. The curvilinear design aroused much interest among the drivers who tested it. However, the test results do not provide a clear indication of drivers' performance or preferences when the electronic curvilinear display is compared with the electromechanical dial display.

The liquid crystal technology used in the electronic curvilinear display was more sophisticated than that used for the earlier model electronic dial display. Hence the problems of washout in bright sunshine were much less apparent.

1. The electronic curvilinear display was read more accurately than the electromechanical dial display at night with 85% of the responses accurate to within ± 2 mph compared with 79% for the electromechanical dial display. The electromechanical dial display was read more accurately during the day time trials with 91% of the responses accurate to within ± 2 mph compared with 85% for the electronic curvilinear design. There was however, very little difference between the scores.

2. All the display designs including the electronic curvilinear display were accurately check read against the current speed limit.

3. In the day time trials the electromechanical dial display was considered easier to read. There was no difference between the display designs on ease of reading during the night trials. The difference in response for the day time trials is much less marked between the electronic and electromechanical designs than with the two dial designs because washout in bright sunlight was much less noticeable with the more sophisticated liquid crystal of the curvilinear design.

4. The electronic curvilinear design was considered easier to use for check reading than the electromechanical dial display, in both day and night conditions. This was probably influenced by the fact that the electronic curvilinear display segments changed colour from green to amber at 30 mph thus providing colour coding as additional information.

5. The electromechanical dial display was clearly considered less distracting while driving, although in the day time conditions neither display design was considered distracting. However, in the night trials nearly half (48%) the drivers considered the electronic curvilinear design distracting.

6. The electronic curvilinear design was clearly considered more attractive than the electromechanical dial design in both day and night trials.

7. Nearly half the drivers in the daytime trials (45%) and in the night trime trials (48%) stated that they would choose the electronic curvilinear design for

their own car. This is slightly more than those who stated they would choose the electromechanical dial display.

8. There was nothing to choose between the electromechanical dial display and the electronic curvilinear display in terms of drivers' general preference. They both scored similar results.

9. In terms of accuracy of reading the electronic curvilinear display in road trials compared with laboratory tests there was a marked change in performance. In Study 1 approximately three quarters of the readings (77%) were exactly accurate (with clutter). In Study 2 only 3% of the readings were accurate to within $\pm$ 2 mph whereas in Study 3, most like real life conditions 85% of readings were accurate to within $\pm$ 2 mph. The percentage correct in Study 3 was even higher than in Study 1. All the display designs were check read accurately against speed limits in Study 3. The results for Study 2 were poor (45% correct) compared with both Study 1 (94% correct) and Study 3 (98% correct).

10. On the measures of driver preference the difference in results between day and night conditions was not so apparent as in the trials with the electronic dial display. The electronic curvilinear display maintained its position as an attractive display established in Studies 1 and 2. As was found in the previous studies it was also considered easy to use to decide whether the speed was within a speed limit. The electronic curvilinear display was clearly considered distracting, particularly in the night trials, an aspect which could not be tested in Study 2 but was remarked on by some of the subjects as a potential problem.

11. It was noted during the night time trials that the electronic curvilinear display produced noticeable reflections on the drivers' side window and on the windscreen. A number of drivers complained that this was annoying while driving.

Electronic curvilinear display - summary of drivers' comments

- Drivers disliked the reflections from the instrument panel of the car interior.

- The movement of the brightly lit segments was considered distracting. The tendency for the leading segment to flash on and off in response to minor speed fluctuations was considered particularly unsatisfactory.

- Drivers also mentioned that the movement of the tachometer in the central area of view was distracting, particularly at night.

- Some drivers found the extra effort necessary to read the display distracting, as was the novelty of the design.

- At night, drivers remarked that the display was too bright and that the colours were too bold. This display did not have a dimmer control.

- The reflection of the display in the windscreen and the drivers' side window was considered unsatisfactory by drivers in the night trials.

- The speedometer and tachometer scales were considered to be too close together.

- One serious criticism which occurred fairly frequently was that the brightness of the speedometer and tachometer detracted from the visibility of the gauges and warning lights. This was mentioned in both day and night trials, but particularly at night.

- The green segments in the range 0-30 mph were considered difficult to read compared with the amber of the rest of the scale because they appeared to be less bright.

- Drivers found the fuel gauge and its scale marking difficult to interpret.

- Drivers liked the modern design, and considered it clear, easy to read and exciting.

- It was felt that this design would appeal particularly to younger drivers, sports car enthusiasts and business executives.

- Drivers also liked the central position of the scales, which were considered easier to see in that position.

- The use of colour, and the change of colour at 30 mph were both thought to be a good idea.

- Some drivers suggested that the two scales should be visually separated by, for example, being of different colours or different brightness.

- Drivers were divided in their views about the colour change of segments at the 30 mph speed limit. Some drivers wanted further changes at 50 mph and 70 mph, others wanted no colour change at all.

6.9.5.4 The electronic digital display test results

Table 6.19 The electronic digital display test results - objective measures

OBJECTIVE MEASURES	ELECTRONIC DIGITAL ACCURACY SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
<u>Reading the speed</u>						
Response correct to:						
± 2 mph	490	100	194	100	684	100
± 3 to 5 mph	0	0	0	0	0	0
± over 5 mph	0	0	0	0	0	0
<u>Deciding whether speed was within a speed limit</u>						
Correct responses	742	100	276	97	1018	99
Incorrect responses	0	0	8	3	8	1

Number of responses:

Reading speed	Day	= 490
	Night	= 194
	Total	= 684
Within speed limit	Day	= 742
	Night	= 284
	Total	= 1026

Table 6.20 The electronic digital display test results - subjective measures

SUBJECTIVE MEASURES	ELECTRONIC DIGITAL PREFERENCE SCORE					
	DAY		NIGHT		TOTAL	
	freq	%	freq	%	freq	%
Easier to read	44	88	19	95	63	90
Easier to decide whether within speed limits	33	66	14	70	47	67
Causes distraction while driving	7	14	5	25	12	17
More attractive	31	62	13	65	44	63
Would choose for own car	37	74	15	75	52	74
General preference	36	72	16	80	52	74

Sample size Day = 50
Night = 20
Total = 70

The electronic digital display - summary of results

The electronic digital display was probably the most novel of the electronic instrument panel designs in the tests. Although digital displays have become more common since the tests were conducted it was unusual to find digital readouts except for watches and clocks. When the digital display was compared only with the electromechanical dial display the results for both performance and drivers' preference were clear. The digital display performed better. In the tests the electronic digital display was produced using 25 mm seven segment tungsten filament displays and hence were less attractive than and had different illumination response characteristics to the liquid crystal digits which would have been used in production vehicles. At the time 25 mm liquid crystal digits were not available even as prototypes.

1. Almost all (99.8%) of the speed readings for the electronic digital display were accurate to $\pm$ 2 mph. The majority were exactly correct. This result indicates that the rate of change of the digits, was at no time so rapid as to cause difficulty or error when reading the speed. The electronic digital display incorporated a time based update frequency of 4 times per second, although the digits would change at this rate only during acceleration and deceleration. This is a particularly interesting result to obtain from road trials in which speeds were adopted according to prevailing traffic conditions, from slow town driving to fast motorway driving. Even when, under fast acceleration conditions, the digits were changing rapidly, no drivers complained that they could not read the digits. The size of the digits (25 mm height) and

the clarity of style would also greatly assist in the ease and accuracy of reading. The accuracy of reading was maintained in both day and night conditions.

2. The electronic digital display scored very well when drivers were asked to decide whether a speed was within a speed limit (99% accurate, total). When compared with the electronic digital display the electromechanical dial display performed equally well.

3. The electronic digital display was clearly considered easier to read than the electromechanical dial display in both day (72% easier) and night trials (80% easier).

4. The electronic digital display was clearly considered easier to use when deciding whether the speed was within a speed limit. This result is unexpected as analogue displays are traditionally considered easier to use for check reading tasks such as this (eg Shackel 1974). The road side speed limit signs are also digital which may have influenced drivers' responses, making the decision making task easier. In the road trials, however, the roadside speed limits were seen only infrequently by the drivers, and the speed limit was also presented verbally in the trials. In the vehicle simulator trials (Study 2) the speed limits were shown on the screen all the time. Comments from Study 2 and Study 3 indicated that some drivers anticipated that it would be easier to use an analogue display for this check reading task, but changed their mind after experience with the digital display.

5. The majority of drivers (86% day and 65% night) considered that neither display was distracting. However 25% of drivers in the night trials and 14% of drivers in the day time trials considered the electronic digital display to be distracting while driving.

6. The electronic digital display was considered to be the more attractive display when compared with the electromechanical dial display in both day and night time trials.

7. Three quarters of the drivers who tested the electronic digital display stated that they would choose it for their own car.

8. Three quarters of the drivers considered that they preferred the electronic digital display overall compared to the electromechanical dial display.

9. The electronic digital display maintained its high level of reading accuracy throughout the three studies (98% with clutter Study 1, 97% Study 2, 100% Study 3). Even during the road trials when the digits were changing in response to driving controls and when the ambient or external light was bright the digital display was read accurately.

10. In Studies 1 and 2 the electronic digital display alway performed well in terms of drivers' preference although in those studies the digital design was being compared with three or four other display designs. In Study 3 when the digital design was only being compared with the electromechanical dial display it performed outstandingly well. The most

interesting result was that of distraction while driving. The vast majority of drivers considered that neither the electronic digital nor the electromechanical dial display caused distraction while driving. However, a quarter of the drivers considered that the electronic digital display did cause distraction. This is a smaller proportion than those in Study 2 who considered it the most distracting design (38%). The road trials were considered to be the hardest test for the electronic digital display, and in particular the night time trials. Yet in the road trials the electronic digital display not only maintained its clear superiority on the favourable measures of Studies 1 and 2 but it also scored extremely well on attractiveness which previously had been considered poor.

Electronic digital display - summary of drivers' comments

- The movement of the brightly lit digits was considered distracting by some drivers.

- Some drivers mentioned that the large size of digits (25 mm) also contributed to the distracting effect.

- The accuracy with which the digital display presented information was considered by some drivers to be distracting in that they tried to keep more exactly to speed limits. One driver mentioned that the changing digits were mesmerising.

- Drivers mentioned that they found the digital display difficult to use to check against speed limits and when changing speed.

- The digits 8, 6 and 0 were considered most difficult to distinguish, particularly when sunlight fell on the display.

- The design was considered rather plain by some drivers.

- Drivers particularly liked the ease with which the digital display could be read, and the fact that it gave exact speed.

- The design was considered clear, attractive and modern.

- The large digits were liked by the drivers as was the fact that the speedometer and tachometer were visually separated by a difference in colour and brightness; the speedometer being the dominant display.

- One driver mentioned that the changing digits would keep the children amused.

- A digital speedometer display was considered a good idea because it made drivers more aware of their speed. However, some drivers found it rather too easy to disbelieve the speed shown.

- A number of drivers felt that the digital display would be improved by the addition of an analogue speedometer in conjunction with the digital display.

- A digital tachometer was considered to be unnecessary and would be better represented as an analogue display.

- Drivers considered that the shape of the digits could be improved to enhance reading.

- Drivers at night mentioned that the display colour should be 'softer'.

- An interesting observation was that many drivers anticipated problems with using a digital display and found that the problems did not exist when they actually had experience of using the display.

6.9.6 General comments

- It was noted several times during the night trials that in lit streets drivers would start the cars containing the electronic displays and drive away without turning on the headlights. This was probably due to the fact that the displays are lit all the time independant of whether the headlights are switched on. Usually instruments only light up when the car lights are on. In lit streets, when it is not always obvious from the external light whether the car lights are on, drivers probably use their instrument lights as clues as to the status of the headlights. As the electronic displays are always lit, this clue is then not applicable and drivers, misinterpreting the clue, fail to switch on the car lights. It is suggested that an additional clue is required, such as a warning light, to indicated the status of the car headlights.

- Drivers frequently remarked on the susceptibility of the electronic displays to variation in ambient illumination. They were also slightly amused by the sudden brightness of the displays when entering darkness such as an underpass or a bridge, after daylight.

- The blank facia of the electronic displays prior to ignition may be a disadvantage. However, the novelty of the sudden appearance of the displays on ignition may overcome this.

- Drivers mentioned the fact that the electronic displays did not show kph, even when they had been told earlier that kph scales would shown separately on command.

- The position of the speedometer on the right of the displays was criticised, and drivers mentioned that they would prefer it on the left hand side. This was particularly the case when the speedometer was partially obscured by the steering wheel and drivers' hands.

6.10 Discussion

The discussion in this chapter is concerned only with the main points of Study 3. Chapters 7 and 8 discuss the whole programme in detail. Many of the points covered in the discussion in Chapter 5 are equally relevant to Study 3 but are not repeated in Chapter 6.

6.10.1 Discussion of the results

The objective measures of accuracy of reading the speed indicates that the electronic digital display was read more accurately (100% within $\pm$ 2 mph) in both day and night conditions than any of the analogue designs. In terms of accuracy of check reading against a speed limit, in the road trials all the display designs performed well (97%-100% correct). The electronic digital display has clearly maintained the high level of reading accuracy obtained in Studies 1 and 2. The results were not surprising in the static tests of Study 1 but the maintenance of the reading accuracy under the simulated and real driving conditions of Studies 2 and 3 is noteworthy. As described in the discussion of the results of Study 2 the update rate of the digits is critical to the ease of use of the digital display. Even in the very variable driving conditions in Study 3 where congested city and open motorway driving were encountered the update rate of the digital display did not appear to affect the accuracy of reading the speed.

Of the analogue display designs the electronic curvilinear was read most accurately (85% within ± 2 mph) in both day and night trials. This is a marked diversion from the results obtained in Study 2 where only 3% of readings were within ± 2 mph. In Study 2 it was noted that the speed readings above 50 mph were much more likely to be inaccurate than those below 50 mph. In Study 3 the differential accuracy of reading depending on the scale position was not noted. Drivers responded equally well or badly regardless of the position of the speed reading on the scale. However, in Study 1 the exact accuracy score was 75%-77% accurate, not very different from that obtained in Study 3. In Study 2 the subjects had very little information which could be used to estimate the speed reading prior to glancing at the speedometer. It is possible that when other clues for speed estimation are missing the subject has to scan the greater part of the curvilinear display to obtain an accurate speed reading. This, given that subjects only glance at the instruments for a very short time, may have led to the large percentage of inaccurate (outside ± 2 mph) readings noted in Study 2. The improvement in performance may well be due to the increased amount of peripheral information available to the driver to assist with speed estimation. If speed estimation is accurate it should cut down the scanning time required to read the instrument accurately.

The effects of lighting conditions were most noticeable on the accuracy of reading the electronic dial compared with the electromechanical dial display. In the day time conditions the electromechanical dial display was read more accurately whereas at night the LCD electronic dial display was read more accurately. This is probably due to the relative brightness of the displays in day and night lighting. In the day time the electromechanical dial display was clear to read and lit by the ambient illumination whereas the electronic dial display suffered from washout particlarly in bright sunlight. In the night trials the trend was reversed. The electromechanical dial display appeared to be dim and poorly lit whereas the LCD electronic dial display was clear, bright and easy to read.

There was no difference between any of the displays under either day or night conditions when the drivers were asked to check read the speed against a speed limit. Nearly all the responses were accurate (97-100% correct). The results are very similar to those obtained in Study 1.

In terms of drivers' preferences the electronic digital display maintained the superiority established in Studies 1 and 2 with the vast majority of subjects (88% day and 95% night) considering it easier to read than the electromechanical dial display. In none of the other trials were the results so clear on ease of reading. Reversal of preference between day and night conditions for ease of reading was noted for the trials in which the electronic dial display was compared with the electromechanical dial display. The drivers' preferences for ease of reading reflected their actual performance scores. The electromechanical dial display was considered easier to read in the day time trials and the electronic dial display was considered to be easier to read in the night time trials. This reversal according to lighting condition is maintained when subjects were asked for their opinions concerning ease of deciding whether the speed was within a speed limit. The greatest number of subjects considered the electronic digital display to be easier for check reading against a speed limit. However the driver preferences for the electromechanical dial (day) and the electronic dial (night) were similar in number to the electronic digital design. In spite of the colour change of segments at 30 mph the drivers showed no clear preference for the electronic curvilinear design or the electromechanical dial design for ease of check reading against a speed limit.

In the majority of trials when asked about distraction while driving most drivers said that neither the electronic nor the electromechanical display design was distracting. The exception was the night trials on the electronic curvilinear design in which 48% of subjects considered the electronic curvilinear design to be distracting while driving although the same proportion considered that neither display was distracting. Of the other two electronic display designs only a quarter of the subjects considered the designs to be distracting at night. This response is important because there have been fears expressed about the distracting effects of discrete or digital display designs, particularly at night. The curvilinear design was similar in the colours used to those in Study 1, in particular the tachometer was amber. It had been found in Study 1 that this was considered distracting because of the relative brightness compared with the speedometer. As the prototype LCD panel for the curvilinear design was produced before the results of Study 1 were known this could not be changed in Study 3. These colour features may well have affected the distraction particularly in night conditions.

When compared with the electromechanical dial display each of the electronic designs were considered more attractive. Three quarters of the subjects in the night trials considered the electronic dial display to be more attractive than the electromechanical dial display. The electronic digital display was rank 2 in both the day and night trials with 62% and 65% respectively of subjects considering it to be more attractive. This was in spite of the fact that the presentation of the digital display as tungsten filament digits was much less satisfactory than the very smart appearance of the two LCD panels.

The most clear result in terms of drivers' choice of a display design for their own car was the preference for the electronic digital design with three quarters of the subjects stating that they would choose the design for their own car. In terms of general preference the electronic digital design continued to perform well with 72% (day) and 80% (night) of drivers stating that they preferred that design generally to the electromechanical design.

6.10.2 Discussion of the research method

In this third stage of the research programme to investigate driver response to electronic instrument panel design the experimental conditions were the most realistic. In the previous studies experiments were conducted under more controlled laboratory conditions, becoming more realistic in the vehicle simulator, Study 2. In this third study the display designs were tested in normal driving conditions. The more realistic the experimental conditions the more difficult it is to control the factors influencing the experiment. Some of the factors were controlled as far as possible by taking each driver along an identical route, and eliciting responses at specific points along that route. The times of the day when the lighting conditions would vary markedly from the start to the finish of the 2 hour experiment, such as at dusk, were not scheduled for tests. In addition, times when the traffic was unusually dense such as at rush hours were also excluded from the schedule. However, subjects' driving styles varied considerably with some driving much faster or slower than others, also braking and accelerating faster than others. Hence subjects experienced different rates of change of the segments or digits depending on their driving styles.

Unlike the previous two studies in which all the subjects compared all the display designs, in this study each driver compared only one electronic display design with the electromechanical design. This changed the nature of the judgements the subjects were making as in the third study the comparative judgements were not influenced by the other electronic designs.

The tests were conducted during daylight and at night whereas in the previous two studies only night levels of lighting were used. During the road trials the light levels varied, for example, in daylight the light included bright sunlight and dull overcast conditions; at night street lighting and unlit country lanes were included. The effects of the different lighting conditions were noted in terms of drivers' preferences and drivers' performance. Clearly, the lighting conditions did have an effect on driver reactions to the electronic display designs, particularly the electronic dial display. However, the technologies employed in the three electronic displays tested were not the same and this may also have influenced the findings. The electronic dial display employed an early version of liquid crystal.

This performed badly in daylight but well at night. The electronic curvilinear display employed a more up to date version of liquid crystal and this display, if anything, performed better in daylight tests. However, this display did not have a brightness control so that at night a number of drivers complained that the display was too bright. Also the curvilinear design was known to be less easy to use from the earlier studies. Therefore, it is possible that if the up to date technology had been used in the electronic dial display this display would have performed better under daylight conditions. The electronic curvilinear display would probably have performed better under night time conditions if a brightness control had been available. The electronic digital display employed tungsten filament technology which responded in a similar way to the up to date liquid crystal display. This display performed consistently well in both day and night conditions. This would indicate that if the display design is satisfactory then the lighting conditions do not influence driver response so critically. It was found, however, that with all the electronic displays there was almost complete washout of the displays when sunlight fell on the displays through the drivers' side window. Also some drivers complained that the displays appeared very dim in bright sunlight, particularly when the sun was ahead. The electronic curvilinear display reflected in the drivers' side window and on the windscreen. A number of drivers complained that this was annoying while driving.

One disadvantage of this more realistic research method was that it was not possible to check the exact accuracy of reading. Although the experimenter had a digital readout of the speed to refer to she did not know exactly when the driver was reading the speed. In the interests of safety the driver had to choose an appropriate time after the cue to read the instruments. A further disadvantage was that it was not possible to record driver response time as had been noted in Study 2. The main reason was that the traffic conditions would and should have a greater influence over driver response time than the ease of reading the displays. Hence it would have been an unreliable measure.

Subjective responses were entirely appropriate in Study 3 as drivers had experience of the display designs in a variety of lighting and traffic conditions as they would do in normal driving. However, as mentioned previously drivers only experienced one electronic design and an electromechanical design. The displays were not all available at once for a comparative test along the lines of Study 2, and it was also impractical to hold long experiments.

6.10.3 Discussion of the display designs

None of the designs were changed markedly from Studies 1 and 2 except for the addition of warning lights. The colours were different for the electronic curvilinear designs compared with Study 2. The scales and segments (except 0-30 mph, green) were all amber. This was considered a disadvantage over Study 2 as the problems experienced in Study 1 were more likely to be repeated. However, the LCD panel had been produced before the results of Study 1 were known.

The electromechanical dial display was the design with which drivers were most familiar and with which each of the electronic display designs was compared. The accuracy of reading was greater in Study 3 (74%, 87% and 95% accurate to within $\pm$ 2 mph), than in Study 2 (47% within $\pm$ 2 mph). This is probably because in Study 2 there was considerable pressure on the subjects to respond very quickly, whereas in Study 3 drivers could set their own reading time for accuracy and to account for traffic conditions. The electronic digital display was read accurately on all occasions, maintaining the levels of accuracy found in the previous static and dynamic tests. The accuracy of reading the curvilinear display improved dramatically (85% $\pm$ 2 mph) when drivers' could set their own reading time. All the display designs could be used accurately for check reading.

Many of the comments made in the discussion section 5.10.3 in Chapter 5 apply equally to the designs discussed in Chapter 6 because the designs did not change significantly. However, the nature of the drivers' decisions, namely comparison of two designs rather than four is noteworthy. Drivers reactions to the novel electronic designs and the new technology were measured by a questionnaire covering a number of topics including ease of use, distraction while driving, attractiveness and general preference. The drivers' responses on these topics relating to the electronic displays were compared with their responses for the electromechanical display. The electronic digital display was preferred to the electromechanical display on all subjective measures in both day and night time trials. The only exception was distraction while driving where the digital display was considered distracting by slightly more drivers than the electromechanical display. The electronic dial display was preferred to the electromechanical display on all subjective measures when tested by drivers at night. However, the electromechanical display was preferred on all these measures except attractiveness by subjects who took part in the day time trials. Driver reaction to the electronic curvilinear display was less clear. The electronic curvilinear display was considered to be attractive and easier to use when deciding whether the speed was within a speed limit. This latter is partly due to the fact that the speedometer segments changed colour at 30 mph. However, the colour change at 30 mph did not enhance the accuracy of making decisions. Also, drivers who tested the electronic curvilinear display in daylight were more likely to say that they would choose that display for their own car. On all the other features there was no difference between the two displays.

The electromechanical dial display was considered easier to read and for check reading against a speed limit, in daylight conditions compared with the electronic dial display. The position was reversed in night conditions. This is clearly the influence of the poor electronic display technology. There is little to choose between the electromechanical dial and the curvilinear design on these two measures. The LCD technology had been improved by the time the curvilinear design was produced. The digital display design scores consistently high on these two factors, as it has done in the previous two studies.

Distraction while driving was an important factor to consider particularly in the much more varied traffic and lighting environments encountered in real life compared with a vehicle simulation. The majority of drivers considered that neither the electronic nor the electromechanical displays were distracting. The exception was the response to the electronic curvilinear design at night when half (48%) the drivers considered it to be distracting. This is probably due to a combination of factors including the design itself, the amber colours (previously found to be unacceptable in Study 1) and the fact that the instrument panel could not be dimmed.

In all cases the electronic display designs were considered more attractive than the electromechanical display.

In terms of choice for own car, only in the case of the electronic digital display is the preference clear. Three quarters of the drivers in both the day and night trials stated that they would choose the digital display for their own car. In the case of the electronic dial display it depended on whether the display was viewed under day or night lighting conditions. The preferences for the electromechanical dial and the curvilinear design are not clear. A similar picture emerged for general preference. This latter measure was introduced in Study 3 but did not give any additional information from that given by the measure 'choice for own car'.

6.11 Conclusions

- The electronic digital display performed better and was preferred by drivers on all measures when tested in both daylight and night time trials.

- The electronic dial display performed better and was preferred by drivers in the night time trials. The electromechanical dial display performed better and was preferred by drivers in the daylight trials.

- The electronic curvilinear display was preferred on a few of the measures when tested in daylight. There was little difference between results for the electronic curvilinear display and the electromechanical display in the night time trials.