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THE PRESENTATION OF INFORMATION
IN CARS

by

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CHAPTER 7 DISCUSSION OF THE DISPLAY DESIGNS

7.1 Introduction

The rapid development of electronic display technologies suitable for use in cars has posed a number of questions for the designers of in-car information systems. These questions include whether electronic display designs have any advantage from a user's point of view over the electromechanical designs still most commonplace; whether any particular designs of electronic display have advantages or disadvantages for the user; whether the information is being presented in the optimum mode and so on. It was questions such as these, posed by Ford Motor Company, which form the basis of this thesis. The questions are fundamental to the application of electronic displays in cars, particularly in the current context of vehicle speed information. There are two main reasons for this, One is that electronic displays, particularly liquid crystal displays, can be almost any size or shape specified by the designer; the other is that the mode of operation of electronic displays is different from electromechanical displays. This means that instead of, for example, a continuously variable pointer which indicates a speed reading on a scale, electronic analogue displays indicate a reading by a discrete illumination/non-illumination of a segment against a scale. In the case of digital displays, instead of rotating drums indicating a value, segmented or dot matrix digits change shape by illumination/non-illumination of matrix components. Hence, not only is the actual style of display design important but also the method of indicating the value.

In this series of studies three electronic display designs were tested with drivers and the results compared with those for an electromechanical dial display commonly found in vehicles at the time. The three electronic display designs comprised an analogue dial, an analogue curvilinear display and a digital display. The four designs were tested on both objective measures such as accuracy of reading the speed and subjective measures such as ease of reading and choice.

How well did the electronic displays compare with the electromechanical display, and which, if any, of the electronic displays was most satisfactory?

7.2 Objective measures

7.2.1 Accuracy of reading the speed

In Study 1 the electronic display designs were all read more accurately than the electromechanical design used in the later studies. In Study 2 the electromechanical dial display was read more accurately than the electronic analogue displays, if an accuracy score of $\pm$ 2 mph is taken. The electronic and electromechanical dial displays were about the same accuracy if a score of $\pm$ 5 mph is taken. The electronic curvilinear display was read accurately by only a very small number of subjects whereas the digital display was read accurately by the vast majority. In Study 3 comparison of the electronic and electromechanical displays' performance was influenced by the lighting conditions. The electromechanical dial was read more accurately (to $\pm$ 2 mph) than the electronic dial in daytime tests, but the reverse was the case in the night time tests. There was no difference at $\pm$ 2 mph level of accuracy between the other electronic designs and the electromechanical dial in either day or night time tests.

The results for Study 1 indicate that when subjects are given a fixed brief exposure time (in this case 450 m secs) in which to view a display the electromechanical design was the least accurately read. This is not an unexpected result as the electromechanical display exhibited features of design which would have made reading more difficult than for the electronic dial display and perhaps even the curvilinear display. The main adverse feature was the scale design, the graduations were only numbered at 0, 20, 40, 60.... mph with large unnumbered graduations at the intermediate 10s and small unnumbered graduations at the unnumbered 5s. In addition the display was cluttered with a kph scale and two odometers located inside the dial. The electronic analogue designs in comparison had numbered graduations at each 10 mph and clear unnumbered graduations at each 5 mph. It could be argued that the amount of effort required to interpolate between scale graduations was greater for the electromechanical dial compared with the electronic analogue designs. As the exposure time was brief and fixed, the consequence of the increased effort was reduced accuracy of reading. Anderson and Fitts (1958) looked at the amount of information which could be gained during brief exposures of numerals and colours and found that as the information content increased so performance increased up to a maximum and then declined. The electronic analogue displays presented the information clearly whereas the electromechanical design presented more redundant information and more distraction. In Study 2 the electromechanical dial display performed better at $\pm$ 2 mph accuracy than the two electronic analogue displays. The subjects were able to adjust the reading time within the limits of the driving task and the average response time for the electromechanical display was slightly longer than for the electronic dial. The electronic curvilinear display had an even longer response time and yet few subjects read the display accurately. The driving task clearly provided a sufficient attention requirement to ensure that the subjects did not take their eyes off the 'road' for too long and the consequence is reduced accuracy. Armour (1985) reports the reading times for various types of display in off-road track tests and although the mean response times are longer in the simulator study (due to the nature of the time measurement), the order of reading times was the same for the different displays in both studies. He reported that the larger (25 mm) digital display was read fastest, the circular dial display was next and the linear display was the slowest. Although in Study 2 the vehicle simulator did have an engine noise and the road scene on the monitor provided some visual feedback as to the likely vehicle speed it was obviously not adequate information to reduce the scanning required to read a curvilinear display. This is emphasised by the fact that in the road trials (Study 3) where the amount of information to guide the driver as to likely speed was normal, the performance of the drivers with the curvilinear display improved considerably.

The comparatively poor performance of the two electronic analogue displays compared with the electromechanical display in Study 2 as compared to Study 1 may also have been due to the dynamic nature of the displays and their mode of operation. In the static tests this would not have differentiated between the displays whereas in the dynamic simulation tests the movement of the segments may have been difficult to become accustomed to compared with the familiar pointer, in the short duration (15-20 minutes) exposure to each display. These factors may all have combined to militate against the electronic analogue displays. However, it may also be that these designs were more difficult for subjects to read accurately.

However, the improvement in both relative and absolute performance of the displays in the road trials argues against this latter conclusion. In Study 3 the only combination of displays which were clearly different in performance were the two dial displays. They also changed in relative performance depending on the lighting conditions. In daytime tests when the LCD dial display suffered from washout in sunlight the electromechanical display performed better. At night when the electronic display was bright and clear the electromechanical dial appeared less bright, and the illumination of the dial less even than the electronic display. The results from the road trials indicate that when given speed cues from the environment and time to read the displays (traffic permitting) then very little difference exists between the performance of the other display designs. The electronic digital display, however, performed highly in all the test conditions and no improvement in performance could have been demonstrated in the more advantageous conditions as the accuracy scores were always nearly perfect.

In Study 1 only was it possible to assess the nature and extent of the errors made when reading the speed, because the displays were static and the incorrect responses could be compared with correct readings in terms of the location on the scale. The results were noted as to whether the errors were made when the correct reading was on a numbered graduation, an unnumbered graduation or between graduations. Ergonomists have argued (eg Morgan et al 1963) that information is read with decreasing accuracy in the order outlined above, although Cohen and Follert (1970) argue that the design recommendations suggesting interpolation no finer than halves is unduly conservative. Only three of the four analogue designs could have readings between graduations, it was not possible with the electronic dial display as the end of each segment corresponded with a graduation. In all three cases the errors were much greater than readings on the numbered or unnumbered graduations. The three dial displays were read most accurately on the numbered graduations, and next most accurately on the unnumbered graduations. There was very little difference between errors on these two conditions for the electronic curvilinear display. There was no discernable pattern to the influence of colour (green 0-30 mph amber over 30 mph) on accuracy of reading although the readings below 30 mph were slightly more likely to be erroneous. However, the readings for the speedometer only conditions with speeds over 40 mph were equally likely to be erroneous. Nor was there any discernable pattern to the few errors recorded for the digital display except that all the errors were under readings. However, the range of errors was very great -21 to -1 and did not appear to correspond to problems with reading individual digits or combinations of digit although Duncan (1977) noted misreadings of '4', '2' and '5' with 7 segment electronic displays and Van Nes (1978) reports perceptual confusions related to similarity of line segments.

7.2.2 Accuracy of check reading the speed against a speed limit

Subjects made very few errors when check reading the speed shown on the display designs against a speed limit. Although there were slightly more errors in Study 1 for the electromechanical dial display, generally all the designs performed equally well. In Study 2, however, the error rate was generally higher than in the other studies for all the analogue displays. The digital design performed well throughout the studies. The error rate was highest for the electronic curvilinear design even though it was ostensibly enhanced for check reading by the segment colour change at 30 mph and over. Less than half the responses were correct overall. A further analysis of the results showed that most errors were made at the 50 mph speed limit and least errors were made at the 70 mph speed limit. No particular advantage was indicated at the 30 mph speed limit where the segments changed colour from green to amber. The generally low check reading accuracy could be attributable to the low reading accuracy noted in the previous section. This does assume, however, that it is necessary, at least in part, to read the display prior to reaching a decision regarding whether the speed is within the speed limit. A recommendation by Murrell (1963) indicates that speed check reading is based on pointer inclination angle although no evidence for this view is cited. Some drivers also reported that they used this mode of check reading. This mode of check reading is only applicable to dial displays with pointers and yet the segment 'pointer' dial display is check read equally easily. The arc produced by the lit segments around the scale may be equally appropriate for check reading. However, the curvilinear display has segment 'pointer' characteristics but the segments do not form an arc comparable with familiar circular dial displays. This may also help explain the poor performance of the curvilinear display for check reading. The unfamiliarity of the positions of the speed limit readings on the scale may also have increased the scanning inherent in reading or check reading linear displays and made it more difficult and erroneous to check read.

The electronic dial display was check read more quickly than any of the other displays including the digital display, although the error rate is similar to the electromechanical dial display. This may help to substantiate the theory that for check reading speed the pointer inclination angle may be one source of information and the extent of the arc on electronic segment displays also provides the basis for check reading in this context. Indeed if the relative response times are accurately reflecting this activity then the extent of the arc is a more powerful source of information, enabling drivers to use it more quickly than the pointer inclination.

The satisfactory performance of the digital display for this check reading task tends to go against the ergonomics literature which has recommended counters for displaying exact quantity and analogue dials for check reading and direction and rate of change. This evidence is based on studies of electromechanical dials and counters used for tasks such as micrometer reading (Murrell and Kingston 1966), altitude reading (Rolfe 1965) and reading clocks (Zeff 1965, Van Nes 1972). This is discussed in more detail in Section 7.5.3.

7.3 Subjective measures

Ergonomists, like other people, have found that what a person does and what he says he does are not necessarily the same thing. Hence, ergonomists try to take the precaution, where possible, of not relying entirely on one source for their judgments. In this series of studies both objective measures of performance were taken together with subject's opinions regarding acceptability of the display designs.

7.3.1 Display designs considered to be the easiest and most difficult to read

In Studies 1 and 2 each subject had the opportunity to compare all of the display designs. In Study 3 they only compared an electronic design with the electromechanical dial display. When asked which display design they considered easiest to read the greatest number of subjects in all three studies cited the electronic digital display. This corresponds with subjects' ability to read the digital display accurately in all three studies. However, when asked which display they found most difficult to read, in Studies 1 and 2, the responses did not reflect the accuracy scores. In Study 1 the curvilinear display was considered the most difficult to read although the two electromechanical dial displays produced the most errors. In Study 2 the electromechanical dial was considered most difficult to read although the curvilinear display produced the greatest number of errors.

The relative importance given to the two sources of information depends greatly on the context. In the vehicle context it is important that drivers are able to read the speedometer easily and accurately, but a high degree of accuracy is not necessarily required. However, it is also important that the driver is satisfied with his/her perception of the ease of use of the instrument otherwise it may influence vehicle purchase. In some cases, where there is no difference between product designs or where the user opinion is very strong preference measures can and should over-rule performance measures, provided that the level of performance is acceptable.

7.3.2 Display designs considered to be the easiest and most difficult for check reading against a speed limit

In all three studies the digital display was considered easiest to use to check read against a speed limit, by the largest number of subjects. In Studies 1 and 2 where all the display designs were compared, the digital display was preferred by half the subjects and was considered the most difficult to use by the smallest number of subjects. In Study 3 only 20% of the drivers considered the electromechanical dial display to be easier for check reading, more than two thirds preferred the electronic digital display.

If the theory that drivers use the pointer inclination (Murrell 1963) as an the main source of information for check reading is correct, then the electromechanical dial display(s) should perform better than the electronic dial displays and much better than the digital display, in terms not only of actual performance (see 7.2.2) but also in terms of perceived ease of check reading. In Studies 1 and 2 the smallest number of subjects considered the electromechanical dial display easiest to read and the largest number (except for the curvilinear display in Study 1) considered it to be the most difficult to use for check reading. This argument is confounded to some extent by the finding that the revised version of the electromechanical dial display was considered easiest to read (except for the digital display) in Study 1. However, in Studies 2 and 3 (where the revised electromechanical display was not included) of the analogue displays the electromechanical dial display performed less well than the electronic displays (except in Study 3 in daylight when the LCD dial was subject to washout). The preference for the electronic dial compared with the electromechanical dial for check reading may indicate that drivers found the extent of the arc of lit segments easier to use than pointer inclination. The preference for the curvilinear display (although somewhat variable) may have been influenced by the colour change of segments at 30 mph which theoretically should make check reading easier, if only at that speed limit. In Study 1 the largest group of subjects considered the curvilinear display most difficult for check reading.

The overwhelming preference subjects indicated in all three studies for the digital display indicates that Nason and Bennett (1973) may well be right to question the bias shown by ergonomists, and others, against digital displays for check reading tasks. Not only did the vast majority of the 400 subjects in this study use the digital display accurately for check reading but the majority also considered the digital display to be the easiest to use compared with a number of analogue display designs. This is probably due to the inherent ease of reading of the digital display which makes an extra calculation (above or below the speed limit) well within the users' capacity. In road conditions the speed limit information is presented in digital form on road signs which should make check reading easier, as a pattern matching task. However, the driver must also hold an image of the speed limit in some form either as a visual or non-visual image for those occasions when the road sign is not in evidence. Even in these conditions the driver uses the digital speed display for the task without difficulty.

7.3.3 Subject's opinions regarding the acceptability of the display designs

In the three studies driver's opinions on the attractiveness of the designs, which of the designs they would choose for their own car, distraction while driving and general preference (Study 3 only) were elicited, as appropriate to the three studies. These opinions were based on experience with the display designs gained during the different trials. The enquiry as to whether the subjects would choose or avoid each display design for their own car was intended as a synthesis question. The purpose was to look at various individual factors such as attractiveness on their own but also try to discover how the subjects responded to each display overall. The choice for the subject's own car appeared to be a useful indication of how committed the subject was to a particular design.

These various aspects were part of the general acceptability of the display designs to the subjects. Acceptability is a most important aspect of any ergonomics assessment but one which is often omitted as being too 'soft' an enquiry for scientists. If a product is not acceptable to the intended users then often they will find faults, whether real or imaginary, with the product and this may well result in misuse or disuse. Hence, the product cannot meet its design purpose if it is not acceptable, regardless of its performance in other respects.

In terms of attractiveness the three electronic display designs were preferred to the electromechanical design in all three studies. However, opinions varied in Studies 1 and 2 as to which electronic displays were considered attractive. The digital display performed marginally better than the curvilinear display in Study 1. However a high proportion of subjects considered the curvilinear display least attractive. In Study 2 the curvilinear display was considered attractive by the largest number of subjects but least attractive by almost the same number.

In Study 3 the relative performance of the designs may be judged by the numbers of subjects preferring the different displays. The digital display was preferred consistently in both day and night trials whereas the number of subjects preferring the curvilinear design declined in the night trials and increased for the electronic dial display.

The measures of attractiveness may also have been influenced by the presentation mode. In Study 1 all the designs were shown as slides. In Study 2 the analogue electronic designs were presented using LEDs back mounted on a screen printed panel, whereas the digital display comprised tungsten filament units front mounted on to a panel. This latter looked less well finished. Similarly in the road trials the electronic analogue displays were presented as LCD panels whereas the digital display could only be presented in the same mode as Study 2, as LCD digits of 25 mm were not achievable at that time. Study 1 is probably a fairer comparison of the displays in terms of attractiveness as they were all presented in the same mode.

In Studies 2 and 3 it was possible to obtain subjects' views on whether they considered the displays to be distracting while driving. In Study 2 the electromechanical dial display was considered least distracting by the largest group of subjects. Of the electronic displays the largest group of subjects thought the digital display was least distracting, however, a larger group of subjects considered it to be most distracting. In Study 3, in the majority of cases the subjects considered that neither electronic nor electromechanical display were distracting (except the curvilinear display at night). Hence in real life conditions where there are many external distractions compared with the simulation study, distraction by the electronic instrumentation was not considered important by the subjects.

In all three studies the electronic digital display was cited as the one which the largest group of subjects stated they would choose for their own car. This occurred in spite of the less satisfactory physical appearance of the display, ergonomists' views that digital displays are less satisfactory for check reading, and designers' concern about the distraction of the changing digits. This finding further substantiates the view of Nason and Bennett (1973) that digital displays are acceptable for check reading. In Studies 1 and 2 it was also possible to investigate which display subjects' would avoid for their own car. The largest group of subjects stated that they would avoid choosing the electronic curvilinear display, in spite of the fact that a large number of subjects considered it to be an attractive design. Clearly the functional properties of ease of use had a greater influence than aesthetic qualities in this case.

In Study 3 a question regarding general preference was also included. However, the drivers' responses to this question are almost exactly the same as their responses to the enquiry regarding choice for their own car. General preference was thought to have a bias towards aesthetic qualities as compared with the choice for own car which was considered to be more related to functional considerations. As there was no difference between the responses to the two enquiries the supposition was erroneous in this case.

7.4 Objective versus subjective measures

Ergonomists tend to put great store by the evidence of objective measures and can consider the evidence of subjective measures as less scientific. There is no doubt that subjective measures are influenced by a wider variety of factors than objective measures but this should not detract from their value in an overall product assessment. It is to the skill of the ergonomist which one should look to ensure the validity and reliability of the subjective data. Nor should one forget the limitations of objective measures. Subjective measures can add greatly to the interpretation of information and overall product assessments. In a study conducted by the author and her colleagues (Galer and Simmonds 1985) investigating drivers' responses to five colours of car instrument panel lighting, it was found that display colour made no difference to the objective performance measures. However, drivers' opinions indicated clear, strong preferences and dislikes among the colours.

In terms of ease of reading there was direct correspondence between the accuracy of reading and perceived ease of reading for the digital display, in all three studies. Generally the curvilinear display was considered difficult to read in the three studies but only in Study 2 was this reflected in the accuracy scores.

In terms of check reading the speed against a speed limit again there was direct correspondence between the accuracy of check reading and perceived ease of check reading for the digital display, in all three studies. However, other comparisons are difficult to make because generally the accuracy scores were high for all the displays (except the curvilinear display in Study 2).

Correspondence between performance and preference measures should not always be expected. The decision making process should take account of both and weight each according to the likely implications for the product.

7.5 The display designs

7.5.1 The electromechanical design compared with the electronic designs

It is clear from the results of this study that the preference for electromechanical or electronic display designs depends greatly on the nature of the designs in question. The electronic digital display was generally preferred to the electromechanical dial, but the same is not the case for the electronic analogue displays, they were not always preferred.

When comparing the analogue displays only there are a number of features of the electronic displays which are novel and will influence the response to the designs. The mode of operation of the displays is different in that the value is indicated by the position of a sweeping pointer against a scale with the electromechanical display. The electronic displays indicate the value by progressively lit and unlit segments against a scale. In the latter case there is also a cumulative effect of increasing lit segments as the scale value indicated increases. It is argued that this cumulative effect producing a lit arc enhanced the electronic displays for check reading compared with the angle of the pointer.

The pointer indicates scale values on the electromechanical dial in a continuously variable mode. The electronic analogue displays however, indicate scale values as discrete units, a segment is either lit or not lit. The segments would have to be extremely small or fine to produce the impression of being continuous, and this is not considered technically feasible at present. There is a compromise which has to be made between accuracy and segment/scale unit size. In order to be accurate to 1 mph, for example, for all scale values, then each segment would have to correspond to one mph units. Hence on a scale such as the speedometer in this study 130-140 segments would be required. This is apparently technically feasible but rather difficult. In the case of the electronic dial each segment corresponded to units of 2½ mph, and 2 mph for the electronic curvilinear display. This has effectively reduced the accuracy of information presentation compared with the electromechanical pointer which can display fractions of one unit (1 mph). The balance between accuracy of presentation and ease of production depends on a number of factors including legal requirements relating to the accuracy of speedometers, the use made of the information, and subjects ability to read the values.

Another consequence of the discrete nature of the electronic analogue displays is the opportunity for error.

If a display can only indicate values in 2½ mph units then the opportunity for error when reading the display is reduced by that order. Hence, the opportunity for making an error with the electronic dial display is only 4 per 10 mph whereas for the electronic curvilinear display it is 5 per 10 mph and the electromechanical dial a minimum of 10 per 10 mph (see Section 3.5.1). It would be expected on this basis that the display with the fewest number of segments would have the least opportunities for error, would be easiest to read and hence produce least errors. In terms of the performance of the analogue displays this was not found to be the case (although the results for the curvilinear display could be confounded by scale shape). If the electromechanical and electronic dial displays are compared the electronic display should perform better than the electromechanical. Only in Study 1 was this found to be the case. In the dynamic tests of Studies 2 and 3 the electromechanical dial was read more accurately than the electronic dial.

level increased. Payne and Pollard (1980) in similar experiments showed that the legibility of LCD displays increased as ambient light levels increased although they did not mention whether the LCDs were transmissive or reflective. Bearing in mind the year of the study it is more likely that the LCDs were reflective as these developed as an improvement on the transmissive LCDs.

The LCDs used in the road trials were not the same for the electronic dial and the curvilinear display. The dial was an earlier LCD type, transmissive, and the curvilinear was a later development, transflective. The difference is shown clearly in the results for day and night trials in Study 3. The accuracy of reading the electronic dial improved from day trials to night trials as the ambient illumination decreased. The washout under daylight conditions was noticeable, and the improvement in brightness very marked at night. The accuracy score for the electronic curvilinear display did not change between day and night conditions. Even more marked is the difference in drivers' preferences for the displays in day and night conditions. The electronic dial display was considered easier to read than the electromechanical display only in the night trials, and choice for own car also reflected the improvement with reduced ambient illumination. The electronic curvilinear display showed no difference in perceived ease of reading between day and night trials nor in choice for own car. With the more satisfactory designs of LCD Akeyoshi and Terada (1983) consider that LCDs are now more suitable than other display devices for electronic instrument panels because, apart from their low operating voltage and low power consumption, they show no washout effect and have versatility of format in design.

The range of display styles available using LCD technology is much greater than can be achieved using electromechanical display technology. The

The update rates for the electronic displays are critical for accuracy and user acceptance. If the update rate is too slow then the requirements for accuracy are not met. If the update rate is too fast the subjects complain of constant flicker from the display particularly in relation to the leading 'pointer' segment. In Study 2 a task involving driving to a speed target investigated this phenomenom to some extent and it was found that subjects reported being irritated by the on/off flicker of the leading segment when trying to cruise at a particular speed. A number mentioned that on motorways they set a cruising speed and only varied speed slightly around that value. This is supported by Denton (1969). With an electromechanical display the movement of the pointer is barely discernable but the on/off flicker of the leading segment attracts attention. Payne and Cooper (1981) have reported the only study on update rates for displays and this concentrates on electronic digital displays. They found that the update rate significantly affected the accuracy of using the displays, the viewing time and the perceived ease of use.

The brightness of the electronic displays compared with the electromechanical display also had an effect on the readability and acceptability of the displays. In Study 1 all the displays were presented as slides hence the brightness was the same for all designs. In Study 2 only night time lighting was used in the vehicle simulator hence the brightness of the electronic displays was most apparent. However, the electronic displays were not LCD as they would be in production, LEDs were used for the analogue displays and tungsten filament for the digital display. In the road trials the analogue electronic displays were LCD and were tested under day and night lighting conditions. Duncan and Konz (1974) showed that performance worsened and preference decreased with transmissive LCD displays. For reflective LCD displays performance improved and preference increased as light level increased. Payne and Pollard (1980) in similar experiments showed that the legibility of LCD displays increased as ambient light levels increased although they did not mention whether the LCDs were transmissive or reflective. Bearing in mind the year of the study it is more likely that the LCDs were reflective as these developed as an improvement on the transmissive LCDs.

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The range of display styles available using LCD technology is much greater than can be achieved using electromechanical display technology. The electromechanical digital displays mainly took the form of rotating drum counters. Analogue displays were either circular, vertical or horizontal linear; although variation could be achieved by varying which part of the display moved, the pointer or the scale. With LCD technology the opportunities for variation on analogue and digital display designs are extensive. The variety of electronic analogue and digital displays currently on the market is evidence enough (Pagel and Sterler - Audi Quattro 1983, Birch et al - MG Maestro 1983). The ergonomics research based on electromechanical displays can be usefully applied to certain aspects of electronic display design but in other areas very little is known to guide the designer. In particular scale design recommendations are often appropriate to both electromechanical and electronic analogue displays but there is no ergonomics data on curvilinear display design as this was not previously feasible using electromechanical technology. Similarly, the acceptability of digital displays is greatly enhanced when electronic digital displays are compared with rotating drum counters.

Colour can increase the information capacity and the aesthetics of a display and provides an advantage to electronic displays compared with electromechanical displays. Colours tend to be used much more in electronic displays in cars whereas electromechanical displays obtain colour from filtered lighting over all the display or from colour codes printed on to the display surface. Colours were used extensively on the electronic displays in this series of studies. In particular the effects of colour on the LCDs in Study 3 are worthy of note. The electronic dial display was the most conservative with both dials for speed and engine revolutions coloured amber throughout. The fuel gauge and clock were green and the odometers amber. The electronic curvilinear display had amber scales for both speed and engine revolutions, with amber segments on the tachometer and above 30 mph on the speedometer.

Segments 30 mph and below were green. The fuel gauge and clock were green and the odometers amber. The digital display had an amber speedometer and a blue tachometer. The odometers were amber. Colour is frequently used in line-graphic type displays as an additional means of encoding information (Booth and Farrell 1979). However, in this study use of colour for encoding was not optimum. In the practice period prior to the tests subjects often confused the electronic dial speedometer and tachometer because only the position and the labelling discriminated the two. As the location of speedometers on instrument panel layouts is not standard this added to the confusion. A change of colour or the relative brightness of the two dials would have improved the ease of use of the electronic dial display. The electronic curvilinear display was even worse in that the scales for both the speedometer and tachometer were the same colour, but the spatial separation was limited, hence making discrimination more difficult. The amber segments on the tachometer were brighter than the green segments from 0-30 mph on the speedometer. This meant that the greater length of bright amber segments attracted the subjects' eyes to the tachometer rather than the speedometer. Again this was observed during the practice period and in the case of both displays the errors were pointed out to the subjects. The digital display used both colour and brightness effectively in that the brightest amber display represented the speedometer and the less bright blue display was the tachometer. (Only the digital display had had an ergonomics input to the design). Amber was considered an acceptable colour by the subjects. Palmai, Schanda and Heine (1980) have shown that yellow (compared with green or red) LEDs produce least reading errors. Wright (1982) in a review of display colours showed that yellow was preferable for CRT displays. The drivers' comments indicated that the electromechanical displays printed white on black with amber pointers, lit by slightly blue-green light appeared less interesting to the eye and less bright than the electronic displays.

7.5.2 The electronic analogue designs

The electronic analogue speedometer displays comprised a circular dial with segments lighting up around a scale to indicate scale values, and a curvilinear display which rose at an angle of 35° to the horizontal from 0-50 mph and then curved to the horizontal plane and remained linear from 60-130 mph. The tachometer displays were similar in design and colour except for the curvilinear speedometer which had green segments from 0-30 mph, all other segments were amber.

The scale design in terms of numbering graduations was satisfactory as each 10 mph graduation was numbered. The dial had each 2½ mph segment aligned with an unnumbered graduation whereas the curvilinear display had 5 mph unnumbered graduation which did not align with any 2 mph segments. It could be argued that the dial scale would be equally satisfactory if only the 5 mph graduations were marked but not numbered (Cohen and Follert 1970). Subjects remarked that the 5 mph graduation on the curvilinear scale were confusing and made it more difficult to interpolate in 2 mph segments between graduations.

Arguments could be put forward in favour of both the 2 mph and the 2½ mph segments. The former presents five segments to each 10 mph and the scale rises in 2's, easy numbers to remember. However the segments cannot align with the central 5 mph point. Cohen and Follert (1970) show that interpolation of fifths and even tenths will provide accuracy satisfactory for most situations without graduations over 5" (130 cm) linear scales, similar in length to the curvilinear display. Hence the 5 mph graduation could be eliminated without loss of reading accuracy. The 2½ mph segments present four segments to each 10 mph, but the scale rises in 2½'s. Although the 5 is easy to manage and align with central graduations, 2½ and 7½ are not. It is unlikely that the added accuracy of reading the speed to 2 mph rather than 2½ is advantageous in normal driving. In both circumstances the subjects quickly learned to use the segments in appropriate units but a number remarked that the 2½ units were unnecessarily detailed. In Studies 1 and 2 the electronic dial was read more accurately than the curvilinear display but in Study 3 even in night illumination where the effect of washout was not present for the dial, the curvilinear display was read more accurately. In Study 2 the curvilinear display performed very badly. In terms of perceived ease of reading, however, in Studies 1 and 2 there was little difference between the two designs but the curvilinear display was considered difficult to read by a greater number of subjects. It is not possible to make similar comparisons for Study 3 but in night conditions the dial was considered easier to read by a greater proportion of subjects than the curvilinear display, both compared with the electromechanical dial.

The evidence comparing the ease of reading circular dials and linear scales is based on experiments with electromechanical displays (Sleight 1948, Grether 1949, Graham 1956). The evidence shows that generally circular dials are easier to read than linear scales, particularly when the linear scales are extended as is the case in these studies,although Thomas (1957) does throw some doubt on these findings. However, the evidence may not apply equally well to electronic displays, nor to the hybrid (circular/linear) curvilinear displays often used in electronic displays particularly in cars eg Maestro MG, Montego MG.

The most interesting feature of the electronic analogue designs is the performance of the curvilinear display. In Study 1 about three quarters of the readings were correct after a brief exposure time (less than the dial), in Study 2 only 3% were accurate to ± 2 mph, and in Study 3 85% of the readings were correct to ± 2 mph (more than the dial).

In Study 1 the exposure time was chosen to discriminate between display designs for ease and accuracy of reading and if one takes account of the ergonomics literature it is then not surprising that the curvilinear display performs less well than the dial. The main feature which makes linear scales less easy to read is that they have to be scanned over a wider area than compact dials in order to locate and read the scale value (Sleight 1948). This takes longer than reading a dial and hence for a given brief exposure time as in Study 1 the curvilinear display should be more likely to be read erroneously. This was in fact the case. In Studies 2 and 3 the same explanation should apply and in Study 2 this is the case. However, the performance of the subjects reading the scale is so poor that it requires more investigation. In Study 2 the displays were dynamic LED simulations of the production LCD designs, and in many respects responded as if they were production LCDs. The display calibrations were checked for accuracy and no fault could be found with the system. The vast majority of readings, two thirds, were inaccurate by an underreading of over 6 mph or 3 segments. The underreading error was greatest with speeds over 50 mph where the scale is horizontal. There are a number of factors which together may explain the results. The upward direction of the scale curves at 50-60 mph to produce the horizontal linear scale from 60 mph to 130 mph. In addition the segments from 0-30 mph are green and less bright than the amber segments of the remainder of the scale. Although the vehicle simulator gave some clues as to likely vehicle speed such as simulated engine noise and visual movement of images on the road scene, these may not have been sufficient for subjects to use the clues to enhance scale scanning, compared with real driving where clues are numerous and learned. Subjects' comments indicated that the display 'stretched out over a longer distance'. It is suggested that the combination of these three main factors, insufficient clues to speed, change of scale direction, and foreshortening of the scale due to the green segments being less bright may account for the results. In addition after the segment colour change and the curve at 50-60 mph the scale is linear and uniform in colour, thus reducing the useful reference points. In Study 3 the same principles should still apply and the display should still perform badly in relation to the others. This is not the case, it performs much better in Study 3 than in Study 2. A likely explanation is that in the road trials the subjects had available all the normal clues as to likely speed. 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. In the car driving situation Denton (1969) indicates that vehicle speed display is rarely referred to except when cruising on motorways and in towns. Reason (1974) substantiated the view that drivers use a 'mental' speedometer as well as the vehicle display. In an emergency the 'mental' speedometer tends to predominate in decision making (Shipley and Branton 1974). These additional and powerful sources of information may well have enabled the driver to pre-judge likely speed and hence only scan the scale over a more limited range.

There may be an additional reason as to why the curvilinear display performed better than the dial and that is the nature of the LCDs employed. The curvilinear display was made up of transflective LCD and the dial of reflective LCD. The latter is subject to washout in sunlight. In the night conditions where the washout effect is not present the dial improved its performance but not up to the level of the curvilinear. Probably indicating the generally more satisfactory appearance of the transflective display in terms of contrast, brightness and resolution.

Of the two electronic analogue designs there was little to choose between them on the positive side of the subjective preference scales. This was partly a function of the experimental design in that only the best/worst were identified and the 'best' was overwhelmed by the response to the digital display. (See Section 3.5.2). However, in Studies 1 and 2 the curvilinear was considered most attractive (and least attractive) by the largest group of subjects. It was considered most difficult to read and use for check reading by the largest group of subjects in Study 1 and would be avoided. In Study 2 it was considered the most difficult to read and would be avoided by the largest group of subjects and in Study 3 it was considered distracting, although compared with the dial it performed well in daylight. Generally, very little positive or negative can be reported about subjects' responses to the electronic dial but the curvilinear aroused much interest, generally negative except on attractiveness.

7.5.3 The electronic digital design

The electronic digital display comprised seven segment, 25 mm high digits, with three digits for the speedometer and two for the tachometer. The speedometer was amber and the tachometer blue. The update rate was based on time sampling approximately four samples per second. In Study 1 the digital display like all the others was presented as slides. In Studies 2 and 3 the same tungsten filament display was used. It was not technically possible at the time to produce 25 mm height LCD digits. The digital display did not have the same quality appearance as the electronic analogue displays, as the tungsten filaments and colour filters were mounted on the front of the panel.

In both the performance measures and the subjective preference measures the digital display performed well compared with the analogue designs. It was expected (Grether 1947) that the digital display would produce the most accurate reading scores and the corresponding perceived ease of use was not unexpected. However, the performance on the check reading task was not as the literature would lead one to expect. The ergonomics literature (Baker and Grether 1963, Bailey 1982, Morgan et al 1963 and many others) has tended to recommend counters (electromechanical digital displays) for displaying exact quantity and moving pointer dials for approximate quantity, for check reading, and for direction and rate of change. Morgan et al (1963) evaluates the digital counter thus "The direct reading counter is an excellent means of presenting a large range of quantitive values, and it requires very lttle panel space. It is not satisfactory however, for qualitative reading and tracking". Rolfe (1965) notes that having made such an assessment it would be expected that some experimental evidence would be included to justify it. Apart from reference to Grether (1947) in relation to quantitive reading of altimeters none was forthcoming. A number of studies (Travis 1959, Innes 1964, Rolfe 1964) have shown that in static test conditions subjects tend to read digital displays and ignore analogue displays. Connell (1948) investigated check reading performance, that was verifying that a certain value was or was not being shown, on a panel of four digital displays. Compared with circular dial displays the check reading times for the digital displays were slower and had a higher number of errors. Simon and Roscoe (1956) compared four methods of displaying present altitude, predicted altitude after 1 minute and command altitude. These were integrated vertical strips, and circular scales, digital counters and separated circular scales. The authors attributed the poor performance of the counter display to its failure to provide direct spatial cues. Rolfe (1965) drew the conclusions that the static experiments which have examined digital displays indicate that digital displays are extremely efficient means of displaying quantitative information, provided that the information does not normally involve spatial relationships with other information, in which case some ancillary analogue may be required to ensure the best display. However, while one digital display may be an improvement on a display panel the addition of other similar displays can make check reading more difficult and make discrimination between displays more demanding. He considers that the indications from dynamic experiments must be treated more cautiously. In his view many recommendations which relate to the effectiveness of digital displays particularly under dynamic conditions are not based upon experimental evidence. Warwick (1954) in his review of counters for airborne use came to a very similar conclusion.

The reading of altimeters is a task similar in nature to reading a speed indicator in a car although the altimeter reading task is more complex and the pilot has less external clues to assist than the driver. However, an influential aspect in the analogue-digital debate also relates to time displays. Zeff (1965) and Van Nes (1972) compared digital and analogue time displays. Van Nes (1972) investigated the speed and accuracy in reading small time differences and found that a small time difference can be determined more quickly and precisely from simultaneously presented displays, if the displays are digital. Zeff (1965) compared the two modes of time display with respect to the speed and accuracy of reading and logging (as in Study 1 in this thesis). It was shown that it takes 3½ to 4 times longer to read from an analogue time display than from a digital one. In addition 10 times more errors were incurred. Sinclair (1971) in a review felt that digital time displays have their disadvantages. On many occasions, it is suggested, a clock is not observed accurately but casually, so as to obtain a rough estimate of the time, and an analogue display would be better. Where accuracy is critical such as to air traffic controllers, digital clocks are recommended. The debate over user preference for analogue or digital watches has continued for many years and no evidence has been produced other than those cited above which considers the suitability of the display types for everyday use. The two studies looked at very specific aspects of use of time information, whereas the general public use time information from watches in a great variety of ways.

Nason and Bennett (1973) compared the precision of reading quantitative information for horizontal dials and counters and concluded that optimally designed counters are superior to optimally designed horizontal dials for quantitative reading for accuracy and for speed reading. They stress that in fact rather than counters being better for quantitative reading, dials 'for rough reading', it is more exact to say that counters are always preferable for quantitative reading and more preferred for higher precision reading. They go on to suggest that for check reading a suitably designed counter should be at least as good as a dial, and for rate and direction of change information any possibility of greater confusion would seem to be overcome by the inherent accuracy of counter reading combined with the fact that the operator generally is aware of the gross state of the system. Applying these arguments to the vehicle speed situation considered in this thesis the argument that the digital display should be more accurate for precision reading is borne out by the findings. In addition, the suggested superiority of digital displays for check reading was also borne out, probably due to the increased ease of reading of the digital display and the fact that the driver has much more powerful sources to provide rate and direction of change information than an instrument. These other sources are visual movement of the environment, engine and wind noise and the response of the vehicle through the drivers' proprioceptive system. Hence, if one agrees with Nason and Bennett it is not surprising that the digital display performs so well in both tasks.

Ishii (1980) in a study comparing the visual recognition time of analogue and digital displays in cars found that the digital displays were read more quickly than analogue displays. Ishii measured the visual recognition time when the driver was driving in normal road conditions for both circular analogue and digital speedometers. A seven segment 21.5 mm character height vacuum fluorescent display was used as the digital speedometer. Measurements of visual recognition time were taken using an eye camera attached to the driver's forehead. The results showed that the visual recognition time of the digital display was about 0.1 sec. shorter than for the analogue display. The visual recognition times for different road classes varied with expressway having the longest time and drivers took longer to read the display on cloudy days. However, the difference in the visual recognition time between analogue and digital display remained the same regardless of road types and weather conditions.

Rolfe (1965) in a post script on electronic digital displays for altimeters indicates why the rotating drum counters may have caused problems under dynamic operation. There is no commonly accepted standard for the direction in which the drums should rotate to signify increase or decrease in the value displayed; at high rates of change the drums rotate so quickly that they are no longer capable of displaying clear information; their speed of rotation can be a distraction; when numerals change slowly portions of two numerals may be displayed at the same time. He then goes on to suggest that electro-optical projection digital displays need not suffer from these drawbacks, and the same is true of electronic digital displays. He suggested using arrows to give direction and rate of change, an idea not yet taken up in digital vehicle instrument panels. Nason and Bennett (1973) suggest that ergonomics writers and practitioners seriously question long standing biases which have interfered with the use of counters. The opportunity that electronic display technology has provided to improve digital display design compared to counters, will only enhance the acceptance of digital displays.

The studies reported in this thesis looked not only at the objective performance of the electronic digital display but also at acceptability. This aspect has not previously been addressed in the literature in a systematic fashion. The results show that for the digital speed display used in these studies user acceptance is very high. An argument often raised against digital displays is that people do not like them, although Murrell and Kingston (1966) recorded in their comparison of scalar and digital micrometers that subjects were almost unanimous in preferring the digital presentation.

It is also important to evaluate other response measures and Singleton (1970) cites stress for operators in systems. In the case of instrument installation this is likely to be psychological rather than physiological stress. He admits that techniques for measuring psychological stress currently leave much to be desired but include interviews and measurements of the electrical activity of the brain. Benson et al (1965) give an example of the use of psycho-physiological techniques in comparing scalar and digital altimeter presentations. They found that measures of 'mental load' showed that scalar presentation was preferable. The tasks demanded of the users of altimeters relate not only to direct reading but also to the rate and direction of change when the additional clues from the environment are limited. This may increase the 'mental load' associated with digital displays. However, in driving this situation does not arise because of the predominance of clues from the environment providing rate and direction of change of speed information. Hence, the argument concerning 'mental load' associated with different display types is highly specific to the context and tasks required of the user.

In the present studies no direct physiological measures were taken but a number of subjective measures which could relate to a stress factor were included, such as distraction while driving and ease of reading. The electronic digital display performed better than any of the analogue designs on the subjective measures of ease of reading and ease of check reading in all three studies; it was considered most attractive in Studies 1 and 3; and in all three studies the subjects stated that they would choose the digital display for their own car. Although in Study 2 some subjects thought the digital display distracting, in Study 3 the majority of subjects considered that neither the digital nor the electromechanical dial display were distracting. The comments made by drivers in the road trials were interesting and with hindsight it would have been useful to have included a measure of attitude change. A number of drivers when faced with the digital display stated that they did not like digital displays and mentioned digital watches as an example. However, after they had gained experience with the digital display and compared it with a conventional electromechanical display many changed their minds. Three quarters stated that they would choose the digital display for their own car.

There was some evidence to show that drivers in the older age group (over 50 years) preferred the digital display slightly more than would be expected. It could be argued that older drivers are more conservative and hence that they would prefer the display designs with which they were most familiar, namely the electromechanical dial display or possibly the electronic dial due to similarity of style. Ths was not the case however, more of the older drivers preferred the digital display. There are a number of possible reasons for this, essentially stemming from the drivers' own comments. These are visibility and ease of information processing. The former is exemplified by the comment "I could see the speedometer for the first time in years". Mourant and Langolf (1976) in a study of luminance specifications for automobile instrument panels indicate that although older drivers' visual acuity losses may be compensated by the use of corrective lenses, their losses in brightness and contrast sensitivity mean that they need about ten times as much light as younger drivers. The studies were concerned with brightness of control legends and not with electronic instrumentation. However, it indicates that the brightness and clarity of the digital display was important. In addition the digit size was well above the minimum size recommended by Mourant et al (1976) of 6.4 mm at 813 mm viewing distance for older drivers. This greatly assists those older drivers who wear bifocal lenses for driving. Bifocal lenses are corrected to infinity in the upper portion and 300 mm for reading in the lower portion. Neither is suitable for reading instrument panels at 750 mm. The large digit size and brightness enables the drivers to read the speedometer in spite of their corrective spectacles.

In terms of information processing a comment also exemplifies this "It tells you exactly what you want to know". This may have been a function of the experimental design in that drivers were asked to say what speed was shown on the speedometer. However, they were also asked to say whether the speed was within a speed limit and this check reading caused no problems either. It is more likely that in fact the digital speedometer does provide the driver with exactly the information that he/she requires because speedometers are used primarily for these two tasks, speed and check reading and not for rate of change information as commonly believed.

Denton (1969) in a study of the use made of the speedometer as an aid to driving showed that although wide differences occur in the use made of the speedometer by different drivers only a small number of drivers used the speedometer when making changes of speed on the motorway such as at exits and roundabouts. On the motorway itself, as distinct from the turn off points, all the subjects made use of the speedometer, some using it a great many times.

Interestingly he also noted that there was very little agreement between what drivers think they do and what they actually do.

7.6 Conclusion

It can be argued therefore that the success of the digital speedometer in the studies presented in this thesis, and particularly in Study 3, is due to the fact that the display is clear and easy to read and that it provides the driver with exactly the information which in practice, rather than in theory, he/she requires. As most people use the speedometer to check read their speed against a speed target (possible a speed limit) as exemplified by Denton (1969) the digital speedometer provides the information in the most satisfactory form. The fact that few people used the speedometer when making speed changes, when rate and direction of change is important, indicates that drivers use other, more powerful, sources of information. These include visual information from the outside environment, auditory information from the vehicle, wind noise and kinaesthetic information (Denton 1969, Branton 1977 for train drivers, Reason 1974). Hence the supposed drawback of a digital speedometer, namely no rate and direction of change information, is in effect not a problem because drivers do not use formally displayed information for that purpose. The fact that drivers are not very good at accurately estimating vehicle speed when accelerating and decelerating (Ekman and Dahlback 1956, Denton 1967) is unfortunate and may amount for the high incidence of accidents at roundabouts, but it cannot be used as an argument against the design of the display.

CHAPTER 8 DISCUSSION OF THE RESEARCH METHODS

8.1 Introduction

The structure of the research programme, the evaluation criteria and investigative techniques employed in the three studies are described in detail in Chapter 3 of this thesis. In addition Chapters 4, 5 and 6 contain discussions of the implications of the research methods in each of the three studies.

It is the aim of this chapter to discuss the research methods used in the context of the design and evaluation process and to discuss the implications for ergonomics and the motor industry.

8.2 Evaluation in the design process

Meister and Rabideau (1965) describe evaluations as either formal or informal. Formal evaluations are "those performed through the medium of special tests conducted under special test conditions and involving the gathering of measurement data designed to answer predetermined test questions".

Informal evaluations on the other hand are "performed by the (ergonomist's) examination of the product as a function of consultation with the designer, without any attempt to test the product or to gather measurement data". All the studies conducted as part of this thesis can, therefore, be described as formal evaluations. However, the suggestion is also made by Meister and Rabideau that the advantage of informal evaluations is that they can be conducted quickly for the "impatient" designer and before functioning equipment is available for test. In Study 1 however, a formal test was conducted on product designs in the form of photographic (slide) representations before the functioning equipment was available. The main time components in the study were preparing the artwork and testing a large number of subjects. Neither of these activities took very long. As a result measurement data could be collected in a relatively short time. In Studies 2 and 3 extensive equipment development of the displays, the measuring equipment and in the case of Study 2 the simulator, had to take place prior to the commencement of the trials.

Study 1, the tachistoscope presentation of the different display designs to potential users (drivers), can, in Meister and Rabideau's context, be described as an evaluation of a static mockup. Mockup tests are a common aspect of ergonomics work because they permit the ergonomist to test various configurations prior to hardware fabrications. An additional advantage is that users participating in product tests are often intimidated by hardware in that they are more loath to suggest design changes, whereas with simple static mockups they appear to have few inhibitions about suggesting major or minor design changes. The static mockups method of evaluation is attractive at the early stages of product development because it can be readily changed to co-incide with design changes and new mockups can be assessed. The static mockup is not a functioning model in that it cannot be operated by the user but often the dimensions are those of the anticipated prototype. The simplest static mockups developed as early as possible in the development process have the greatest value.

Two types of ergonomics evaluation of static mockups can be made: observational and demonstrational. In the observational method the ergonomist records observations against a checklist. The demonstrational method was used in Study 1 in which subjects simulated performance of the essential tasks (reading the speed and check reading against speed limits) the ease of conducting these tasks was judged and subjective opinions solicited. Additionally measurements of performance were recorded.

Study 2, the assessment of dynamic models of the display designs in a vehicle simulator, can be described as an evaluation of a functional mockup. A functional mockup is a three-dimensional full scale equipment model which, in contrast to the static mockup, can function in a relatively operational manner. The degree of function in the mockup can vary considerably. In Study 2 the level of function was highly sophisticated, for the speedometer and tachometer operated exactly as they would do in real life, although the other instruments were static. The computer was used to control the displays and record various measurements from the simulator. The major difference between the functional mockups in Study 2 and the prototype production displays in Study 3 was the technology used to present the designs. The development of LCD designs was extremely lengthy and very costly. In Study 2 the display designs were built up from LED components which were readily available and relatively inexpensive. They looked, to the naive subject, sufficiently 'electronic' to be convincing but did not respond to illumination in the same way as LCD designs. Hence this latter aspect could not be tested in the functional mockup stage, Study 2.

The functional mockup can be used to assess the performance of the product design and, unlike the static mockup, to study the performance of users in a simulated operational situation. The functional mockup provides more information than does the static mockup. The ergonomist can, in the functional mockup, evaluate the adequacy of the equipment's operating characteristics. In Study 2 this was essential for the evaluation of the users' response to the dynamic properties of the electronic displays. The analogue display designs operated in discrete segments lighting and unlighting to indicate scale readings. The digital display segments were lit and unlit to produce different numerals. Although there is some literature concerning ergonomics aspects of electronic digital displays (van Nes and Bouma 1978, Buckler 1977) none has been identified concerned with the discrete operational mode of electronic analogue designs.

To some extent Study 3 can be considered a highly *sophisticated functional mockup test*, as one is loath to describe any experiment as truly 'real life' when there are experimenters present and test procedures in operation. In Study 3 the displays were prototype LCD, were installed in standard Ford Granada cars and were driven in normal traffic conditions. However, the opportunity to alter the display designs was available as the displays were prototypes not production equipment. The test procedure in Study 3 closely followed that employed in Study 2 except for variations associated with the requirements of test route and the additional information which could be gained from the tests in different lighting conditions.

One outcome of the research programme was to show how much time must be allowed, when dealing with complex products/systems or with novel applications, for the findings from one stage of the research to be incorporated into the design process and assimilated before the next stage is embarked upon. LCD displays take a long time to build particularly when the design is novel, hence building the displays for use in Study 3 had to begin before the results from Studies 1 and 2 were available. This meant that, for example, the tachometer scale and segment colours in Study 3 were not optimum. As Meister and Rabideau stated in 1965, designers are 'impatient', and have not changed their nature in the ensuing 20 years. Ergonomists must develop research methods which can fit into the design process in an effective fashion and the education of designers must continue.

8.3 The use of simulation in ergonomics

Simulation, according to Stammers (1983) is used in three main roles in ergonomics. Firstly in the development of man-machine systems where various forms of simulation are used to predict optimal equipment design or task assignments. In the second role, simulators can be used for measurements of performance or physiological indices when data collection is not possible in the real situation. The aim in this case is to collect data that best approximate to the real situation. In the system development case, the emphasis is on low cost alternatives to building the real thing (as in Study 1) and then trying it out. In the second case, the concern is more with simulators that give data that are valid approximations to the real thing (as in Study 2) and therefore puts emphasis on high face validity of the simulator. There is a third area of simulation, that used for training. In this case, the focus of interest is on the transfer of learning that occurs from practice on the simulator to real life.

8.4 The role of simulation in the product/system development process

The concept of simulation in the product or system development process is linked closely to evaluation and later to training. Evaluation, using various levels of simulation as described in Section 8.2, can be used as a design tool, a research tool and also a training tool.

As a design tool the use of simple simulations, static mockups, can be an integral part of the product assessment and development procedure. The ergonomist and designer can work together using simple simulations to achieve one or more approximations to the desired product or system. At this stage design flexibility is essential, therefore the simulations must be quick and easy to construct. This is amply illustrated in Study 1. The static mockups were produced as artwork which could easily be amended. This technique can, in certain circumstances such as in Study 1, also enable the ergonomist to conduct simple tests to investigate some aspects of the ease of use of the product. In the area of display design particularly, this is a useful technique and one which has been used by the author in a number of different studies. For example, in a study of environmental controls for a luxury vehicle, a symbol for the humidity control was designed. A number of alternative designs were produced as artwork and tested with other symbols for associative strength and readability using a box tachistoscope (Galer and Spicer 1981).

The process of design development often identifies queries about the product or system in terms of ease or convenience of use, safety and so on which the ergonomist is not able to answer from the published literature. This is particularly so when ergonomists are working with sophisticated products or novel technology applications as very little is published in this area.

In this case the ergonomist uses simulation as a research tool and the functional mockup is appropriate in these circumstances. The ergonomist needs to conduct carefully designed and controlled experiments to provide answers to questions posed during the design and development process. In addition, the outcome of the experiments may be more generally applicable not only to the specific product or system under development but to other similar products or systems. Study 2 described in this thesis is an example. Although the tachistoscope experiments conducted in Study 1 provided some design information it left certain fundamental questions unanswered. These were mainly related to the dynamic properties of the electronic displays and could only be tested in a functional mockup. Study 2 provided the designers with new information about the ease of reading and driver response to the operational aspects of the electronics displays including the update rates, the discrete action of the segment pointers, the change of digits. This information was essential for the development of these particular products but could also be applied to the development of other equipment in the future. The functional mockups enable greater control over the experimental conditions and the experimental measures. It was only in Study 2, for example, that measures of driver response time could be taken. The functional simulations also ensure that tests on products where any safety aspects are involved can be conducted. In a study carried out by the author and her colleagues (Galer et al 1983) a proposed design of in-vehicle trip computer was installed in a functional simulator and a series of experiments conducted to identify the optimum logic sequences linking nine trip computer functions with three call-up buttons. When the initial sequence was tested drivers found it difficult to operate, made many mistakes, and took their eyes off the 'road' for long periods of time. It would have been hazardous to have tested the initial sequences on the road.

Later in the product or system development stage the functional simulation can be used as a training device or to assess the adequacy of training or instruction procedures, again without any hazard to the users or the experimenters. In another study (Southall and Galer 1984) the instruction manual for a complex electronic instrument panel was assessed in a vehicle simulation. The outcome not only provided an evaluation of the instruction material but also identified areas for design development in the product itself.

It is not often possible in the context of commercial research to assess designs/systems using a variety of test methods. However, in the studies described in this thesis it was possible to assess the displays under different levels of simulation. Usually, when contributing to the design process those designs or products which do not appear to be acceptable, for any of a number of reasons, in the early stages are modified or abandoned for subsequent stages. This means that designs are rarely assessed through all stages of the design process, hence the validity of the simulation cannot be verified. Designs considered to be unsatisfctory in the early stages are eliminated and hence cannot be shown to be unsatisfactory, or otherwise, in simulations which approximate more closely to real life. In the studies described in this thesis, because of the LCD display development lead time, it was not possible to change the designs radically from one study to another. One interesting outcome of this is that the poor performance of the electronic curvilinear display, expected from the ergonomics literature and noted particularly in Study 2, was not upheld in the more realistic conditions of Study 3. It was seriously considered whether it was worthwhile including the electronic curvilinear display in the road trials after the outcome of Study 2.

8.5 Simulation fidelity

Simulation has been defined earlier in the thesis (Section 3.7) as an attempt to reproduce the characteristics of a product/system, situation, event or phenomenon in a setting other than the one in which the original occurs.

Although a number of vehicle simulators have been developed (O'Hanlon 1977, Allen, Klein and Ziedman 1979, Blaauw 1979) the validity of these simulations has only rarely been investigated in detail. In the literature validity is generally defined with respect to two aspects (Mudd 1960, McCormick 1970). The first is the correspondence between the behaviour of the user in the simulator and in the real situation. The second focuses on the physical correspondence between the two systems, simulation and real life. As Rolfe et al (1970) stated "the value of a simulator depends on its ability to elicit from the operator the same sort of response that he (she) would make in the real situation". Most simulator studies mention the physical correspondence but do not often analyse the behavioural correspondence. Many vehicle simulations have been developed to study driver response to various aspects of the driving task such as the influence of motion and audio cues (McLane and Wierwille 1975), steering characteristics (McRuer and Klein 1976) and other vehicle response characteristics (Repa 1976). In the studies reported in this thesis the levels of simulation used are described in detail in Chapters 4, 5 and 6. The purpose of the studies undertaken was to assess driver response to a product as a component of the vehicle simulator ie the electronic instrument panel in a vehicle, rather than aspects of driving behaviour or training. In this sense the development of the simulations, particularly that in Study 2 were orientated towards those aspects related to the product under test. The equipment used in the studies closely resembled the production displays in some respects but, according to the level of simulation, were quite unlike in others. The display design details were almost the same throughout. However, the displays were static in

Study 1 and of a technology, LED, different in Study 2 to the production technology, LCD. Those aspects of the environment and the task associated with the instruments were reproduced to different levels, and were chosen for their direct relevance to the performance of the products under test. Chapter 3 describes the levels of simulation in more detail.

Although it is not possible directly to compare the results of the tests for each of the three levels of simulation fidelity, the performance and preference measure trends canbe assessed. In Studies 1 and 2 the subjects made comparisons between all the display designs, whereas in Study 3, for practical reasons, only one electronic design was compared with the standard, the electromechanical design. Hence the inability directly to compare the results at each level of simulation.

8.6 Predictive ability of the simulations

If Study 3 is considered to be real life then it is interesting to assess how closely results from Studies 1 and 2 correspond to the results from Study 3. There are two general measures which can be assessed, the performance measures and the preference measures. These are also discussed in more detail in Chapter 7.

The performance measures show that in terms of accuracy of reading and check reading the results from Study 1 resemble those from Study 3. The results from the dynamic tests in Study 2 resemble the results of Study 3 only for the electronic digital display. In all except this latter case the accuracy of reading results for Study 2 show a lower level of accuracy obtained by the subjects than in Study 3. All the displays, except the electronic dial display in daylight conditions, performed better in the road trials, Study 3, than in either level of simulation. It can be argued that the displays should be read more accurately in road trials (real life) because the subject can make use of the various clues to speed available from the environment. This was clearly the case in these studies. The vehicle simulation was the study in which the dynamic properties of the displays could be tested in more controlled conditions than in road trials. However, the resemblance of the performance results from Study 2 to the road trials was limited. The drivers' comments and their subjective responses did correspond somewhat better. In these tests therefore the advantages of road trials emerged as dominant.

In terms of user preference only four measures were used throughout, ease of reading and check reading, attractiveness and choice for own car. Distraction could only be assessed in dynamic test conditions (Studies 2 and 3) and general preference was only included in Study 3. Also it must be remembered that subjects were making different judgements in Studies 1 and 2 compared with Study 3. Some general trends tentatively emerge from the data. In terms of perceived ease of reading and check reading the digital display's high performance was reflected in each study. There is no clear pattern for the analogue displays. Also the subjects consistently stated that they would choose the electronic digital display for their own car. In terms of distraction while driving the drivers' comments in Study 2 indicated that there may be some problems with the electronic displays but in Study 3 for all three displays the majority of drivers stated that neither display was distracting.

It was unfortunate that the practicalities of Study 3 meant that, in the end, the full validation of the various levels of simulation could not be achieved. The prototype LCD display designs were not all available for test at the same time.

8.7 Product evaluation

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), if any, would be most easy to use and most acceptable. It was assumed that from a technical point of view each of the designs would perform equally reliably and efficiently.

As described in Chapter 3 a number of indications for the evaluation can be identified. Firstly, the tests should involve users or potential users; secondly, comparisons are to be made between different designs of the same product and thirdly the criteria on which the designs are to be assessed should include both objective performance measures and subjective preference measures.

The panel of users in these studies comprised over 400 drivers of both sexes and ages from 17 years upwards. As the product was designed for the general driving public there were no other constraints on the choice of subjects. They were considered to represent the general driving public. The number of subjects used in the studies was very large compared with other reported studies such as Armour (1985) who used 38 subjects and Ishii (1980) who apparently used only four. The large number of subjects used in the studies had several benefits, in particular there was little chance of bias influencing the results, and it gave the company confidence in the outcome of the research. This is especially important where sophisticated or novel concepts, products or systems are involved.

When products are compared in different levels of simulation it is important that the tasks the users are given should be valid representations of the real life situation. As Rennie (1981) states ...."the tasks should be selected according to a task analysis; and should follow a logical sequence". In these studies the tasks were strictly limited to those associated with the displays. The primary tasks were reading and using the instruments, the secondary tasks (from the point of view of the experiment, though not necessarily the subject) were related to driving the vehicle simulator or car. There has been a considerable amount of research related to the driving task (e.g. Denton 1967, 1969, 1971, Brown 1962, Blaauw 1982) and Denton (1969) has looked specifically at the use made of the speedometer. From the evidence it was considered essential that the tasks should enable judgements to be made about ease and accuracy of reading the speed, and check reading the speed against a speed limit. As a result of carrying out these tasks it should be possible to evaluate the designs against the ergonomics criteria of safety, efficiency, comfort, convenience or ease of use and acceptability as related to the product. In these studies the performance measures assessed safety and efficiency in terms of accuracy of use, and the preference measures assessed subjects' views concerning ease of use and acceptability. Comfort was assessed only indirectly in that subjects may or may not have mentioned comfort related aspects such as angle of view, or eye strain in their general remarks.

There are no clearly defined thresholds against which these products (the displays) can be assessed on the ergonomics criteria. There is no minimum accuracy of reading, nor maximum level of distraction, for example, prescribed for these types of products. Therefore, it is difficult to make absolute judgments without firstly defining the range of acceptability. When conducting comparative evaluations this problem is alleviated to some extent in that relative values can be assigned to the product performance. Hence, products can be ordered according to their performance on the criteria, and the best and worst products identified.

This does not, however, indicate whether all or any of the products are ultimately satisfactory, only that some are more satisfactory than others.

In commercial terms this is often very useful information, particularly if the company's rival products are included in the evaluation. However, it is not always as satisfactory from the user's point of view.

As mentioned earlier, it was assumed that from a technical point of view each of the display designs would perform equally reliably and efficiently. This assumption is becoming more realistic in the area of product evaluation as technical standards for products improve. However, the ergonomics standards, the features such as ease of use, convenience, and so on are not invariably met in products. Companies are becoming increasingly aware that as the general technical standard of products improves it is only on the ergonomics criteria that their product can gain a market edge. An example of this has been quoted earlier (Galer and Simmonds 1985). In a study of car instrument panel lighting no difference was found between the five colours in terms of accuracy of use. Hence, on those grounds, the company could have chosen any of the five colours for their next range of vehicles. However, the user preference measures showed very strong preferences and dislikes for certain of the colours. Not only that, but preferences and dislikes could be attributed to different age and sex groups in the user population. Hence, the company could appeal to different market sectors. In this case the company made their decisions based on subjective user preference information.

8.8 *The benefits of the evaluation programme*

When Ford Motor Company first considered applying electronics technology in its vehicles there were a number of questions the answers to which were not obvious. The designers were freed from the design constraints of electromechanical displays and were able to present vehicle information in a variety of ways. What they did not know was how the user, the driver, would respond to the novel designs both in terms of accuracy of use and preference compared with the standard electromechanical displays generally in use.

Study 1 was an example of a simple experiment which not only provided the designers with ergonomics information on the designs as drawings, but also provided test results on readability. The tests were highly controlled in that the subjects all received the same information and gained the same experience. There were no risks to the subjects or experimenters, the study was cheap and quick to conduct compared with prototype development, there was high design flexibility if required, in that the artwork could readily be amended and it was conducted at a very early stage of the company's development programme. The results gave a broad brush overview of the likely response from users even though the displays were static. Meister and Rabideau (1965) argue that it is not generally possible to conduct tests at such an early stage in the design development programme and that the main contribution of the ergonomist is to provide comment on drawings. This is not the case with the study described in this thesis, and in other studies involving quite different aspects of display design (Galer and Spicer 1981) similar techniques were equally successful. It is argued, therefore, that the simple use of tachistoscopic presentation techniques can provide valid information about display designs quickly and cheaply. The results of Study 1 held up well when compared with the results from the road trials in Study 3.

Study 2 was an example of new product/system testing in a functional mockup or simulation. The tests were controlled to a high degree with the exception of the subjects' driving style which would have affected their experience with the displays. There were no risks to the subject or the experimenters and a number of objective measurements could be taken using the instrumentation in the simulator, such as subject response time. If an appropriate simulator is already available then the tests can be conducted readily. However, suitable simulators are not usually readily available and instrumented to activate and record the appropriate vehicle and display features. The dynamic models also have to be produced and operated, which immediately restricts design flexibility. In the vehicle simulation used in Study 2 the vehicle controls responded to actions from the subject, particularly in terms of acceleration and deceleration and steering actions, by influencing the computer-generated road scene. The displays under test also responded to the subjects' control actions and hence gave realistic readings. In two later studies (Galer et al 1983, and Southall and Galer 1984) different simulations were used effectively. The displays under test, namely a trip computer and vehicle condition monitor (Galer et al 1983) and a full instrument panel including trip computer and vehicle diagnostics (Southall and Galer 1984), were installed in more simple car rigs and the displays activated by the experimenter via microprocessor controlled display simulators external to the vehicle simulators. The vehicle controls did not respond to the subject's control actions but the subject was able to carry out the actions. The road scenes were video recordings of a route taken from the drivers' seat in a car. It was considered essential for the tests that the subject's attention was directed primarily towards the road scene as in normal driving, only turning attention away to operate the equipment under test. The video road scene was found to be highly successful for these tests in that subjects gave priority to looking at the road scene. This indicates that the level of sophistication of the simulation in Study 2 may have been unnecessarily high. The information gained from Study 2 on the users' response to the dynamic properties of the display designs was essential however, for establishing the designer's confidence in the tests and hence the designs.

Study 3 was an example of product/system testing in real life conditions (except for the experimental schedule) using high level prototype displays. By this stage the design flexibility was limited in many respects, because each prototype was extremely expensive to produce, but the design development was still in relatively early stages as the contract was initiated by the Advanced Research Group of the company. This meant that production deadlines were not imminent and further prototypes could be tested at later stages in the process. In view of the great cost of changing from electromechanical displays to electronic displays the company had to be certain that there were clear advantages for the driver. In addition, the outcome of Studies 1 and 2, namely that the electronic digital display was performing extremely well, was highly controversial both within the company and in the automotive world generally. The company were loath to accept the findings until what they considered incontrovertible evidence could convince them of the findings. Road trials with a large group of the driving public was the only answer. The tests were highly controlled in many respects with the exception of the day to day traffic environment and the subjects' driving styles. All 204 drivers carried out the tests in a very similar manner, in day and night lighting conditions over a variety of road and traffic conditions along a test route. The major outcome, the outstanding performance of the electronic digital display, remained the same in all three studies. Not only, therefore, did the company receive evidence concerning user response to the designs tested but a considerable amount of additional information was obtained which was of more general benefit in the design of electronic displays. The company's confidence in the findings was also considerably enhanced by the research.

The studies described in this thesis present a classic example of the role of ergonomics in the design development process. The products under development were sophisticated and new technology was being applied in a novel environment. There were many aspects of the use and acceptability of these new products which could not be predicted. This is not always the case. There is a considerable body of ergonomics information which can be applied to products or product developments. The information can be found in design guides such as Bailey 1982, van Cott and Kinkade 1972, Shackel 1974, or from the specialised ergonomics literature (Galer and Simmonds 1984, Gorrell 1980, Simmonds 1979), or from the special expertise of individual ergonomists. It is not always necessary to conduct extensive evaluations in order to make a useful ergonomics contribution to the design process. Expert appraisals can be carried out by ergonomists; limited user involvement in tests, group discussions, and so on can be undertaken; as well as the formal product evaluations described in this thesis and in recent publications (Galer 1984, 1985).

The value of the ergonomics contribution in the total research and development budget must be in proportion to the requirements of the product. In the studies described in this thesis the costs involved in research and development for electronic vehicle instrumentation plus the re-tooling for production were very great indeed. The costs of making the wrong decision were also very great and the information available on which to make those decisions, from the ergonomics point of view was extremely limited. If, in the future, the electronic displays had to be withdrawn due to lack of user acceptability the costs would have been enormous. This is not always the case and with simple products or those about which much is already known then extensive evaluation programmes may well not be necessary or even desirable.

8.9 The development of an ergonomics design guide

A further outcome of the evaluation programme described in this thesis was that it stimulated a great deal of interest among designers within the Ford Motor Company. These designers were responsible for the design of electronic instrumentation not only for primary displays but also secondary displays, in-car entertainment, environmental controls and many other applications of new technology. Some of the queries could be answered from the research undertaken and some from a mass of literature of varying quality and applicability, others could not.

The Institute for Consumer Ergonomics was commissioned by the Advanced Vehicle Concepts Group of Ford Motor Company to produce guidelines for their designers and engineers on ergonomics aspects of electronic instrumentation. The aim was to produce a coherent reference manual based on the available literature and research studies. The design guide was seen as an enhancement to the design process which brings information to the attention of the designer. The design guide also attempted to integrate the rapidly changing technology and the requirements of vehicle design to the characteristics and capabilities of the drivers (Simmonds and Galer 1984). The design guide was in use for several years within Ford Motor Company, during which time it was reprinted on a number of occasions. The design guide is now published by the Society of Automotive Engineers (Galer and Simmonds 1984) and is presented in Appendix 1.

8.10 Conclusion

The studies described in this thesis provide a classic example of the role of evaluation and simulation in the design and development process. The level of simulation in the studies progressed from the simple static mockup in Study 1 to the sophisticated functional mockup in Study 2 and on to real life prototype tests in road trials in Study 3.

The benefits of the studies as part of product development programmes, and particularly as part of an Advanced Research programme are:

- the company has the benefit of an ergonomics input at all stages in the design and development programme

- queries about the product and user response which cannot be answered from available information can be answered by research via controlled experiments

- the company gains knowledge in that area which can be used, as appropriate, for the development of other products

- the company has confidence in the application, acceptability and safety of the recommended products

- advantage can be taken of the experiments and knowledge gained to design instruction manuals for the potential users of the product, or the potential designers of new products

- the company has a model for future product design work which has been tried and shown to be beneficial

- the company can use the example of the research programme and the knowledge gained from it for in-house education and marketing

- the company can establish a market edge, if it is equal technically and in terms of cost to its rivals, in that the product is known to be acceptable to the potential customer.

CHAPTER 9 CONCLUSIONS

9.1 Introduction

The study reported in this thesis has ranged over a number of areas within ergonomics and outside the discipline. These areas include display design dating back to the immediate post-war era for electromechanical displays to the latest information on electronic displays; the use of simulations for system and product development, for the assessment of driver behaviour and for training; driver behaviour on the road; the role of ergonomics in the design and development process; advances in electronic display technology and the application of those developments.

This concluding chapter aims to bring together these diverse fields and show what contribution this thesis has made to its own subject, ergonomics, and to the motor industry. The opportunity is also taken to take a tentative look forward to the future.

9.2 Conclusions from the research findings

The studies set out to answer two main questions set by the Ford Motor Company

- Are electronic displays preferable to electromechanical displays from a user's point of view? and if so

- Which of the electronic designs tested is most satisfactory?

In true academic fashion the answer is - it depends.

It cannot be said from the research findings that the electronic displays as a group, performed better than the electromechanical dial display. The results are only clear for one electronic display design, namely the digital display, which performed consistently better than the electromechanical dial display.

In terms of the objective measures, namely accuracy of reading the speed and accuracy of check reading the speed against a speed limit, the digital display performed better than any of the other displays with accuracy scores for reading the speed of 97-100%. This result is not as surprising as the check reading results which still showed the digital display to be better than the analogue displays.

- In terms of accuracy of reading and check reading the speed only the electronic digital display consistently performed better than the electromechanical display.

Of the analogue displays in Study 1 the two electronic displays performed better than the electromechanical display. It was only in this study that the illumination of the displays could be said to be equal. In Study 2, the electromechanical display performed better than the electronic analogue displays. In this test, conducted only in night conditions, the electromechanical display was edge lit whereas the electronic displays were LEDs. In Study 3 the performance of all the analogue displays improved but was influenced by the day and night lighting conditions as would be expected with LCD designs. The electronic dial display performed better in night conditions because it was of an older type LCD (reflective) than the curvilinear display (transflective LCD) which performed well in both conditions.

- Neither of the electronic analogue displays performed consistently better than the electromechanical display for accuracy of reading and check reading the speed.

In terms of the user preference measures, namely perceived ease of reading and check reading, attractiveness, distraction, choice for own car, the digital display generally performed better than any of the other displays. It was considered easiest to read and to check read against speed limits, and more drivers stated they would choose it for their own car in all three studies when compared with the other displays. It did not perform so consistently well on attractiveness or distraction while driving. In terms of attractiveness the mode of presentation, tungsten filaments front mounted onto a panel, was not as aesthetically pleasing as the LCD or LED presentations. The electromechanical display generally performed better than the electronic displays in terms of distraction while driving but of the electronic displays the digital display performed well.

In the road trials of Study 3 all the displays were read and check read reasonably accurately although the digital display performed best. However the drivers opinions clearly indicated a preference for the digital display.

- The electronic digital display was consistently preferred by the drivers on most of the preference measures including ease of reading and check reading and choice for own car.

In answer to the question 'Which electronic display is most satisfactory from the driver's point of view?' the electronic digital display is clearly the leader.

This is not to suggest that any other design of digital display would provide the same results. The tests carried out in these studies, those of Ishii (1980) and Armour (1985) used digits of 25 mm, 21.5 mm and 25 mm height respectively. Armour also used 6.4 mm height digits and found an increase in speedometer reading times, although he does not mention reading accuracy in his report. One of the advantages of the digital display mentioned by the drivers, particularly those in the older age group, was that it was large and hence clear and easy to read. Those people wearing bifocal lenses also found that they could read the large digits readily even though their lenses were not corrected for the 750 mm viewing distance for the instrument panel. If the digits were larger than 25 mm height there is a possibility, mentioned by some of the subjects, that the changing digits would be more distracting. The colour and brightness may also influence the distraction aspects of the display as undoubtedly will the update rate of the numerals. The attractiveness of the digital display can clearly be enhanced by good design and a more satisfactory mode of presentation than the tungsten filament digits which had to be used in the study. In spite of this, no problem was found with the amber, 25 mm height digits with a sampling update rate of 4 times per second.

- It cannot be concluded that the results arrived at in these studies would apply to other designs of digital speed display.

9.3 Conclusions from the research method

The main conclusion that can be drawn from an assessment of the research methods is that simple tests on static mockups can provide useful information for designers very early on in the design process. The mockups, artwork presented as slides, had the advantage of design flexibility and yet still enabled some tests to be conducted. The author has used tachistoscopic presentation techniques subsequently for other aspects of display design equally successfully.

- Static mockup evaluations can provide useful information early in the design process.

The vehicle simulator tests were essential to test the user response to the properties of the displays in controlled and safe (off-road) conditions. In terms of predicting *actual levels of user performance they were disappointing*, particularly for the analogue displays. The road trials were also essential to validate the findings from the two laboratory tests and to assess the driver response to the LCD designs in real life with various lighting conditions.

Although Study 1 provided useful information about the display designs all three stages of the research programme were essential because entirely new ground was being covered. In the future, more simple tests may suffice because the groundwork has already been prepared in these studies.

- All three studies were necessary to establish the reliability of the findings and to break new ground in ergonomics.

The *importance of the two sources of evaluative information* is also evident from the studies. Both objective measures of performance and subjective measures of user preference were taken in the studies. The objective measures gave an indication of the accuracy with which the designs can be used both absolutely and relative to the other displays. There is no clear level of expected accuracy for speedometer reading against which the designs can be assessed, but the results relative to the standard, the electromechanical design were enlightening. The perceived ease of reading and check reading corresponded well with the scores for accuracy of reading. However, it is also interesting to note that that ease of reading did not necessarily correlate directly with drivers' choice of display for their own car. In the trials the subjective measures more clearly indicated design recommendations than the objective measures where all the display designs performed reasonably well. Hence it is argued that both objective and subjective measures must be taken when evaluating products.

- Objective and subjective measures both provided valuable evaluative information.

The number of subjects used in the trials was high compared with most other studies reported in the literature. Over four hundred drivers tested the displays in the pilot and main studies whereas in Armour's study (1985) thirty eight subjects were used and apparently only four in Ishii's study (1980). Very often the number of subjects is not reported. The large number of subjects arose from the requirement that each subject should only take part in one study and also that a representative sample of the driving population was employed. Very often in the motor industry tests are conducted on the designers, engineers and their colleagues, who cannot be said to represent the range of anatomical, physiological and psychological capabilities of the driving public. This is particularly important when subjective measures are employed because the driving public's views, requirements and expectations of cars may well be quite different from those whose livelihood is involved in the product.

- It was essential therefore, that a large representative sample of the potential user population took part in the studies (otherwise we may never have discovered that older drivers prefer the digital display).

9.4 What contributions have the studies made to ergonomics?

A review of the ergonomics literature related to the design of displays shows the enormous amount of research which has been conducted over the years. Most of this research has been concerned with electromechanical displays, both analogue and digital. Work on electronic displays has mainly been concerned with applications in the aeronautical field and VDUs in offices and elsewhere. Very little information has been added to the body of ergonomics knowledge concerned with the application of electronic displays in cars. The information has primarily been concerned with detailed aspects of the display technology such as in the publications of Shepherd, Beatty and Duncan.

- This thesis contributes information on user response to electronic vehicle information both in terms of objective performance measures and subjective preference measures.

A further assessment of the ergonomics literature indicates that although a considerable amount of research has been carried out on drivers' use of vehicle instrumentation such as in the publications of Denton, Armour and Matthews very little has been conducted on the relative merits of speed display presentation mode. Armour and Ishii looked at speed of reading certain types of display but no information was reported on the relative accuracy of use or driver preferences.

- This thesis contributes information on the comparative merits of speed display presentation modes.

The debate over the merits of analogue or digital presentation of information has always been active, with studies by Sleight, Rolfe, Nason and Bennett spanning four decades. The contexts of these investigations have varied and include micrometer scale design and altimeter design. With the advent of electronic technology in the motor industry the interest in analogue and digital presentation mode extended to cars, particularly as electronic digital displays are much cheaper and easier to produce than electronic analogue displays. The previous literature has been interpreted as indicating that although digital displays were satisfactory for precise reading they were *not* suitable for check reading or rate and direction of change information.

- This thesis shows that electronic digital speed displays in cars are easy to use for all relevant aspects of driving.

- Ergonomists should review the recommendations given in design guides and seriously question long-standing biases which have influenced the use or non-use of digital displays.

In the studies reviewed for this thesis very little evidence has been found concerned with user preferences for different display modes. Murrell, Nason and Bennett report favourable user reaction to digital displays but these represent the few references to user opinion. This study has taken the opportunity to investigate not only accuracy of use but also user opinion on several factors including perceived ease of use, attractiveness and choice.

- This thesis, therefore, contributes to the body of ergonomics knowledge concerned with user opinions about analogue and digital speed displays.

It is only since the advent of electronic display technology that the hybrid curvilinear display designs could be assessed, as in the past these were very difficult to achieve in electromechanical mode, and no research on curvilinear displays has been found in the literature.

- *This thesis contributes to the body of* knowledge relating to curvilinear displays, although precisely what it contributes is debatable.

The operating mode of electronic displays particularly that concerned with the indication of scale values has been neglected in the ergonomics literature with the exception of a small number of studies on digital display update rate. Electronic analogue displays indicate the scale value by lit and unlit segments around the scale. The 'pointer' in these studies was the end of the last lit segment with cumulative lighting of segment to produce an arc. Although this aspect was not tested systematically there is an indication that the 'lit arc' concept may be easier to read than the 'angle of inclination' concept prevailing for analogue dial needle pointer displays.

- This thesis makes some contribution to the understanding of electronic display operating mode.

The evaluation methods employed in the study were classic examples of static and functional mockup evaluations. However, the success of the tachistosopic method for making an initial assessment of early design concepts is a useful tool for the ergonomist.

- Tachistoscopic presentation techniques can be added to the ergonomists' tool kit for various applications related to the initial assessment of display concepts.

During the course of the research programme a great many queries were raised by designers and engineers about ergonomics aspects of electronic display design, some but not all, of which could be answered from the appropriate application of information in the literature. This literature was not readily available to designers nor was it in a form which they could readily apply. Hence the publication SP576 produced as an outcome of the research programme, has brought together a wide variety of information in a design guide form for use by designers.

- The design guide (see Appendix 1) is a starting point for the accumulation of knowledge about ergonomics aspects of electronic displays, in a form of which can be readily applied by designers.

9.5 What contributions have the studies made to the automotive industry?

Until the advent of electronic displays for automotive applications the interest in digital presentation of speed information was limited. However, as electronic displays were developed the interest, from the electronics engineers, in digital displays grew because they are very much easier to engineer than analogue displays.

Apart from Ishii's study in 1980 there was no user information on electronic digital displays, as Armour's study, although conducted in the early 1970s was only published in 1985. These two studies were concerned with speed of reading whereas the studies described in this thesis were concerned with both user performance and preference. Hence until the first publication of the results of Studies 1 and 2 in 1980 there was no information on use and driver acceptability of electronic speed displays. (Although analogue and digital tachometers were included on the instrument panels their performance was not systematically evaluated.)

- This thesis has provided a firm base for the automotive industry seriously to consider digital speed displays for cars.

Knowledge of drivers' use and the acceptability of analogue displays had previously been based on electromechanical displays, particularly circular dials, occasionally linear strip displays, and fixed window moving drum quasi-digital displays. The automotive industry had very little information about the ease of use and acceptability of electronic analogue displays. In the studies reported in this thesis two forms of electronic analogue display were subjected to the test programme, a circular dial and a novel design curvilinear display. The operating mode for indicating scale values in each case was the same namely cumulative lit segments with the edge of the last lit segment acting as the 'pointer'. Although this aspect was not studied systematically a considerable amount of information about this mode of operation was produced.

- This thesis has provided some information for the automotive industry on user response to the mode of operation of electronic analogue displays.

- The studies have also provided a considerable amount of information on the electromechanical dial display included in the tests, a display found in a variety of current vehicles.

It is hoped that this research programme has indicated to the motor industry by example, how ergonomics can be incorporated into the design and development process. When the study began in 1978 it was considered to be a fairly revolutionary step but the interest in the study from within the company, ultimately resulting in the design guide showed that at least Ford Motor Company benefitted from the association. The techniques used were not new, they were a logical progression from static mockup, to functional mockup in a vehicle simulation and on to real life road trials. However, the methodology set a basic pattern for product evaluation. In addition, the ease of conducting the tachistoscope presentation laboratory study showed the company how readily design concepts could not only be appraised by ergonomists but also tested by users. A number of other studies (unpublished) were subsequently carried out for the company using the same techniques with other display concepts. Electronic displays, particularly LCD can be extremely expensive to produce as prototypes for testing, and once produced the design flexibility is immediately compromised. Hence the ability to conduct evaluations on designs, before prototype production, while maintaining design flexibility is very important.

- The motor industry has gained a useful technique for early display design concept evaluation which provides both an expert appraisal and user tests.

- The research programme has also established a pattern for future novel display evaluation, with a working example for the motor industry to use.

As mentioned in Section 9.4 the literature pertaining to electronic displays, particularly in relation to automotive applications had never been readily available to designers and certainly not in a form which they could easily use when designing electronic instrument panels.

- The motor industry, through its own interest and demand, has gained a design guide on ergonomics aspects of electronic display (Society of Automotive Engineers SP 576 1984).

9.6 The way forward

Although the electronic digital display performed well in these studies there were some aspects of the design which were not so clearly outstanding, these were attractiveness and to a lesser extent distraction while driving. Although van Nes and Bouma and others have conducted a number of studies on the legibility of segmented digital displays further work on the aesthetic aspects of electronic digital displays would be beneficial. Some such studies have been conducted by the author and her colleagues (unpublished). It is difficult, however, to record improvements in performance when the accuracy of reading is already almost perfect (97-100%). Subjective measures of preference should prove more successful. The acceptability of digital displays can also be assessed in terms of the interaction with other tasks or task requirements. For example, the use of digital displays in one aspect of an integrated display may make the performance of a task associated with another aspect of the display more effective.

- Further work on the aesthetic design of electronic digital displays using subjective assessment measures would be beneficial.

- Research on the interaction of analogue and digital displays in integrated displays and the effect on overall performance would be interesting.

- Research on optimum update rates to further reduce distraction would be beneficial. Distraction is probably closely related to digit design, hence the two aspects should be studied together.

The mode of operation of the electronic analogue displays was not studied systematically particularly in terms of indicating scale values. There is the possibility, even within designs identical to those used in the tests, that the segments could be cumulatively lit or that only the single segment corresponding to the 'pointer' indicates the scale value. The size of the segments (2 and 2½ mph in these studies) should also be investigated in more detail. Smaller segments would give an appearance of more continuous motion rather than the discrete steps of the larger segments. This must be considered in relation to the update rate and damping of the leading segment to reduce flicker and possibly distraction, and also the desired level of accuracy of information.

There are other methods of indicating scale values for electronic analogue displays not investigated in these studies. For example, using an electronic 'needle' style pointer as with some electronic analogue watches; increasing the brightness of the scale markings for the given scale value; larger areas of arc may give more of an appearance of angle of inclination; or the scale may only illuminate for the cumulative value of the scale reading and the remainder be unlit. There is no ergonomics information on the ease of use or acceptability of alternative means of indicating scale values.

- Further investigation of the segment mode of indicating scale values for electronic analogue displays is urgently required, as these types are most commonly used at present.

- Investigations of other methods of indicating scale values should also be undertaken.

- The update rate for electronic analogue displays should also be investigated in relation to the flicker effect and possibly distraction, as the leading segment can flicker on and off while the vehicle is cruising.

Each display design in this study had almost identical speedometer and tachometer. They tended only to differ in colour, if at all. This caused subjects confusion on occasion as the speedometer and tachometer were not easily distinguishable. It was generally agreed by subjects that although the digital speedometer was advantageous, this did not necessarily apply to the digital tachometer. The curvilinear tachometer was considered distracting in that, as the values changed rapidly except when cruising, the constant segment movement over such a large linear display attracted attention to the display. Tachometers are used for quite different purposes in vehicles to the speedometer hence it is not appropriate to assume that the findings in these studies related to speedometer design should apply equally to tachometer design.

- Further work on the design and use of tachometer displays is needed. Similar requirements will apply to tachometer design as apply to speedometer design in terms of investigation of segment or other 'pointer' design, update rates and so on, mentioned above.

- Tachometer and speedometer design must be assessed as a whole, not only as individual items.

Rate and direction of change information is needed in relation to vehicle speed and although it has been argued in this thesis that digital displays work perfectly well and that rate and direction of change information is amply provided from other more powerful sources, such as the visual environment, the motor industry is not yet convinced. There are a number of current design concepts which combine electronic analogue and digital speed displays. Although research by Travis, Innes and Rolfe has shown that in static test conditions subjects tend to read the digital displays and ignore the analogue displays, work needs to be done to validate these findings with regard to the design of electronic speed displays for cars. Investigations of ease of use and acceptability of electronic analogue/digital combination speed displays will be enlightening, however it will be difficult to improve accuracy of reading and check reading as the results for the digital display alone are already almost perfect (97-100%). However, as with improved digit design, the user preference measures may provide a better indication.

- Research is required on the ease of use and acceptability of electronic analogue/digital combination speed displays, and their performance in integrated displays.

The research findings relating to the electronic curvilinear display were intriguing, particularly the poor accuracy of reading the display in the simulation tests of Study 2. In the road trials the display performed well on accuracy of reading, although driver response in all the studies was mixed. In the past electromechanical displays were either circular or linear as curvilinear were difficult to engineer, however, now once the designer has opted for an analogue display rather than digital, then the constraints on the production of electronic analogue displays are much less than for electromechanical displays. Many electronic display design concepts now use curvilinear designs of some form either for the speedometer or the tachometer, the latter being most common. There is no ergonomics information available on electronic curvilinear displays. The designs of circular dial displays can refer to data based on studies of electromechanical displays but there are none available for curvilinear displays. There is only research on linear displays which, in the author's view, has limited application. Even the data provided by these studies are somewhat equivocal and in effect raise more questions than they answer.

- It is essential that ergonomists turn their attention to providing information on curvilinear displays.

The studies undertaken in this research programme were a thorough investigation of ease of use and users response to the display designs. It has been mentioned previously that road trials were essential for the credibility of the research in view of the findings. However, opposition to digital displays among many people in the automotive industry is still strong, and it has been remarked on a number of occasions that although the digital display may have performed well in the 'short' duration road trials (1½-2 hours) drivers' attitude will change after extended exposure to the designs. As Ford Motor Company have not yet produced a production vehicle fitted with an electronic digital speed display it was not possible to take the research one stage further and conduct long term user appraisals. The motor industry has rarely published the outcome of any surveys of long term use of new product concepts. The impression is given that very little information on field experience with products is systematically collected. Other companies including, Austin Rover Group, have installed digital speedometers but unfortunately the author has not had the opportunity to assess the long term acceptability of the designs.

- It would be very interesting to put the results from these studies to the ultimate test of long term use, particularly with regard to the electronic digital display.

Ergonomists have much to contribute to the design and development of electronic displays. There are major financial and practical constraints on the evaluation of prototype displays, hence the ergonomist must devise ways of providing a valid and useful contribution to the design process at an early stage. There are two main requirements. There is a need for up to date information on the user response to the technical properties of different display technologies such as illumination, viewing angle, glare and so. This would enable the optimum requirements of legibility and so on to be met in advance. Research of this nature has been underway within the electronics industry for some time and the work of Beatty and Shepherd provide prime examples of this. Snyder has also produced a chart which enables decisions to be made concerning the technologies to ensure an appropriate technology is employed. What is lacking however, is a means whereby ergonomists can make a contribution to the design concepts at an early stage in the development process. As so little information is currently available on the user aspects of electronic displays the ergonomist is not always able to answer the many questions posed by the novel application of new technology. The design guide (SAE SP 576) is noticeably thin on many important issues because there is simply no information available. The ergonomist must therefore, devise simple, quick techniques for testing design concepts to assist directly in the design process. The tachistoscopic presentation technique used in this study provides an example. The drawback is the static nature of the displays. Another approach is to produce dynamic designs using the high quality colour graphics facilities available on microcomputers (Galer et al 1983) which can be readily reprogrammed to produce design amendments.

Simple vehicle simulation techniques can also be used to some effect. The simulation used in Study 2 was sophisticated and took some time to develop. However, with a flexible simulation available static or dynamic tests are perfectly feasible. Other studies (Galer et al 1983, Southall and Galer 1984) have successfully used less sophisticated vehicle simulations. What is important is to identify those aspects of the simulation which are critical to the product under test and control those effectively.

- Ergonomists must devise additional methods for providing a useful input to the design of displays at an early stage in the development process.

It is also important that ergonomists can continue to make an input throughout the development process, usually by design evaluation, comparing alternative designs or assessing individual products (Galer 1984, 1985). The constraints of commercial contracts often means that resources or time are limited. The ergonomists must devise methods of product evaluation which can cope with commercial constraints and still provide a timely and reliable input to the design and development process. The studies reported in this thesis were conducted in unusually advantageous conditions in that the financial resources were generous and, because the work was commissioned by the Advanced Research Group, the time scale was not unduly restricted. This is not usually the case when conducting commercial research and development work.

- Ergonomists must develop existing evaluation and assessment techniques to cope with the constraints of commercial contracts, in order to provide a continuing, timely and reliable input to the design and development process.

The design guide (SAE SP 576) was first produced for use within Ford Motor Company in 1983 although the literature review was completed in 1982. The same guide was subsequently published by the Society of Automotive Engineers in 1984. The advances in technology which have taken place during that time are extensive. The design guide contains principles which will always apply and also applications and recommendations associated with technologies which become rapidly out of date, and are so already. The design guide has virtually no information on a number of important issues because there are no data on which to base recommendations. Many of the examples are cited in this section such as update rates for segment points, design of curvilinear displays and analogue/digital combination displays.

- Ergonomists should look towards filling the gaps which exist to enrich and update design guides, and their own knowledge.

9.7 In-vehicle information systems in cars of the future

This decade is witnessing a revolution in in-vehicle information systems. The revolution has arisen from a co-incidence of activity in a number of areas. Research and development in the automotive industry has produced new and reliable methods of monitoring the condition of vehicle components and vehicle performance. Research and development in the telecommunications field has produced information transfer systems which can be applied in vehicles as well as elsewhere. Major advances have been made in display technology, both audible and visual, through research and developments in electronic engineering, and the special requirements of the automotive environment have been actively addressed by Shepherd, Beatty, Dellande, Gilbert and many others.

The application of these and other areas of research and development in new technology to vehicles means that the driver can now receive information on the state of the vehicle and its components; on the traffic and other aspects of the physical environment related to the vehicle or the journey; and information unrelated to the vehicle but of interest to the driver or other users. 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.

What information can be made available to the driver?

Some examples of current and future applications:-

Information about the vehicle and its components - the driver can be given information on speed, engine revs. tyre pressure, use of seat belts, brake pad wear, coolant level, state of the battery and the anti-lock braking system (ABS), whether doors, boot and bonnet are latched and secure, washer fluid level, lamp status; the driver can also be given information about vehicle performance such as average and instantaneous fuel consumption, and average speed. These data are provided by on-board monitors.

Information about the driving environment - the driver can receive information about traffic congestion, road works or accidents on the route; route guidance information; the relative positions of vehicles or other objects in the path of the vehicle and to the rear. This information can be provided by on-board monitors as with location of other vehicles or by receiving information from outside the vehicle such as about traffic congestion.

Information about the physical environment - the driver can be provided with weather information, ice or freezing fog warnings, vehicle lighting requirements. Again this information can be from on-board monitors or by receiving information from outside the vehicle.

Information about the driver - the driver can be provided with information about his/her own physical and mental state. There are a number of devices which monitor aspects such as alcohol or drug levels, drowsiness and fatigue and alert the driver to the situation.

Information relevant to the driver - the driver can receive telephone or radio messages; can be reminded of appointments by an electronic diary; messages can be dictated into on-board recording systems; salesmen's orders can be recorded and transmitted from the vehicle information system and many other business applications are possible.

Information relevant to other users - service engineers can receive information about vehicle and component condition from the output of a vehicle diagnostics system; children can play electronic games in the vehicle.

It can be seen from these examples that the potential for providing information to the driver or other vehicle users is very great. The way in which this information is presented should be and indeed, is, of great interest to the ergonomist.

The availability of the information from in-vehicle monitors or other sources in a reliable form is only the first step in the development process. Now that microprocessors are available in a number of vehicles, albeit mainly for other purposes such as engine and fuel management, the information can also be processed and presented in different forms. An example is the location of other vehicles on the road. A status display can present, in graphic form, the relative locations of vehicles. With the aid of a microprocessor the relative closing speeds of the vehicles can be estimated, a time projection calculated and warning of potential hazard displayed. Automotive headway control devices take this information a stage further and control the speed of the vehicle to militate against collision.

This is an interesting example because it shows the development of the presentation of information in cars in perspective. In the past, status information was presented for a number of features such as fuel level and coolant temperature, road speed and so on. Warning displays indicated when these functions reached a critical condition and the driver was expected to respond accordingly. The advent of microprocessors has meant that processed information can now be presented, such as how far the vehicle can travel on the fuel remaining in the tank, or the estimated time of arrival. Or, in the case of the vehicle location monitor, the driver could be instructed to change speed or alter course. Sophisticated and reliable control devices can now take advisory information and translate it into appropriate vehicle control actions as in the case of the automatic headway control device. Other examples of advisory information being translated automatically into action include a device to monitor moisture on the windscreen and automatically operate the windscreen wash/wipe mechanism, and a device to monitor ambient light and automatically activate the vehicle lights when the ambient illumination drops, or turn them off when the illumination increases.

Ergonomists must turn their attention towards the requirements of the information user, whether that user is the driver of the vehicle, a passenger, or a mechanic. They should consider, now that many new features can be reliably monitored, what information is required by the user; in what form is that information required and what are the conditions in which that information will be conveyed. For example the driver may wish to know that the brake pad wear on one wheel is unacceptably high. How should this information be conveyed, in visual or audible form (there may be others who would be alarmed by this message), should the vehicle be moving or stationary when the message is conveyed, how much effector information should the user be given and at what point?

The ways in which the various forms of information are presented and the interaction with the user pose many interesting questions for the ergonomist. Ergonomists may wish to consider different displays or different content depending on the type of user. The advances in display technology not only apply to visual displays. There are speech synthesis systems in current production cars and voice recognition is imminent.

As CRT systems are being developed the need for dedicated panel space for each individual instrument no longer applies. A single display can present a wide variety of information in the same location but at different times.

This then introduces the related aspects of call up systems and driver interaction with those systems. Users must also learn conceptual orientations of displays, i.e. the order of presentation of information, whereas at present a geographic allocation is normally employed i.e. the speedometer is to the right of the tachometer.

The content of the information has in the past been limited by engineering possibilities, monitoring systems and space in the vehicle. Now textual or verbal messages can be received by the driver and any other users such as passengers and mechanics. Furthermore the length of the messages and the amount of information conveyed can be extensive. The message centre on most current trip computers provides a visual message such as "Distance on remaining fuel 27 km". A voice synthesis message in a current vehicle advises the driver that the washer fluid is low and suggests reference to the vehicle handbook. As it is generally recognised to be advisable to reduce the in-vehicle visual load on drivers to enable them to concentrate on the road, the increased use of voice messages seems very likely. The ambient noise level in the vehicle can be monitored and the output level of any auditory message adjusted accordingly. The form and content of such extended verbal messages should take account of the knowledge of the user and his/her ability to understand and act on those messages. Moreover, the system can accommodate the different levels of skill and knowledge in the user population by providing more or less information, advisory or effector information depending on the requirements and abilities of the user population.

The major part of the ergonomics work which has been undertaken in relation to the application of new technology in vehicles has been technology specific. This thesis is an example of that. However, there is also a requirement to contribute to knowledge concerning the user requirements of future developments which are not related to the technology employed. For example, ergonomists know very little about user requirements for vehicle diagnostics information, the form and content of the information to be presented, regardless of whether that information is to be presented on a CRT, fixed form LCD display or as a verbal message.

In summary, a great deal of information about the vehicle and its components; the driving environment; the physical environment; and the driver; as well as information unrelated to the vehicle but of relevance to the driver or other users of the vehicle can be monitored and presented. The presentation can be visual or audible. The information can be presented as status information or translated where appropriate to advisory or warning information. This information in turn can give instructions to the driver or other user as to appropriate action. In addition, the vehicle control systems can effect the action independent of the driver and may then advise the driver that this action has been taken.

The modes of visual presentation can range from simple LED telltales to complex mimic diagrams of the vehicle, or involve changing spatial relationsips as with vehicle location and route guidance.

The modes of audible presentation can range from tonal warning sounds to speech communication of complex messages or be interactive with the driver as with voice recognition.

All of this is far removed from the original basis of this thesis, the presentation of speed information. Much has progressed since the studies began in 1978 but the progress, as the preceding passages indicate has been more in the technology than the ergonomics.

There is much to do.

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APPENDIX 1

SP-576

ERGONOMIC ASPECTS OF ELECTRONIC INSTRUMENTATION:

A GUIDE FOR DESIGNERS

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ERGONOMICS ASPECTS OF ELECTRONIC INSTRUMENTATION

a guide for designers

1983

INTRODUCTION

This handbook has been produced for designers and design engineers in Ford Motor Company Ltd. The purpose is to bring together information on ergonomic aspects of instrumentation for use by designers when developing new forms of electronic instrumentation for use in and associated with cars. General principles are given so that in future developments designers are able to make decisions based on known information. In addition information relevant to the car environment is provided where possible.

In the future, as now, the requirement to apply electronic technology in vehicles will grow. It is impossible to predict where the technology will be applied and hence a wide coverage of relevant information has been included. Visual displays can be used for, for example instrument panel design and external diagnostic panels. Speech and other forms of sound communication can be used for warnings, trip computers and route guidance devices to name but a few examples of current and future developments.

The driver of the car is the centre of attention in this document. However, where appropriate, it has been broadened to include passengers, service and maintenance engineers and others associated with the vehicles.

As the applications of electronic technology in vehicles advances the designer is likely to come across queries about the interaction with people the answers to which are not immediately obvious. In these cases try out the ideas with a range of potential users, take account of the changes in hearing and sight associated with age by having young and older drivers, include normal colour vision and colour defective drivers. Use members of the public, your colleagues may not be typical members of the public as far as cars are concerned.

MARGARET GALER
Institute for Consumer Ergonomics

GORDON SIMMONDS
Advanced Vehicle Concepts

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ergonomics design principles

1. TYPES OF INFORMATION ✓

What type of information are you trying to convey to the driver?

warning — information which is of vital importance to the safe running of the vehicle, e.g. brake failure.

- The driver's attention must be attracted to the warning; the significance of the warning must be apparent.

advisory — information which is useful to the safe running of the vehicle, and which can also convey vehicle state information, e.g. main beam ON, seat belt not fastened

- The driver's attention should be attracted to the information but it should not subsequently distract from the driving task. This covers a wide range of information from simple tell tales to trip computers.

diagnostic — information about the condition of the vehicle for maintenance purposes.

- The driver should be able to choose the appropriate opportunity to assimilate the information.

entertainment — *some vehicle related information is available via* the entertainment facilities e.g. traffic bulletins

- Ensure that other audible forms of information presentation are not masked by the entertainment system.

2. PRESENTATION METHOD

Visual or auditory?

Consider whether the information should be presented visually or auditorily. The choice of the presentation method depends on the nature of the signal, the conditions under which it must be received and the characteristics of the person involved. The general principles which follow apply to all potential users of the vehicle, not only the driver.

General principles:

- Use auditory presentation if:

  The message is simple

  The message is short

  The message will not be referred to later

  The message deals with events in time

  The message calls for immediate action

  The visual system of the person is overburdened

  The receiving location is too bright or dark - adaptation integrity is necessary

  The person does not remain at the same location relative to the display

- Use visual presentation if:

  The message is complex

  The message is long

  The message will be referred to later

  The message deals with location in space

  The message does not call for immediate action

  The auditory system of the person is over-burdened

  The receiving location is too noisy

  The person can remain in one position

2.1 AUDITORY PRESENTATION ✓

- Auditory presentation is recommended:
  - for signals of acoustic origin
  - for warning signals - it is omnidirectional
    - it cannot be involuntarily shut off
  - to supplement over loaded vision - to draw attention to visual indicators
  - when information must be presented independently of the orientation of the head
  - when vision is limited or impossible

- Tonal or noise signals can be used when:
  - the message is extremely simple
  - the signal designates a point in time that has no absolute value
  - the message calls for immediate action
  - speech signals are over-burdening the listener
  - conditions are unfavourable for receiving speech messages (tonal signals can be heard in noise that makes speech unintelligible)
  - speech will mask other speech or annoy other listeners for whom the message is not intended

- Speech can be used when:
  - flexibility of communication is necessary
  - it is necessary to be able to identify the source of the message
  - rapid two-way exchanges of information are necessary
  - the message deals with a time-related activity
  - situations of stress might make the listener forget the meaning

- In the vehicle environment auditory presentation cannot be relied on solely because there is no reason why users should not have partial or full deafness. Therefore, auditory displays can only be a back-up to visual displays.

2.2 VISUAL PRESENTATION

Before the details of a display are designed the following items of basic data are needed:

- The total range of the variable to be indicated
- The maximum accuracy required in the transfer of information
- The speed required in the transfer of information
- The maximum equipment error of the unit/component about which information is to be presented
- The normal and maximum distance between the display and the users of the information

The way in which the person will use the information presented is an important consideration in the design of displays.

- Consider the type of action the user will be expected to take while or after he receives the information from the display.

Generally displays are used in one or more of the following ways:

Quantitative reading, i.e. reading to an exact numerical value. An example is reading the miles shown on an odometer.

Qualitative reading, i.e. judging the approximate value, trend, rate of change, or direction of deviation from a desired value. An example is noting that engine temperature is going up.

Check reading i.e. verifying that a normal or desired value is or is not being shown. If the reading has deviated from the desired value, the user may look more carefully (make a qualitative reading) to decide in which direction the value deviates and whether the deviation is large enough to require corrective action.

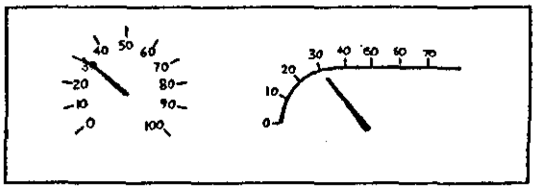
Combination and integration of displays

More than one function can be presented by a single display

Advantages	Disadvantages
Saves panel space	Identification of the desired information is more difficult
Economy of eye movements	Continued eye fixation on a small area can produce an hypnotic effect and reduce alertness
Simplification of interpretation	There can be penalties in reliability, maintenance and cost

3. TYPES OF DISPLAY

3.1 Analogue displays

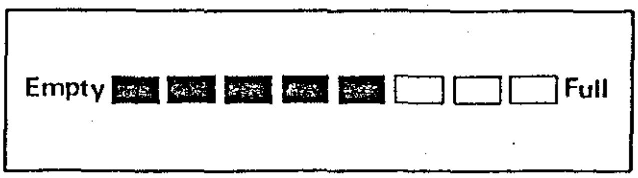


These are so called because the position of the pointer on the scale is analogous to the value it represents. An analogue display can also be used to convey qualitative information, as when a red portion of the scale signifies danger.

Analogue displays include circular dials, linear scales and curvilinear combinations, e.g. tachometer, fuel gauge.

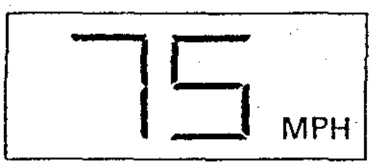
Analogue displays are generally better than small digital for quick check reading, and for rate and direction of change information.

3.2 Discrete displays



These are analogue displays where the readings are discrete rather than continuous. An example is an 8-segment fuel gauge. Discrete displays give quantity information but not in such detail or with such accuracy as scalar displays described above. The display is formed as discrete sections.

3.3 Digital displays

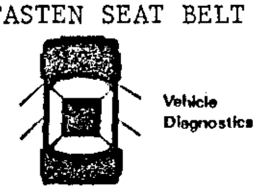


The information is presented directly as a number, e.g. odometer. These are displays with a digital output, many displays have digital inputs. Digital displays are better than analogue displays if precise readings are required. Certain displays such as the Citroen have an analogue display where only the scale marking is shown through a window to provide the reading. These are not digital displays.

3.4 Alphanumeric displays

Alphanumeric displays consist of information presented as messages in full or abbreviated form e.g. FASTEN SEAT BELT

3.5 Representational displays



These provide the user with a "working model" or "mimic diagram" of the process or machine. They enable the user to observe the function of each part in relation to the whole, and to locate faults quickly e.g. vehicle diagnostics diagram.

4. INTELLIGIBILITY ✓

Intelligibility and hence performance is greatly affected by the language, by the nature of the message and by the set of messages displayed.

Alphanumeric displays will be used more extensively in future vehicles to display, for example, trip computer messages, vehicle diagnostics messages, route guidance and so on.

- The form of words used should be easy to understand, unambiguous and informative.

- If abbreviations are used they should be readily understood. Some words likely to be used in vehicle related displays will not have standard abbreviations. The context of the message can assist with the correct interpretation of the abbreviation.

Message content

- The message should contain 3 main elements, preferably in order:

CONTEXT
STATE
ACTION

Examples:

Vehicle warning	-	BRAKE/	FAILURE	/STOP
		WASHER/FLUID	LOW/	REFILL
		Context	State	Action
Route guidance	-	WALSALL/	ROADWORKS/	FOLLOW
		A38	AHEAD	SIGNS FOR A42 STAFFORD
		Context	State	Action

Message-type displays are language specific, however, it is possible to program a number of languages in to the message generator. The language structure will vary but the principle message components context, state, action will be the same.

5. INSTALLATION ✓

The uses of visual displays can be grouped into two main classes, according to whether or not they are associated with controls. This will directly affect the optimum installation positions of the displays.

- Displays should be located where they can be easily read without attention being distracted from the driving task or from more important displays.

5.1 Displays associated with controls

These displays are associated with controls which enable the user to make any necessary adjustments himself. Examples are the dial on a radio which is adjusted by the tuning knob or a warning/indicator light on a switch.

- Whenever a variety of controls and displays have to be used, their location and arrangement should aid in determining:
  - Which controls are used with which displays
  - Which equipment component each control affects
  - Which equipment component each display describes

- The displays associated with controls should be located as close as possible to the controls, particularly if fine movements are required, or should bear some logical spatial relation to the control.

The interaction between the control mode and the display function is most important in the efficient use of the facility.

- The direction of movement of the control must be related appropriately to the change that it induces in the associated display. Correct direction-of-movement relationships will reduce reaction time or decision time, improve the correctness of initial control movements, improve the speed and precision of control adjustment, and reduce learning time.

- The control associated with a display should be located so that the driver's hand does not block his view of the display.

- Controls operated by the left hand should be located below or to the left of their associated displays. Controls operated by the right hand should be below or to the right of their associated displays.

5.2 Displays not associated with controls

These displays give the user information which he may have to record or on which he may base executive action. Examples are the clock in a vehicle, warning gauges etc.

The location of these displays is more flexible than the displays associated with controls.

Head-up displays project a display image close to the driver's view of the road ahead. The image is usually focused at infinity. The advantage is that reading the display requires a smaller eye movement than a display positioned on the instrument panel but the driver's attention will be directed to interpreting the display in the same way as a conventiontional display.

If a number of different displays are presented in this fashion simultaneously they could interfere with the driver's ability to interpret the road images. These displays are best used only if the display is integrated with the outside environment e.g. a braking distance indicator.

- In-vehicle displays should be located as near as possible to the driver's line of sight. The optimum position is directly below or above the line of sight as vertical head/eye movements are easier and quicker to make than lateral movements.

5.3 Display layout

There are some general principles which should be kept in mind when planning the layout of a display panel.

- Visibility - the driver should be able to see all displays from his normal driving position allowing for some head movement.

- Identification - it should be easy for the driver to find the display he needs.

- Grouping - displays should be arranged in functional or sequential groups.

- Associations - display arrangements should be compatible with functions they display and with the controls that affect the readings.

Layout for good visibility

- The plane in which the display lies should be perpendicular to the line of sight.

- The driver's view should be unobstructed by the steering wheel, hand position, light shields or projections.

- The distance between displays should be minimised to reduce eye movement. However, it may also be useful to spatially separate some displays to avoid confusion when reading them quickly.

Layout for identification ✓

- All displays should be properly labelled
- Location and separation - location on the panel is one of the best aids to identification. Locate primary instruments, e.g. speedometer and warning gauges in primary space.
- Functional grouping - by grouping displays in terms of their functional use, the designer can reduce the area over which the user must search to find a display. Place displays in groups according to their functional use.
- Standardised location - wherever possible standardise the location of displays or functional groups of displays.

Grouping displays for check reading

Some displays maintain stable values for given operating conditions and are used primarily for monitoring purposes. Readings are of special interest only when they deviate from desired values.

- Arrange the displays so that the normal readings are in alignment, preferably horizontal or vertical,rather than diagonal or in other arrangements.

5.4 Viewing distance

Viewing distance is the distance from the driver's eye to the display, and will vary to some small extent due to head movements during driving. The viewing distance in current cars is about 750mm. The viewing distance will affect the optimum display sizes. To overcome this, display sizes are calculated in terms of subtended angle.

NB. Drivers who wear bifocal lenses will have difficulty reading some displays as the reading lens is usually focused at 300mm and the top lens is usually focused at infinity.

5.5 Viewing angle

The angle between the line of sight and a perpendicular to the display screen is the viewing angle. The acceptable viewing angle for good readability is affected by ambient illumination, screen curvature, use of lenses, contrast, resolution and character size. Consequently there is a relatively wide range of acceptable viewing angles for good readability.

- 15^{o} is the most comfortable viewing angle, viewing from above.

  30^{o} is the maximum angle recommended

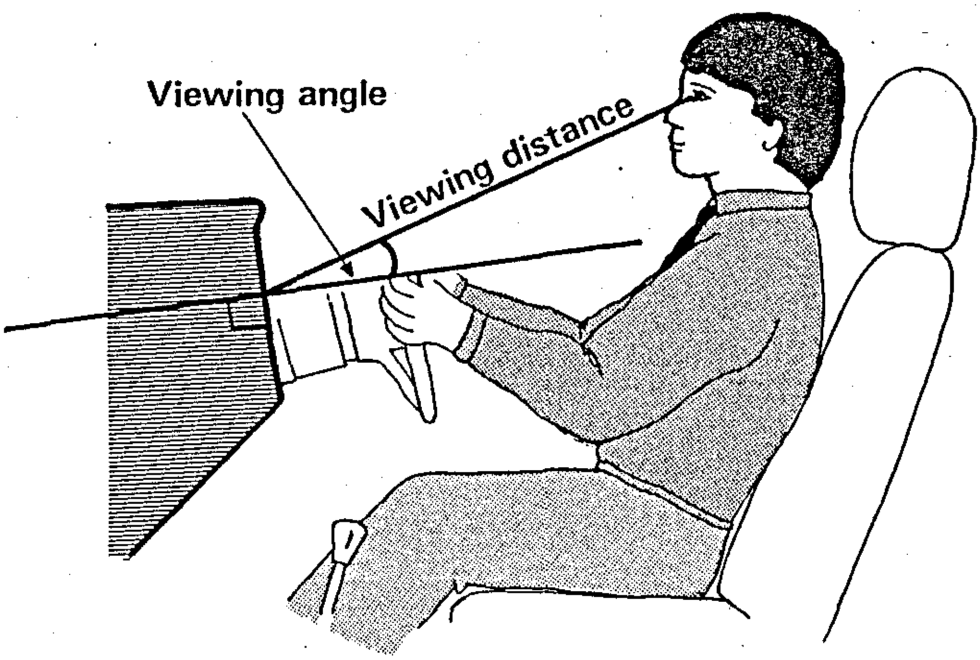
5.6 Visual acuity

Viewing an electronic display is quite different from reading printed material and persons who do not normally have an acuity problem may experience some difficulty viewing electronic displays because of the different luminance levels, flicker, contrast, character generation, resolution and so on.

Visual acuity is measured in terms of the size of detail the eye is capable of resolving.

Defective vision is common among the adult population and it cannot be assumed that spectacles will always overcome the defect. Drivers who wear bifocal lenses may have special difficulty because of the way the bifocal lenses are designed. The viewer must look out of the top or bottom half when viewing the display. Neither are exactly suited to the 750mm viewing distance usual for vehicle displays (see Section 5.4)

- The electronic displays should be designed such that they can be clearly read by persons with the range of vision found in drivers. Use larger characters and display configurations than would be required if the displays were only used by people with normal vision.



Viewing distance and viewing angle

6. Pl TERISTICS
VI S

6.1 Br

The m ht level to which the human visual system will respond is well any expected level of display luminance. The optimum display nesses will vary according to the technology employed, the aim is to ensure that the display is bright enough to be read easily and not so bright as to distract or irritate the user.

- The brightness of the electronic displays should be controlled by the user to enable adjustment of brightness levels under a wide range of ambient illumination, 500-60,000 lux.

Ambient illumination incident upon the display and its surround has a considerable effect on the ability to see the displays clearly. Light reflected from the display surface adds to the light emitted by the display and causes the mean luminance level to increase while the legibility is reduced. To counter this:

- If the display has sufficient dynamic range the luminance levels can be increased. However if the display luminance is too great the eye will be unable to make out fine detail.
- Use filters on the surface of the display to reduce adverse effects of high ambient illumination. Neutral density filters and polarising filters give improvements in readability.
- Narrow band width display emissions with matched absorption filters can give an even greater improvement in readability, but red displays have been found to be less acceptable to drivers than other colours. See Section 6.10.
- Directional filters in which a structure of louvres or cells is arranged to prevent ambient light falling on the surface of the display except from the direction which is effectively masked by the driver's head can also enhance display visibility in high ambient illumination.

6.2 Contrast

The higher the contrast between characters and background, the better the readability. People can read light on dark and dark on light equally well, however, many people prefer dark on light to light on dark (This is particularly so for CRT displays). However, the overall effect of display brightness and ambient illumination should be considered. In a vehicle light on dark is most appropriate because bright panels are distracting in dark conditions and reflections from the panel can occur in the windscreen and side glass.

Ambient illumination levels affect how well a display may be read. The contrast between display luminance and ambient luminance is the parameter which must be controlled.

The ratio is defined as $Fs = \frac{La}{Ld}$

Where Fs is the surround factor
La is the ambient luminance
Ld is the display luminance

- To minimise potentially disturbing contrast changes in the peripheral field of vision of the driver Fs should be greater than 0.2 - 0.3.

6.3 Glare

The colour and reflections of all surfaces, both in the vehicle and in the surroundings, will have an effect on glare and the contrast between the display and its surroundings.

- Glare may be reduced by assuring low reflectivity of all surfaces and by shielding the display and the driver from the reflective effects. There is a computer based assessment program available to identify potential glare problems.

6.4 Resolution

Resolution is the smallest discernable or measurable detail in a visual presentation. One minute of arc is the accepted limit of resolving power.

For electronic displays resolution is usually defined as the number of dots per character height (for dot matrix displays) or the number of lines per character height (for raster-type CRTs).

- For CRTs the minimum recommended resolution is 10 lines per symbol of height.

- For individual alphanumeric characters a 7 x 9 dot matrix display is superior to a 5 x 7 matrix. (A 3 x 5 matrix has too little resolution and cannot be read easily.) However, for messages, where word content will add to intelligibility a 5 x 7 matrix may be adequate.

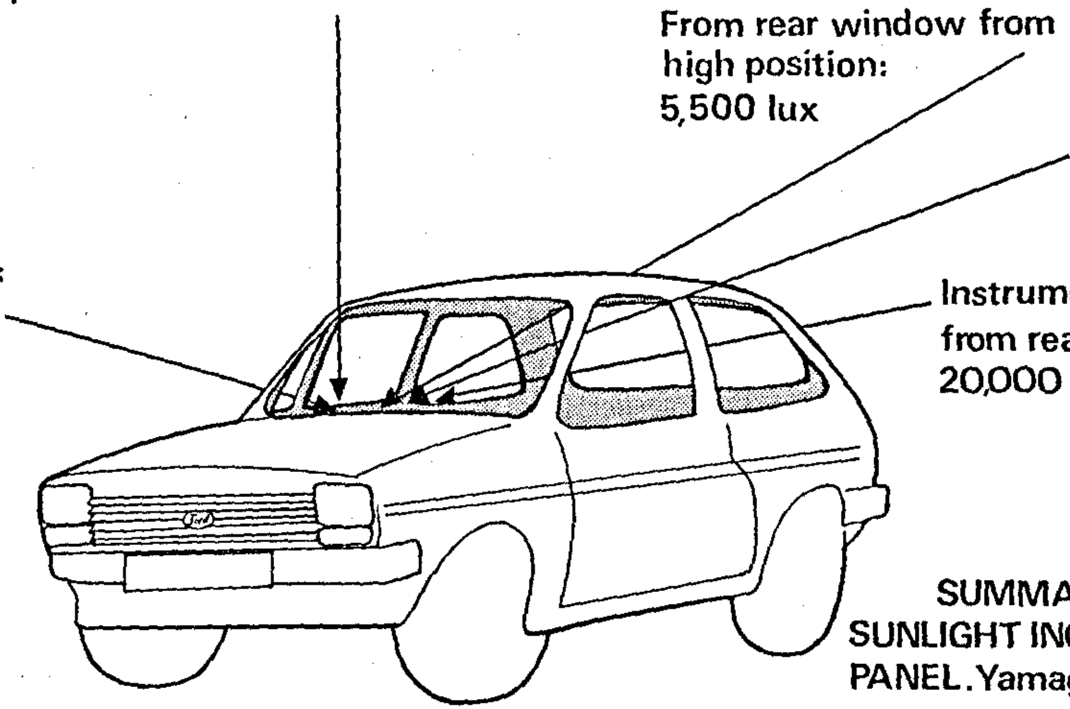
Character size and resolution are closely related. As the resolution increases the symbol size required to maintain good readability decreases.

The optimum resolution is described in combination with character size.

- Under good viewing conditions 10 lines per character   15 min. of arc subtended angle is recommended. (see Section 6.6)

- Under poor viewing conditions 16 lines per character or 21-25 min. of arc is recommended.

- Vibration of either the display or the user in relation to the other can adversely affect the readability of a display. Where vibration is likely to occur, increase the size and clarity of the displays to enhance readability.



SUMMARY OF 'WORST CASE' SUNLIGHT INCIDENT ON INSTRUMENT PANEL. Yamaguchi et al 1982 SAE 820013

LIGHT MEASUREMENTS AFFECTING BRIGHTNESS OF ELECTRONIC DISPLAYS

6.5 Percent Active Area

Percent active area is that portion of the symbol that is actually emitting light.

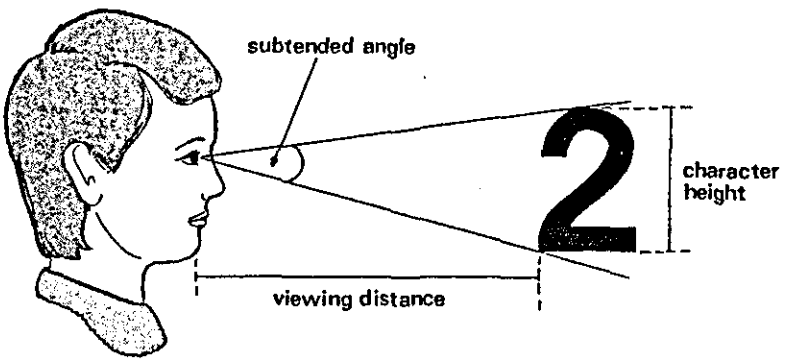
The active area is increased by increasing the emitter size or decreasing the spacing between emitters. The dot spacing is decreased by increasing resolution or by decreasing character size.

- Large, dimmer emitters are more legible than small, bright emitters.

- To make dots run together and appear as a continuous line, the spacing between the dots should subtend no more than 1 minute of arc (see Section 6.6). As 1 min. of arc is the minimum spacing that the normal eye can perceive, anything less will be imperceptible.

6.6 Character size

Character size is usually defined in terms of subtended angle. This allows for differences in viewing distance by measuring character height relative to viewing distance.



- Characters viewed from less than 1m require a slightly larger subtended angle than those viewed at a greater distance.

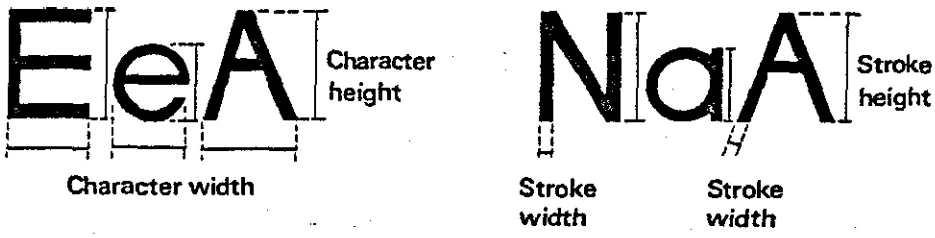
- 15 min. of arc is the optimum subtended angle for electronic displays. This gives a minimum character size for near error free reading.

- At 750mm this gives a minimum character height of 3.25mm I3.25mm

This is appropriate for scale markings but is not appropriate for primary digital instruments such as a speedometer (see Section 14.1). The Institute for Consumer Ergonomics tested several sizes of digital speedometer in laboratory tests and found 18mm was most acceptable.

6.7 Character width and height

Character width i.e. the width of the matrix within which each character image is formed should be 70-80% of the character height.



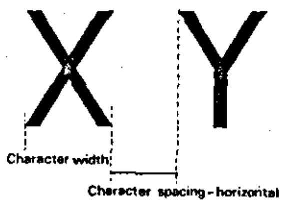
Stroke width to height is dictated by the symbol generation technique and resolution. For example, a 7 x 9 dot matrix will have a stroke width to height ratio of 1:9 (i.e.11%)

It is important that the ratio does not become too small or the character strokes will blur or run together.

- Recommended stroke width-to-height ratio is 10-15% for electronic displays. This ratio should be increased slightly for reflective displays and decreased slightly for emissive displays.

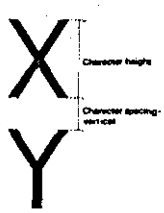
6.8 Character spacing

Horizontal character spacing is the distance between the beginning of a character and the end of the preceding character.



- 75% of the character width is recommended as a maximum as legibility decreases beyond this. However, there is some controversy over this issue.

Vertical character spacing is the distance between adjacent lines.



- 30-50% of the symbol height is recommended, with a maximum of 100% for continued text e.g. messages.

6.9 Font

Font characterises the shape and geometry of the alphanumeric characters.

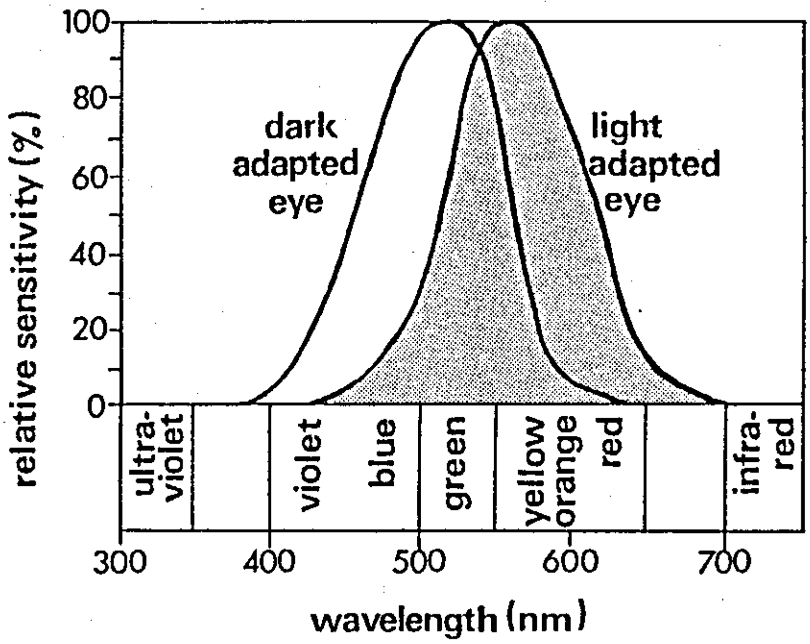
- For electronic displays the font must be simple, without serifs and italics.
- Only upper case letters should be used for dot-matrix and segmented bar displays as these are easier to read given the current character generation technology. However, in general combined upper and lower case words are easier to read than all upper case or all lower case words.
- Dot matrix upper case characters are more easily read than segmented characters. Matrices larger than 7 x 9 do not show significant improvements in legibility.
- Use upright characters, slanted characters are more difficult to read.
- Widely accepted fonts for electronic displays:
  Leroy
  Military specification MIL-M-18012
  Lincoln/Mitre

6.10 Colour

Can the user do better with colour in the display than he can with black and white or monochrome? In vehicles it is essential to use colours to enhance the use of the displays and conform to standards.

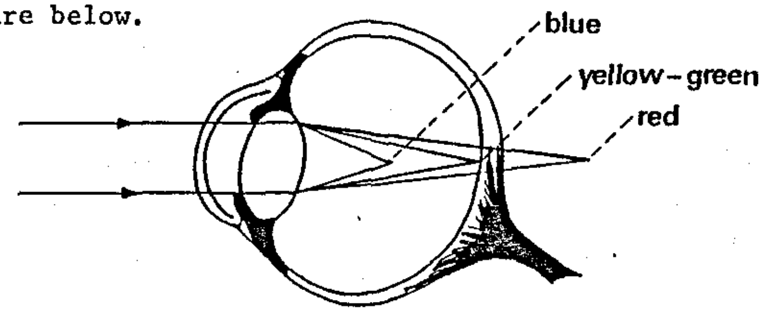
Information can be visually coded by colour, brightness, shape, size orientation and other factors. Colour coding is commonly used in displays, but is not necessarily superior to other means of conveying visual information such as size or shape.

- Use colour to group information displays and to highlight particular displays.
- The brightness sensitivity of the eye is greatest at a wavelength of 555nm which is blue-green-yellow. However this does vary according to whether the eye is dark adapted or light adapted. The graph below should help when choosing appropriate display colours.



SENSITIVITY OF THE EYE TO COLOUR

Chromatic aberration is the inability of the eye to focus all wavelengths (colours) equivalently at any instance of time, as shown by the figure below.



THE ABILITY OF THE EYE TO FOCUS COLOURS

- When many colours are employed on the same display surface do not superimpose colours which cannot be focused together. For example do not put red characters on a blue background. If red and blue objects are placed at the same distance from the eye, the eye must refocus to transfer attention from one to another.

- For the same reason care must be taken when different colours are displayed sequentially in the same space.

The peripheral retina is able to detect red and blue much more readily than green but the eye's response time to red peripheral stimuli is much longer than that for either blue or green. This should be borne in mind when choosing colours to meet particular display requirements.

Colour does not affect accuracy of reading displays as much as brightness and contrast.

- The maximum number of colours to use in a visual display is 5, and under optimum conditions as many as 7 are acceptable. In cars, optimum lighting conditions are unlikely to occur so do not exceed 5 colours. The colours should be clearly discriminated one from another.

- The best colours to use for electronic displays are green, yellow, with red for particular displays, and possibly white. Yellow legends on a black background are most preferred. Other combinations in order are yellow on red, black on green, and green on black for graphic displays.

Colour deficiency

If colour is used in electronic displays then colour deficiencies must be considered.

About 8% of the population, mainly males, is limited in the extent to which it can use the information contained in different colours.

- Avoid using red and green, or yellow and blue in pairs. Protanopes have a reduction in sensitivity to red. Protanopes are only a small proportion of the population. A general reduction in sensitivity of colour vision due to the yellowing of the lens in older drivers should also be considered.

- Avoid using the blue end of the spectrum for important displays.

- Highly saturated, bright colours are found irritating by young drivers but are preferred by older drivers.

* Driver response to different coloured electromechanical dashboard lighting. (Institute for Consumer Ergonomics report to Ford Motor Co. 1980)

Five broad band colours of instrument lighting were tested in a simulator under night time conditions - RED, GREEN, YELLOW, ORANGE, and BLUE-GREEN.

- There was no difference in the drivers' abilities to read and use the instruments with any of the display colours.

- The blue-green display was preferred for:

  Ease of reading

  Ease of deciding whether the speed was within a speed limit

  Distraction while driving (it was least distracting)

  Attractiveness

  Choice for own car

  General preference

- The yellow display was the next most preferred display colour.

- The red display performed worst on all the preference measures except distraction while driving.

WHO LIKED WHAT

BLUE-GREEN

- Considered easiest to read by all the age and sex groups except men over 50 years who considered it difficult to read.
- Particularly attractive to men and women in the 30-50 years age group.
- Men in the 30-50 years age group and women aged 30 years upward thought blue-green was least distracting.

RED

- All age and sex groups considered red a difficult colour to read.
- Some women aged 17-30 years considered the red display attractive.
- Both men and women over 30 years considered the red display least attractive, and most distracting.
- Drivers wearing bifocal lenses also disliked the red display.

GREEN

- Men and women below 50 years considered green easy to read, but both sexes considered green difficult to read in the over 50 years age group.
- Men under 50 years considered green to be an attractive display colour, but men over 50 years considered it an unattractive colour.
- Men under 50 years also thought the green display was least distracting.

ORANGE

- Men in the over 50 years age group considered orange easiest to read and most attractive.
- Women under 30 years and men aged 30-50 years considered orange difficult to read and least attractive.
- Men in the 30-50 years age group considered orange a distracting display colour.

YELLOW

- Men and women aged over 30 years found yellow easiest to read, and most attractive.
- Men in the 30-50 years age group found yellow difficult to read and unattractive.
- Women under 30 years and men aged 30-50 years found the yellow display distracting, but men over 50 years found it least distracting.
- Drivers who wore bifocal lenses generally preferred the yellow display.

Colour blind drivers found red an unsatisfactory colour, but otherwise they showed no colour preference.

7. PHYSICAL CHARACTERISTICS ✓

AUDITORY DISPLAYS ✓

7.1 Speech and noise signals

Speech is the primary audible communication method for urgent signals and the maximum dependable rate of transmission is 250 words per minute (wpm).

Tonal or noise signals contain limited information compared with speech or morse code. However, tonal signals can be heard in noise that makes speech unintelligible. Tonal signals are used most frequently for warning or alarm messages.

7.2 Auditory signals for alarm and warning

- Use sounds having frequencies between 500 - 3000 Hz as the human ear is most sensitive in this range.
- In a noisy environment use signal frequencies as different as possible from the most intense frequencies of the noise. In this way the masking of the signal by the noise is minimised.
- To attract attention use a modulated signal, such as intermittent beeps repeated at rates of one to 8 beeps per second or warbling sounds that rise and fall in pitch.
- Use complex tones rather than pure sinusoidal waves because relatively few pure tones can be positively identified, whereas a large number of complex sounds can be identified. Some people experience deafness to specific tones often caused by exposure to industrial noise, hence complex tones are particularly important for such drivers.
- Use frequencies below 500Hz when signals must bend round obstacles or pass through partitions. High frequencies cannot pass through or around solid objects as well as can low ones.
- Hearing sensitivity at high frequencies tends to decrease with age, particularly for men, so avoid using high frequencies above 2000Hz for warning signals. Industrially induced hearing loss occurs in the speech wave bands 500-2000Hz and can have serious implications for speech communication in vehicles. Use complex tones to give these drivers the ability to hear at least some of the signal.
- Overloading the audible communication channels can lead to irritation and stress. Older drivers are particularly intolerant of additional audible communication.

7.3 Which audible warning to choose:

Types of Alarms, Their Characteristics and Special Features

Alarm	Intensity	Frequency	Attention Getting Ability	Noise Penetration Ability	Special Features
Horn	High	Low to High	Good	Good	Can be designed to beam sound directionally Can be rotated to get wide coverage
Siren	High	Low to High	Very good if pitch rises and falls	Very good with rising and falling frequency	Can be coupled to horn for directional transmission
Bell	Medium	Medium to High	Good	Good in low frequency noise	Can be provided with manual shutoff to insure alarm until action is taken
Buzzer	Low to Medium	Low to Medium	Good	Fair if spectrum is suited to background noise	Can be provided with manual shutoff to insure alarm until action is taken
Chimes and Gong	Low to Medium	Low to Medium	Fair	Fair if spectrum is suited to background noise	
Oscillator	Low to High	Medium to High	Good if intermittent	Good if frequency is properly chosen	Can be presented over intercom system

If audible warnings or speech communication are used in vehicles, great care must be taken to avoid causing irritation to the vehicle occupants. To date there is little information available on what causes irritation but it is certainly related to frequency of repetition.

7.4 Speech communication systems

The performance of a speech-communication system depends to a great extent on the size of the message set or vocabulary that is used, the degree of standardisation of the messages, and the familiarity of people using the system with the messages and with the vehicle.

- Provide context for critical words by embedding them in phrases or sentences.
- Use familiar words rather than unfamiliar ones. With novel applications it may be necessary to test the understanding of words and phrases with potential users.
- Use as small a total vocabulary as possible. The fewer the alternatives the greater the intelligibility.
- To obtain words that are easily distinguished select polysyllables. The more syllables in a word, the more likely it is to be heard correctly.
- Avoid words that contain sounds that are easily confused e.g. P and T are readily confused.

8. MODE OF PRESENTATION

8.1 Information presentation

The presentation of information using electronic displays can be either permanent or temporary.

The display areas can be dedicated to one function or a variety can be displayed sequentially in the same location.

The feasibility depends on the type of electronics technology employed. For example, a variety of functions can be displayed in the same position on a CRT screen, at different times.

Displays can be visible all the time or only become visible when required. For example, the display associated with battery state could be permanently visible or only become visible when the battery state reaches a pre-determined critical level.

Functions can be automatically displayed or can be called-up by the user when required. The call-up facility is most appropriate for information or advisory type displays.

- A cancel facility is essential for some displays to enable the driver to reduce distraction effects. Where displays have dedicated positions for particular functions they can either be blank until activated or illuminated at a low level becoming brighter when activated.

- It is recommended that the minimum amount of visual information is presented to the driver under normal driving conditions in order to reduce distraction and to enhance the attention getting ability of the displays when activated.

8.2 Priority of displays

- Priority of displays can be indicated by colour coding. It is usual for red and yellow to be used for warning, green and blue for information, in vehicles.

- If a variety of functions are to be presented in the same space in the panel then some system of priority rating must apply. Otherwise hazard warnings may be blocked from appearing by, for example, fuel economy figures being shown in the same space.

- High priority displays should appear in the primary space on the instrument panel where all drivers can see the displays readily.

8.3 Multi-modal displays

Displays can be entirely visual, or entirely auditory. They can also be a combination of these two modes.

- Non-speech audible displays in combination with visual displays can be very powerful information transmitters. For example, a warning symbol plus audible signal will have the advantage of drawing to the driver's attention the fact that there is a fault and the warning symbol can indicate the nature of the fault.

It is also feasible to enhance visual displays with speech communication. However, there is little information on the best modes of presentation of the functions relevant to vehicle performance and driving.

9. CHARACTER GENERATION

9.1 Character generation methods

There are essentially three methods for generating alphanumeric characters in electronic displays. These are:-

- Raster-type CRTs
- Dot matrix
- Segmented bar matrix

For readability, raster type generation is currently the best method because it provides the greatest resolution at a reasonable price. In a dot matrix, as the number of dots in the matrix increases the readability improves. However, as more dots are added, the character size increases, hence the number of characters being displayed must decrease or the display size must increase.

Dot matrix characters are easier to read than simple segmented-bar generated characters. There is no difference in readability between dot matrix and complex segmented bar characters.

9.2 Dot matrix displays

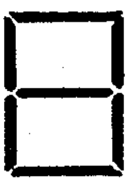
A basic 5x7 matrix consists of 35 discrete locations in which an illuminated dot may or may not appear. The dots may be large enough to overlap or may appear as discrete elements without seriously affecting the legibility of the display. Although this matrix is acceptable for groups of characters presented in a context, it does result in some confusions when single characters are shown. Larger 7x9 matrices are also available, but in general matrices larger than 7x9 do not lead to marked improvements in the legibility of alpha numeric displays.

Larger dot matrices are available for generating symbolic and pictographic displays.

- Although character height: dot diameter ratios can range from 7:1 for overlapping dots to as large as 13:1, to avoid confusion of letters resulting from excessive spacing between dots it is best not to exceed 10:1.

- Lower case characters are not generally available.

9.3 Segmented displays



7 segment

Seven segment font displays are limited to numerics and a few alphas, and are used mainly in calculators.

14 segment

16 segment

The 14 or 16-stroke starburst has the same characteristics of fixed strokes as the 7 segment display but considerably expands its capability by increasing the number and positions of the strokes.

Multistroke characters which provide the closest approximation to print quality use from 13 to about 30 strokes with a stroke repertoire of one to five lengths and as many as 40 orientations. The advantage of this type of essentially random stroke format over the fixed stroke formats is the large improvement in accuracy obtained with the random stroke font.

Dot matrix vs segmented characters

Dot matrix characters are more easily read than the simple segmented characters. For equivalent fonts there is no significant difference in accuracy between dot matrix and the elaborate segmented displays.

9.4 Raster displays

The number of raster lines within which each character matrix is formed affects the degree of refinement of the character shapes.

- Generally the number of raster lines per character should not be less than 10 for normal VDU sizes.

- Character heights of 7-8mm are a minimum for a viewing distance of 750mm because the luminance gradient of electronically generated characters is flat and the dot-or-dash raster technique does not lead to a homogeneity of the character comparable to printing.

9.5 Cursive Writing (Sequential Stroke)

This type of display generates a succession of short strokes in sequence that are combined to form an approximation of written script.

- The number of strokes available is variable but in general the more strokes there are available the better the appearance and legibility of the character.

Depending on the type of generator used there can be detectable differences in luminance within the characters which will reduce the legibility.

9.6 Fixed printed displays

It is also possible to produce fixed displays in a printed form as with LCDs "printed" in to shapes such as symbols.

9.7 Refresh systems

On CRT display systems the display device has no built-in memory and retains the image for only a limited period of time. The human visual system is adversely affected by luminance variations that occur below the CFF (Critical Flicker Frequency), so it is necessary to provide a means of repeating or refreshing the image at a rate higher than the minimum required to avoid the sensation of flicker. This is normally in the range 50-60Hz at normal luminance levels.

10. CONTROLS FOR ELECTRONIC DISPLAYS

10.1 Types of controls

The suitability of any control depends on its appropriateness for the task it is to perform.

The first step in selecting the best type of control is to consider:-

- The function of the control
  - What is its purpose?
  - How important is it?
  - What will it control?
  - What sort of change should it bring about?
  - What is the extent and direction of that change?
- The requirements of the task.
  - What precision is needed?
  - How fast should the control be operated?
  - What is the range of the control?
  - What force is required to operate it?
- The drivers' information needs
  - how will he locate and identify the control?
  - How will he determine the control setting?
  - How will he sense a change in the control setting?
- The constraints of the driving package.
  - What is the amount of available space?
  - Where is the available space located?
  - How important is it that the control be located in a particular place?
  - How will the control interact with other controls, displays and equipment?

10.2 General control design principles

- The direction of movement of the control should take account of:-
  - the location and orientation of the driver/passenger relative to the control.
  - the position of the display relative to the control and the nature and direction of the display response.
  - the change exhibited as a result of the control movement.

- The direction of movement of the controls and displays should be related to the purpose underlying each control movement rather than to any particular mechanism or method of actuation.

- Direct movement relationships should be used whenever possible.

- Use detent controls when the controlled object or display can be adjusted in a limited number of discrete steps.

- Use non-detent controls when precise adjustments are needed along a continuum or when a large number (usually more than 24) is required.

- Combine functionally related controls if they reduce reaching movements, aid in sequential or simultaneous operation of controls or economise on the use of panel space.

- Controls should be easily identified by location, shape, texture, colour, size, labelling, illumination or mode of operation. Primary and hazard controls should be identifiable both visually and by touch.

10.3 Choice of controls

Settings	Controls
2 discrete settings	Pushbutton Toggle switch Rocker switch
3 discrete settings	Pushbutton Toggle switch Rotary selector switch Rocker switch
4-24 discrete settings	Rotary selector switch
Small range of continuous settings or more than 24 discrete settings	Knob Lever

11. The role of the microprocessor

The use of microprocessors in vehicles can have an effect on certain aspects of control design. Controls can be logically linked with a range of alternative actions via the microprocessor. This can simplify the design of controls.

For example, a single action pushbutton on a trip computer can, via a microprocessor, bring about a variety of displays. Press once for average speed display, press again for fuel consumption, press again for distance covered. Alternatively, press once and each will be displayed sequentially.

There are a number of questions to consider when deciding on the form of control for specific electronic displays:-

- Does the display need to be reset? How can this be achieved?
- Does the display need to be displayed at all times or can it be called up? Should this be automatic or normal and how?
- Should the same control operate a number of functions/displays? Which ones and how should they be arranged in relation to each other?
- Should the control be operated by physical action or in other ways such as speech activation or light activation?

electronic technologies

12. PASSIVE DISPLAYS ✓

12.1 Liquid crystal displays LCD

Character height	5-25 mm
Character style	7, 14, 16 segment 16 stroke starburst dot matrix not practical
Colours	White filtered
Contrast ratio	20:1
Maximum viewing angle	$90-120^{\circ}$

LCDs have excellent readability in bright sunlight. Various backlighting techniques are available for night viewing including very low power AC electroluminescent panels.

LCDs have an inherent capacity to reflect incident light so that high ambient illuminance conditions increase display brightness without causing a loss of contrast.

93% level of active area of presently produced LCDs does not have an adverse effect on readability.

Reflections from the surface of LCD panels can be a problem and should be reduced to a minimum.

Transmissive displays - a light source is positioned at the side of the display out of view of the observer. This light source is lit at all times the display is on.

Good visibility in low ambient illumination. Wash out in high levels of ambient illumination.

Reflective displays - the back of the display is opaque and fully reflective.
Good visibility at high levels of ambient illumination.
Poor visibility at low levels of ambient illumination.

Transflective displays - a partially reflective and partially transmissive backing is applied to the display. It is generally considered that transflective LCDs are best suited to automotive applications because they can behave reflectively in bright ambient illumination and transmissively in darkness. The display should be continuously lit so that there is no sudden appearance of transition as the ambient illumination changes.

Colours in LCDs

- Colours must not appear to be different depending on whether the illumination is by transmitted or reflected light.

Colour filters are a simple way of producing colour. Even with reflective LCDs yellow filters improve the contrast ratio over conventional LCDs. In transmissive mode colour filters are particularly appropriate and can be used to produce coloured segments and black backgrounds or vice versa.

Colour polarisers are also an effective method of producing colour and can be used in both the transmissive and the reflective modes.

Dye contained LCDs have restrictions for automotive applications because of the unreliability of current dichroic dyes.

Multi-coloured displays can be produced by the use of small area filters.

13. EMISSIVE DISPLAYS ✓

13.1 Vacuum fluorescent displays VF

Character height	13-19 mm
Character style	7 segment 14 segment
Colours	Blue-green + some filters
Contrast ratio	10:1
Maximum viewing angle	150^{o}
Luminance	30 nits

If a V-F display is used with the addition of an optical filter then the optimum compromise for use with two conflicting illumination conditions of direct sunlight on the display and sunset driving is:-

- For a black background a 15% transmission filter. This is independent of the display luminance over the range 3750 - 9700 cd/m^2.

- Matching the display background colour to that of the 'ON' segments of the display significantly improves daytime readability. A white background display requires only 4/7ths the display luminance of a black background display to maintain readability. This reduction in a needed display luminance is especially important where electrical power considerations are of concern.

- The minimum brightness level for legibility of VF displays in bright sunlight is 4000 cd/m^2 with character heights of 8mm or more. At 8000cd/m^2 legibility is excellent for all filters.

- Blue-green phosphor using green and blue smoke filters give best legibility in bright sunlight.

13.2 Plasma gas discharge displays

Character height	5-18mm
Character style	7 segment dot matrix
Colour	Neon orange
Contrast ratio	20:1
Maximum viewing angle	120^{o}
Luminance	30 nits

No further ergonomics data available.

13.3 Light emitting diode displays LED

Character height	2.5 - 250mm For larger sizes need dot matrix or assemblies of discrete LEDs.
Character style	7, 14, 16 segment dot matrix 5 x 7, 7 x 9
Colours	Red Green Yellow Amber
Contrast ratio	10:1
Maximum viewing angle	150^{o}
Luminance	30 - 100 nits

LEDs are often used for warning lights, indicator lights and so on.

- The visibility of LEDs is highly dependent on LED colour. Chromatic aberration can reduce the legibility of red LEDs (see Section 6.10).

  Red LEDs produce the highest luminances.

- The light intensity of LEDs is sufficient to be visible in bright sunlight but not dazzle in the dark.

13.4 Cathode ray tubes CRTs

The recent work on CRTs has almost all been related to the use of VDUs in offices. The applicability of some data to vehicles is not known.

- For good legibility the number of raster lines per character is important. For VDUs the minimum number of raster lines per character is 10.

- The minimum character height at 750mm is 8mm.

- Luminance - a range of 0.2 cd/m^2 to $200cd/m^2$ is needed to cover both dark and bright conditions in offices. In vehicles this will have to be extended.

- There are only small differences between green, yellow-green, yellow, orange and white characters on CRT displays in terms of readability.

- There are significant differences in user preference:

  MOST PREFERRED
  YELLOW WITH AMBER FILTER
  YELLOW/GREEN
  GREEN
  WHITE
  ORANGE
  LEAST PREFERRED

- Brightness and contrast of CRT display characters have more effect on accuracy of reading than colour.

vehicle instruments

14. VEHICLE INSTRUMENTS

14.1 Speedometer

- Position where it can be seen fully by all drivers, without having to make head movements.

- A digital display gives highly satisfactory results in terms of accuracy of use and driver preference (Simmonds GRW et al 1981)

- Digital vehicle displays are recognised faster than analogue displays and drivers take their eyes off the road for shorter periods to read them.

- However, it is recommended that a combination analogue-digital speedometer display is considered for the following reasons:

  - analogue displays provide rate of change information not provided so well by digital only displays.
  - digital displays are read more quickly and accurately than analogue.

There is no evidence available in which electronic combination analogue-digital displays have been evaluated with drivers.

- Analogue speedometer

  - use circular or semi-circular rather than horizontal or vertical scales as these are easier to read (Simmonds GRW et al 1981)
  - use a conventional progression system of 1, 2, 3... Put major scale markings at 0, 10, 20...or 10, 30, 50, 70 to relate to current British speed limits, intermediate markers at 5, 15, 25... and where appropriate use minor markers for individual numbers.
  - pointers of whatever form must line up with scale markings.
  - to enable the pointer position on the scale to be easily read and not distract the user, the sensitivity of the pointer must be damped.
  - the full scale should be permanently available to the driver, the value indicated by a pointer.

- Digital speedometer

  - values on a digital display must remain visible long enough to be read accurately, approximately 500 - 1000m.secs.
  - the characters should be upright rather than slanted
  - the character height should be 15-20mm

<u>Controls</u>

- the Imperial to metric switch will be infrequently used and should not be activated inadvertently. It may be positioned in secondary space on the dashboard panel.

14.2 Tachometer

- If a tachometer is to be provided then the display should be permanently displayed when the engine is running.
- An analogue display is more appropriate for a tachometer than a digital display or an analogue-digital combination.
- The analogue display for the tachometer should not be confused with the speedometer display. This can be done by manipulating style, colour, relative brightness.
- The warning condition zone should be indicated on the scale in red or yellow.
- Locate in primary space only if possible otherwise in secondary space.

Sèe speedometer for details of analogue display design (section 14.1).

14.3 Odometer

- Digital display
- Place in secondary space to avoid clutter and confusion with trip odometer.
- Minimum sizes appropriate, if too large it will interfere with digital speedometer reading.
- The odometer should be less bright than the speedometer.

Trip Odometer

- Digital display
- Place where it can be easily read by drivers.
- Minimum sizes appropriate as above.
- The trip odometer should be less bright than the speedometer.

Controls

The trip odometer control will be used frequently and should be easy to reach. The control should be easy to reach but not be inadvertently operated.

14.4 Fuel indication

- Use an analogue display
- Use an analogue style which shows the range of fuel level.
- Qualitative readings are all that are needed for fuel indication. Further scale markings will probably not enhance the use of the display.
- Low fuel level warning should be red or yellow.

14.5 Other features

It was noted in road trials on electronic displays (Driver response to electronic dashboard instrumentation, ICE report to Ford Motor Company 1981) that drivers often failed to turn on the vehicle headlights when starting off at night in lit streets. A probable explanation is that drivers use the instrument panel lights as a cue as to whether or not the headlights have been turned on. In lit streets external cues are often not available.

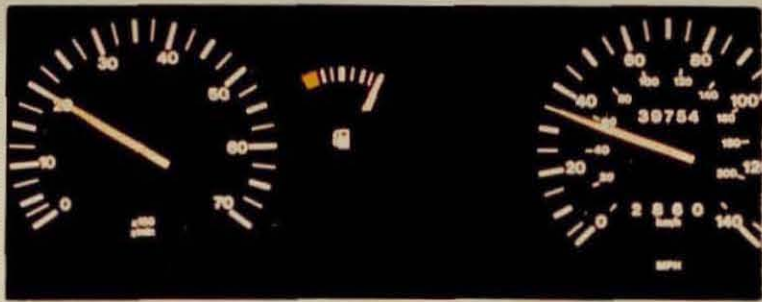
- It is recommended that an additional display is required for permanently illuminated electronic instrument panels to indicate whether or not the headlights are on.

- It is essential that drivers are able to control the brightness of the electronic instrument panels.

APPENDIX 2 THE DISPLAY DESIGNS

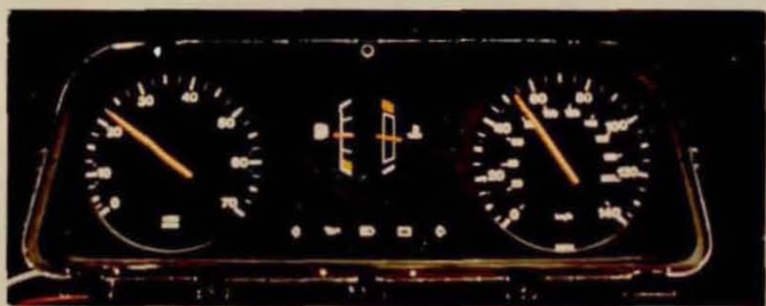
ELECTROMECHANICAL DIAL DISPLAY

STUDY 1 ORIGINAL

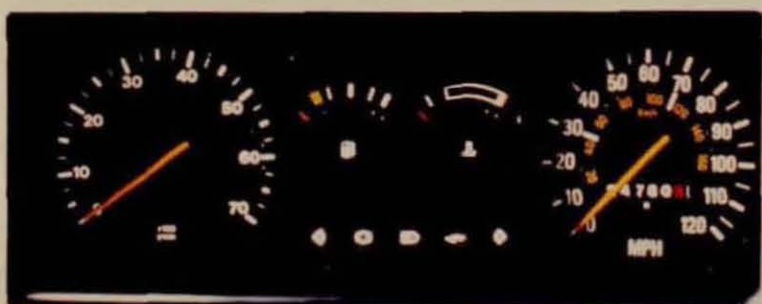


REVISED

STUDY 2



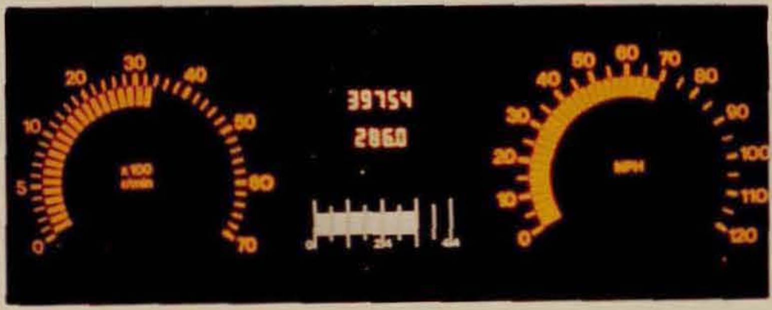
STUDY 3



ELECTRONIC DIAL DISPLAY

STUDY 1

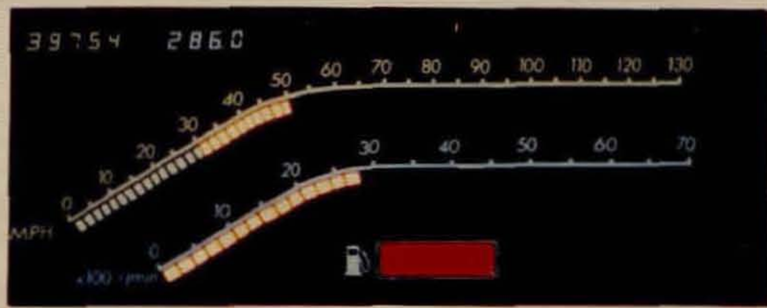
STUDY 2



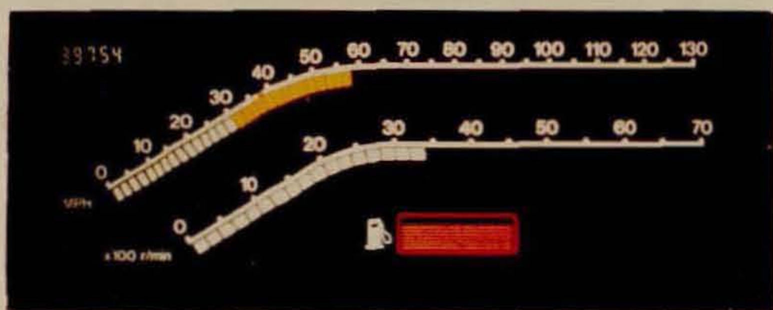
STUDY 3

ELECTRONIC CURVILINEAR DISPLAY

STUDY 1



STUDY 2



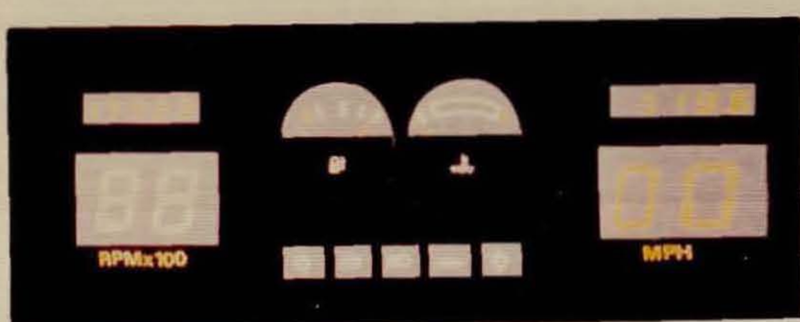
STUDY 3

ELECTRONIC DIGITAL DISPLAY

STUDY 1

STUDY 2

STUDY 3



APPENDIX 3 THE EXPERIMENTAL MATERIALS

STUDY 1

INSTITUTE FOR CONSUMER ERGONOMICS

DISTANCE AND COLOUR VISION TESTS - CAR DASHBOARD DESIGN PROJECT

SUBJECT NO. | | | | | DATE | | | |

SNELLEN TEST

WITHOUT SPECTACLES
(Tick box if whole line correct)

WITH DRIVING SPECTACLES

Without spectacles	R	L	Both		With driving spectacles	R	L	Both
Y				1	Y			
E Z				2	E Z			
L P N				3	L P N			
T J A V				4	T J A V			
U E N L A				5	U E N L A			
P C T V L H				6	P C T V L H			
X O F J D Y T				7	X O F J D Y T			
H V T U Z P C D				8	H V T U Z P C D			
A E J F T O L P N				9	A E J F T O L P N			
N C P T X U Z H E J				10	N C P T X U Z H E J			
D L T P N Z J E O A F				11	D L T P N Z J E O A F			

ISHIHARA TEST

(Circle response)

12	1	2	Other
8			Other
6			Other
57	5	7	Other
5			Other
15	- 1	5	Other
74	7	4	Other
2			Other
6			Other
5			Other
7			Other
16	1	6	Other
-			5
-			45

ALL CORRECT [ ]

DO YOU WEAR SPECTACLES?

NO - NOT AT ALL [ ]

YES - FOR CLOSE WORK ONLY
e.g. reading [ ]

YES - FOR DISTANCE ONLY
e.g. driving [ ]

YES - ALL THE TIME [ ]

If you wear spectacles for driving:

Do the spectacles you wear for driving have bifocal lenses?

YES - BIFOCAL LENSES [ ]

NO - NOT BIFOCAL LENSES [ ]

SPECTACLES WORN
DURING EXPERIMENT [ ]

RESPONSE SHEET

BJECT No. [| | |] DATE OF TEST. [| |] SHEET No. 1 2 3 4 5

1		21		41		61	
2		22		42		62	
3		23		43		63	
4		24		44		64	
5		25		45		65	
6		26		46		66	
7		27		47		67	
8		28		48		68	
9		29		49		69	
0		30		50		70	
11		31		51		71	
2		32		52		72	
3		33		53		73	
4		34		54		74	
5		35		55		75	
6		36		56		76	
7		37		57		77	
8		38		58		78	
9		39		59		79	
[illegible]		40		60		80	

INSTITUTE FOR CONSUMER ERGONOMICS

QUESTIONNAIRE - CAR DASHBOARD DESIGN PROJECT

SUBJECT NO. [| | |] DATE [| |]

In general, complete the questionnaire by ticking the box opposite the correct answer

---

NAME ______________________

ADDRESS ______________________

____

____

Your AGE GROUP:

17 - 30 YEARS	
31 - 50 YEARS	
51 YEARS OR MORE	

What is the make and model of the car you normally drive?

MAKE & MODEL OF CAR ______________________

____

What is the registration number and year of the car?

REG. NO. ______________________

YEAR ______________________

How long have you been driving that particular car?

LESS THAN 6 MONTHS	
6 MTHS - 1 YEAR	
1 - 2 YEARS	
MORE THAN 2 YEARS	

How long ago did you pass your driving test?

LESS THAN 1 YEAR	
1 - 3 YEARS	
4 - 8 YEARS	
9 - 17 YEARS	
18 - 34 YEARS	
35 YEARS OR MORE	

Does the car you normally drive have a rev. counter?

YES	
NO	

swer by circling one display
r each question.

ich of the dashboard designs
d you find easiest to read?

B C D E

ich did you find most
fficult to read?

B C D E

ich of the dashboard
signs was the easiest
tell whether the speed
own was within the
eed limit?

B C D E

ich did you find most
fficult to tell whether
e speed shown was within
e speed limit?

B C D E

ich of the dashboard designs
d you find most attractive?

B C D E

ich of the dashboard designs
you find least attractive?

B C D E

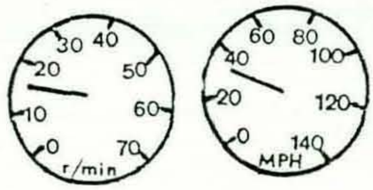
rall, which dashboard would
choose for your own car?

B C D E

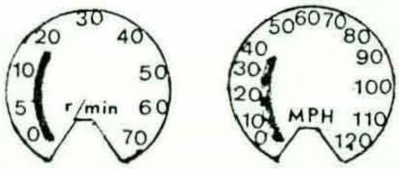
ch would you avoid?

B C D E

Dashboard Displays

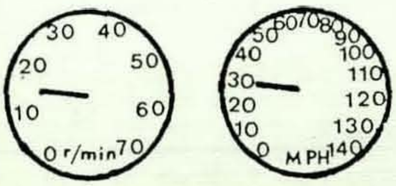


A

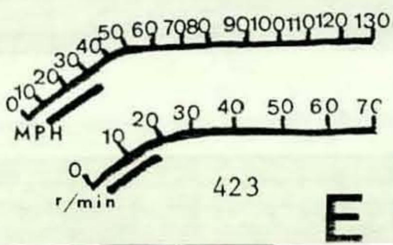


B

C



D



E

Write any comments about
the dashboards in the appropriate
spaces below.

COMMENTS ABOUT **A**

COMMENTS ABOUT **B**

COMMENTS ABOUT **C**

COMMENTS ABOUT **D**

COMMENTS ABOUT **E**

STUDY 2

Sheet A

INSTITUTE FOR CONSUMER ERGONOMICS

EYESIGHT MEASUREMENTS - CAR DRIVING PERFORMANCE PROJECT STAGE II

SUBJECT NUMBER [| | |]   DATE [| |]

EXPERIMENTER [CJ | MG | AB]

DO YOU WEAR SPECTACLES?

NO	- Not at all	1
YES	- For close work only (e.g. reading)	2
YES	- For distance only (e.g. driving)	3
YES	- All the time	4
	Contact lenses	5

IF YOU WEAR SPECTACLES FOR DRIVING:

Do the spectacles you wear for driving have bifocal lenses?

YES	- Bifocal lenses	1
NO	- Not bifocal lenses	2

SPECTACLES WORN DURING EXPERIMENT	YES	1
	NO	2

ISHIHARA TEST

(Circle response)

Normal	Red green	Total
12	12	12
8	3	X
6	5	X
29	70	X
57	35	X
5	2	X
3	5	X
15	17	X
74	21	X
2	X	X
6	X	X
97	X	X
45	X	X
5	X	X
7	X	X
16	X	X
73	X	X
X	5	X
X	2	X

Normal	1
Red/green	2
Total	3

HEIGHT [| | |] mm

MASTER VISION SCREENER

CHECK	INSTRUCTIONS	
1	Look through upper peepholes and read the words	*Underline correct words in each line:-* Red Far Are Dear Tar Car Let Call Lost Tall Pull All
2	Now read what you can see	*Circle last item:-* REAR POT
3	Now read what you can see	*Circle last item:-* LAND LOT
4	How many dots are there above the line?	*Circle response:-* 0 1 2 3 4 5 6 7 8
5	Which letter is the arrow nearest?	*Underline nearest letter or inbetween two (If arrow moves, subject must glance at row of squares then back at arrow).* A B C D E F G
6	In each word, one letter may seem nearer. At the top, do you see the letter N nearest? Which letter is nearest in 2, 3, 4, 5 and 6?	YES 1 NO 2 *Circle correct responses* O T F I X
7	Read these words please	*Tick sentence read out* Now look down lower 1 Now through the lower peepholes 2 Complete sentence (underlined) 3
8	Read these words please	*Underline correct words:-* Run Car Her Rat For
9	Read these words please	*Underline correct words:-* Lot Old Love Look Hall
10	How many dots above line?	*Circle correct response:-* 0 1 2 3 4 5 6 7 8
11	Which letter is the arrow nearest?	*Tick correct response* K ☐ L ☐ M ☐ N ☐ O ☐ P ☐ Q ☐
12	Read words in circle Read words in square	*Underline correct words* READ DOOR LOT HILL
13	Read the top line first Now those in box below	*Underline correct words* BUT JOB BAT BUS MOP DO SO UP
14	Some words may be nearer to you than others. Which is the nearest one of all? Which is the next nearest?	*Underline* This is the last picture NONE This is the last picture NONE

Sheet (

INSTITUTE FOR CONSUMER ERGONOMICS

CAR DRIVING PERFORMANCE PROJECT STAGE II - QUESTIONNAIRE

SUBJECT NUMBER [| | |] DATE [| |]

PLEASE ANSWER ALL THE FOLLOWING QUESTIONS. Circle the appropriate number.

Which age group are you in?	17 - 30 years	1
	31 - 50 years	2
	51 or more years	3

What is the make and model of the car you drive most frequently? ________________

____

How long have you been driving that particular car?	Less than 6 months	1
	6 months - 1 year	2
	1 - 2 years	3
	More than 2 years	4

How long ago did you pass your driving test?	Less than 1 year	1
	1 - 3 years	2
	4 - 8 years	3
	9 - 17 years	4
	18 - 34 years	5
	35 years or more	6
	No test taken	7

REFER TO PHOTOGRAPHS OF THE DASHBOARD DESIGNS

Which of the dashboard designs did you find easiest to read?	Design	1
		2
		3
		4
	NONE	5

Which of the dashboard designs did you find most difficult to read?	Design	1
		2
		3
		4
	NONE	5

Which of the dashboard designs was the easiest to tell whether the speed shown was within the speed limit?	Design	1
		2
		3
		4
	NONE	5

Which of the dashboard designs did you find most difficult to tell whether the speed shown was within the speed limit?	Design NONE	1 2 3 4 5
Which of the dashboard designs did you find the most distracting while you were driving?	Design NONE	1 2 3 4 5
Which of the dashboard designs did you find the least distracting while you were driving?	Design NONE	1 2 3 4 5
Which of the dashboard designs did you find the most attractive?	Design NONE	1 2 3 4 5
Which of the dashboard designs did you find the least attractive?	Design NONE	1 2 3 4 5
Overall, which dashboard would you choose for your own car?	Design NONE	1 2 3 4 5
Which would you avoid?	Design NONE	1 2 3 4 5

Write any comments in the spaces provided.

Do you think your use of the driving simulator accurately reflected your normal driving performance?

Was anything about the driving simulator difficult to get used to?

Any other comments about the simulator?

What did you particularly like about the dashboard designs?

Design 1

Design 2

Design 3

Design 4

What did you particularly dislike about the dashboard designs?

Design 1

Design 2

Design 3

Design 4

How would you improve the dashboard designs?

Design 1 ______________________________

____

Design 2 ______________________________

____

Design 3 ______________________________

____

Design 4 ______________________________

____

Was there anything about the dashboard designs which you found distracting?

(a) While you were driving?

____

____

(b) While you were using the speedometer?

____

____

Any other comments about the dashboard designs?

____

____

INSTITUTE FOR CONSUMER ERGONOMICS

CAR DRIVING PERFORMANCE PROJECT - STAGE II

SUBJECT NUMBER [| | |]   DATE [| |]

BUZZER

Presentation 1

PASS	1
FAIL	2

Presentation 2

PASS	1
FAIL	2

BEEPER

Presentation 1

PASS	1
FAIL	2

Presentation 2

PASS	1
FAIL	2

PRACTICE DRIVE

Number of practice buzzes in minutes 4 + 5 [ ]

Number of practice buzzes in minutes 7 + 8 [ ]

TASK C - RATING SCALE

DISPLAY 1
R MODULE

VERY EASY	1
EASY	2
NEITHER	3
DIFFICULT	4
VERY DIFFICULT	5

DISPLAY 2
DIAL

VERY EASY	1
EASY	2
NEITHER	3
DIFFICULT	4
VERY DIFFICULT	5

DISPLAY 3
LINEAR

VERY EASY	1
EASY	2
NEITHER	3
DIFFICULT	4
VERY DIFFICULT	5

DISPLAY 4
DIGITAL

VERY EASY	1
EASY	2
NEITHER	3
DIFFICULT	4
VERY DIFFICULT	5

SITTING
EYE HEIGHT [| | |] mm

SEAT
POSITION

1	2	3	4	5	6	7

(circle response)

STUDY 3

INSTITUTE FOR CONSUMER ERGONOMICS

CAR DRIVING PERFORMANCE PROJECT - STAGE III

SUBJECT NAME ....

SUBJECT NUMBER [| |] DATE [| |]

CONDITION:

DAY	1
NIGHT	2

ROUTE:

LOUGHBOROUGH	1
LEICESTER	2
DERBY	3
NOTTINGHAM	4

ANSWER ALL THE FOLLOWING QUESTIONS. Circle the appropriate number

Which age group are you in?

21 - 30 years	1
31 - 50 years	2
51 years or more	3

What is the make and model of the car you normally drive? ....

How long have you been driving that particular car?

Less than 6 months	1
6 months - 1 year	2
1 - 2 years	3
More than 2 years	4

How long ago did you pass your driving test?

Less than 1 year	1
1 - 3 years	2
4 - 8 years	3
9 - 17 years	4
18 - 34 years	5
35 years or more	6

You have now driven two vehicles with different dashboards. From your experience of these two dashboards, please answer all the following questions.

Circle the appropriate number.

1. Which dashboard did you prefer in general?

Design	1
	2
Neither	3

2. Which dashboard did you find easier to read?

Design	1
	2
Neither	3

3. Which dashboard did you find easier to tell whether or not you were within the speed limit?

Design	1
	2
Neither	3

4. Which dashboard did you find the more attractive?

Design	1
	2
Neither	3

5. Which dashboard would you choose for your own car?

Design	1
	2
Neither	3
Both	4

6. Did you find that either of the dashboards distracted your attention from the road?

Design	1
	2
Neither	3
Both	4

7. If you found one of the dashboards distracting, what was it about that dashboard that distracted your attention from the road?

Design 1 ....

....

Design 2 ....

....

8. What did you particularly like about the dashboards?

Design 1 ....

....

Design 2 ....

9. What did you particularly dislike about the dashboards?

Design 1 ....

....

Design 2 ....

....

10. What improvements would you make to the dashboards?

Design 1 ....

....

Design 2 ....

....

11. For what type of vehicle do you think Design 2 is best suited?.............

....

INSTITUTE FOR CONSUMER ERGONOMICS

EYESIGHT MEASUREMENTS - CAR DRIVING PERFORMANCE PROJECT STAGE III

SUBJECT NUMBER | | | | |

DATE | | | |

DO YOU WEAR SPECTACLES?

NO - Not at all	1
YES - For close work only (e.g. reading)	2
YES - For distance only (e.g. driving)	3
YES - All the time	4
Contact lenses	5

IF YOU WEAR SPECTACLES FOR DRIVING:

Do the spectacles you wear for driving have bifocal lenses?

YES - Bifocal lenses	1
NO - Not bifocal lenses	2

SPECTACLES WORN DURING EXPERIMENT	YES	1
	NO	2

ISHIHARA TEST

(Circle response)

Normal	Red green	Total
12	12	12
8	3	X
6	5	X
29	70	X
57	35	X
5	2	X
3	5	X
15	17	X
74	21	X
2	X	X
6	X	X
97	X	X
45	X	X
5	X	X
7	X	X
16	X	X
73	X	X
X	5	X
X	2	X

Normal	1
Red/green	2
Total	3

HEIGHT | | | | | mm

MASTER VISION SCREENER

CHECK	INSTRUCTIONS	
1	Look through upper peepholes and read the words	*Underline correct words in each line:-* Red Far Are Dear Tar Car Let Call Lost Tall Pull All
2	Now read what you can see	*Circle last item:-* REAR POT
3	Now read what you can see	*Circle last item:-* LAND LOT
4	How many dots are there above the line?	*Circle response:-* 0 1 2 3 4 5 6 7 8
5	Which letter is the arrow nearest?	*Underline nearest letter or inbetween two (If arrow moves, subject must glance at row of squares then back at arrow).* A B C D E F G
6	In each word, one letter may seem nearer. At the top, do you see the letter N nearest? Which letter is nearest in 2, 3, 4, 5 and 6?	YES 1 NO 2 *Circle correct responses* O T F I X
7	Read these words please	*Tick sentence read out* Now look down lower 1 Now through the lower peepholes 2 Complete sentence (underlined) 3
8	Read these words please	*Underline correct words:-* Run Car Her Rat For
9	Read these words please	*Underline correct words:-* Lot Old Love Look Hall
10	How many dots above line?	*Circle correct response:-* 0 1 2 3 4 5 6 7 8
11	Which letter is the arrow nearest?	*Tick correct response* K ☐ L ☐ M ☐ N ☐ O ☐ P ☐ Q ☐
12	Read words in circle Read words in square	*Underline correct words* RED DOOR LOT HILL
13	Read the top line first Now those in box below	*Underline correct words* BUT JOB BAT BUS MOB DO SO UP
14	Some words may be nearer to you than others. Which is the nearest one of all? Which is the next nearest?	*Underline* This is the last picture NONE 437 This is the last picture NONE

OUT

NAME ....SUBJECT No. ....DATE .... DAY [ ] NIGHT [ ]

R MODULE [ ] DIGITAL [ ]

	Reading	Speed Limit	Light	LIGHT D/B	W	Actual Speed	Response	Error
A 50 FROM LEICESTER	30B							
	30B	30	+					
	1A	40	+					
COUNTY HALL	2A	50	+					
	70B	70	+					
	3A	50	+					
	70B	70	-					
	4A							
	5A	50	+					
	70B	70	-					
AT MOTORWAY ROUNDABOUT 22 RIGHT TO J23	6A							
	70B							
	7A	70	-					
	70B							
	8A							
LEFT AT MOTORWAY ROUNDABOUT TOWARDS SHEPSHED.		60	+					
LEFT (B5330) SIGNPOSTED CROPSTON	60B	60	-					
	60B							
AT CROSSROADS LEFT ONTO NANPANTAN ROAD	60B							
	60B	60	-					
LEFT ONTO SNELL'S NOOK LANE	9A							
	60B	60	-					
RIGHT ON TO ASHBY ROAD	10A	40	+					
	30B	30						
LEFT AT ROUNDABOUT	30B	30	+					
RIGHT AT ROUNDABOUT	30B	30	+					
LEFT AT A6								
RIGHT ONTO SWINGBRIDGE ROAD								

438

Observation - night only

1. Brightness regulator

Conversation - day and night

2. Have you found any problems in reading the display? Y/N [ ]

3. (a) Is it difficult to read the display now?

Day
- Sunlight ahead [ ] Y/N
- Sunlight behind [ ] Y/N
- Overcast [ ] Y/N

Night
- Lit road [ ] Y/N
- Unlit road - headlights front [ ] Y/N
- Unlit road - headlights back [ ] Y/N
- Unlit road - no headlights [ ] Y/N

3. (b) What is the problem?

....

4. Is the display bright enough?

Day
- Sunlight ahead [ ] Y/N
- Sunlight behind [ ] Y/N
- Overcast [ ] Y/N

Night
- Lit road [ ] Y/N
- Unlit road - headlights front [ ] Y/N
- Unlit road - headlights back [ ] Y/N
- Unlit road - no headlights [ ] Y/N

Sun visor [ ] Y/N

RETURN

NAME................ SUBJECT No. .... DATE......................

Route	READING	SPEED LIMIT	LIGHT	LIGHT D/B	LIGHT W	ACTUAL SPEED	RESPONSE	ERROR
FROM SWINGBRIDGE ROAD		30						
LEFT ONTO DERBY ROAD								
RIGHT ONTO ALAN MOSS ROAD	30B		+					
LEFT AT ROUNDABOUT	30B		+					
RIGHT AT R/B ONTO ASHBY ROAD	30B		+					
	1A	40	+					
LEFT ONTO SNELLS NOOK LANE	60B	60	-					
	2A							
RIGHT ONTO NANPANTAN HILL	60B		-					
	60B							
(RIGHT AT CROSSROADS TO SHEPSHED B5330)	60B	60	-					
	60B							
RIGHT AT T JUNCTION TOWARDS M.1.		60	+					
AT MOTORWAY ROUNDABOUT 23 RIGHT TO J22	70B							
	3A							
	70B	70	-					
	4A							
	5A							
AT J22 LEFT AT ROUNDABOUT ONTO A50 TO LEICESTER.	70B	70						
	6A	50	+					
	7A	70	-					
	70B							
	8A	50	+					
	70B	70	+					
COUNTY HALL	9A	50	+					
	10A	40	+					
	30B	30	+					
	30B							

DAY ☐ NIGHT ☐

R MODULE ☐ DIGITAL ☐

Observation - night only

1. Brightness regulator

Conversation - day and night

2. Have you found any problems in reading the display? Y/N ☐

3. (a) Is it difficult to read the display now?

Day
- Sunlight ahead ☐ Y/N
- Sunlight behind ☐ Y/N
- Overcast ☐ Y/N

Night
- Lit road ☐ Y/N
- Unlit road - headlights front ☐ Y/N
- Unlit road - headlights back ☐ Y/N
- Unlit road - no headlights ☐ Y/N

3. (b) What is the problem?

....

4. Is the display bright enough?

Day
- Sunlight ahead ☐ Y/N
- Sunlight behind ☐ Y/N
- Overcast ☐ Y/N

Night
- Lit road ☐ Y/N
- Unlit road - headlights front ☐ Y/N
- Unlit road - headlights back ☐ Y/N
- Unlit road - no headlights ☐ Y/N

Sun visor ☐ Y/N

APPENDIX 4 STUDY 1

FIGURES

Figure 4.1 Study 1 - Sequence of operations

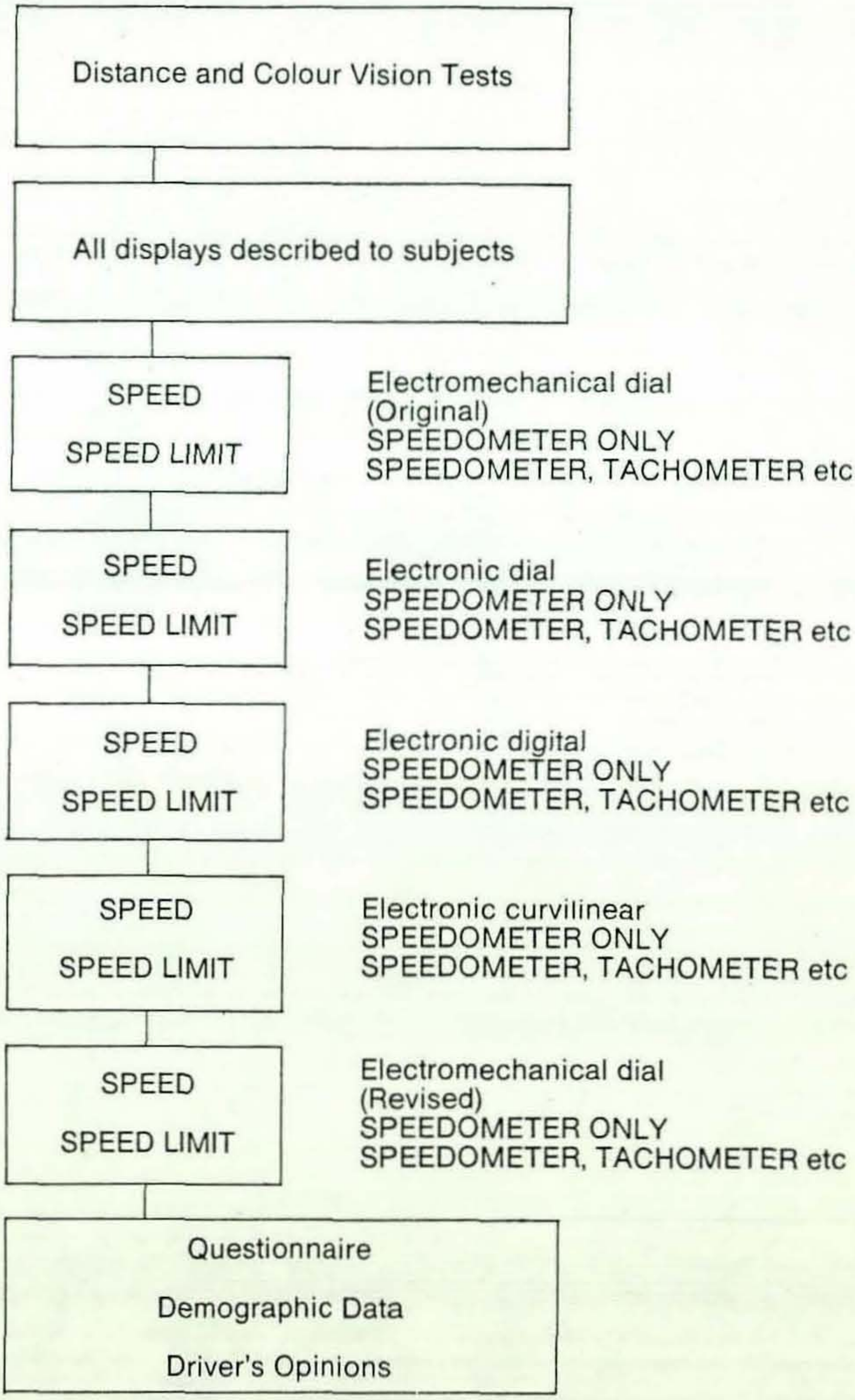


Figure 4.2 Study 1 - The experiment in progress

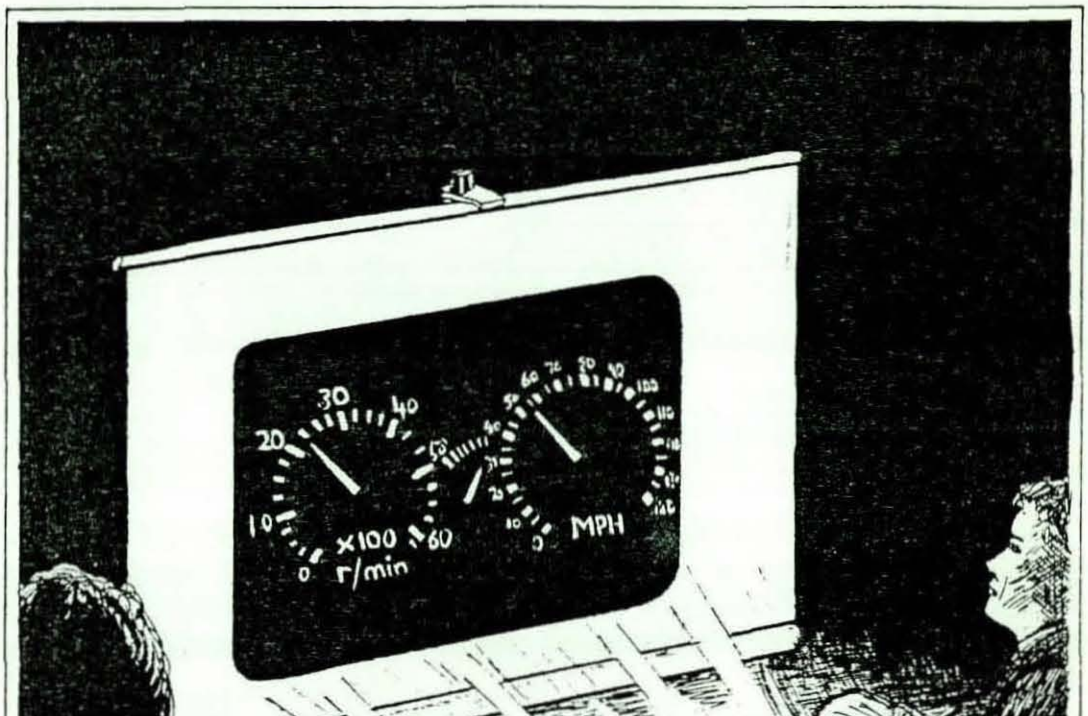


Figure 4.3 Study 1 - The percentage of errors made when reading the speed

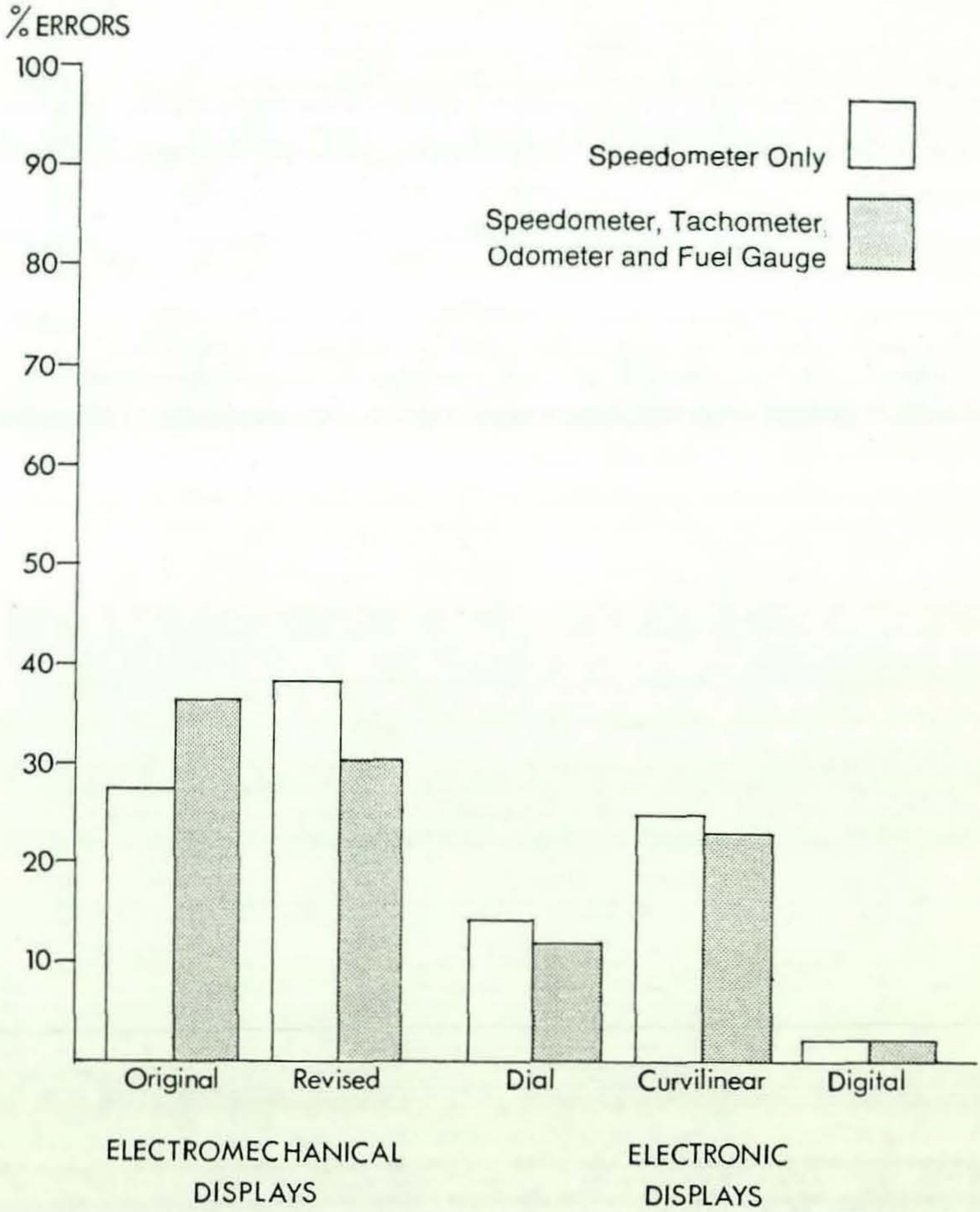


Figure 4.4 Study 1 - The percentage of errors made when deciding whether the speed is within a speed limit.

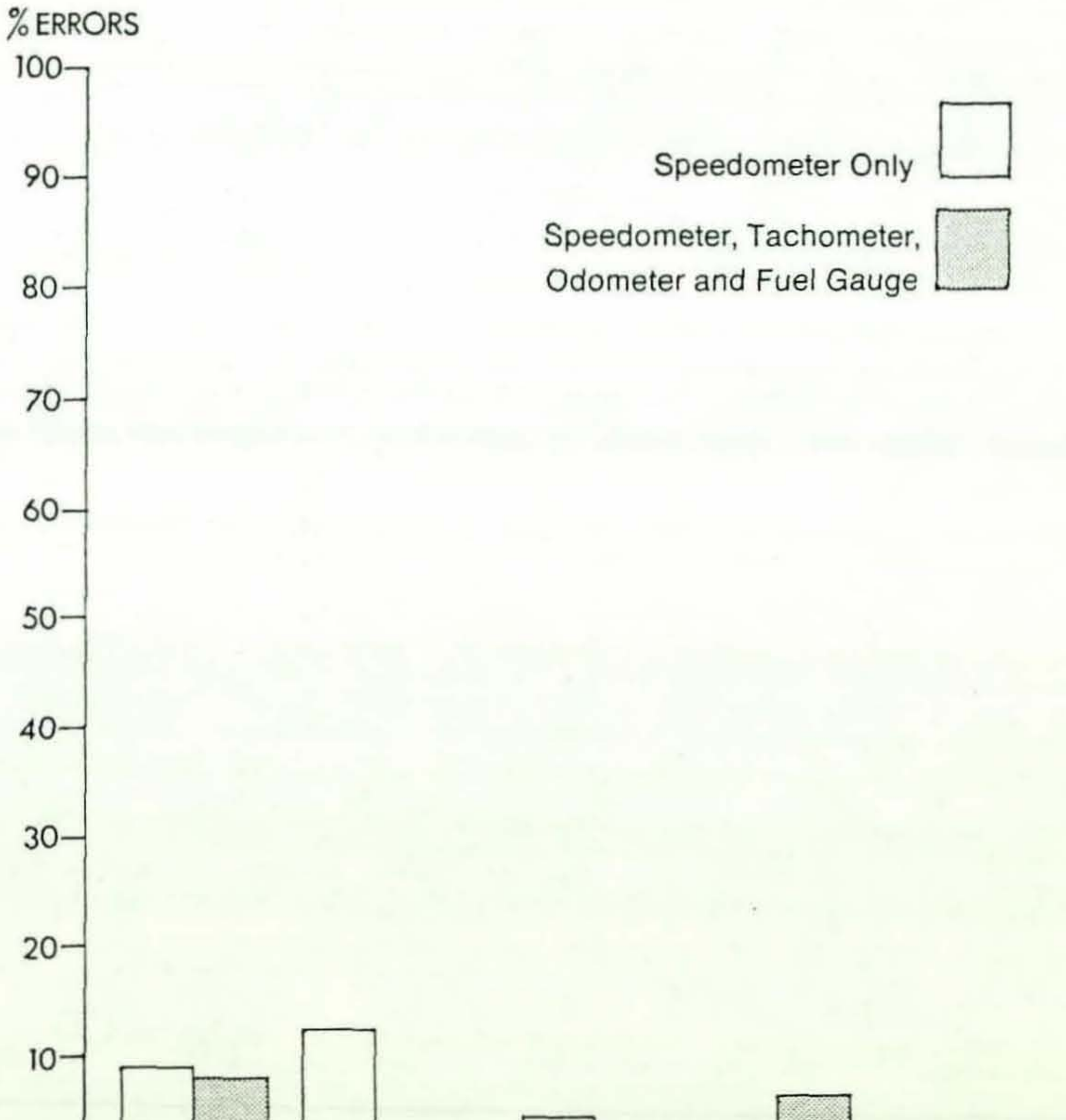


Figure 4.5 Study 1 - Which display was considered the easiest and the most difficult to read?

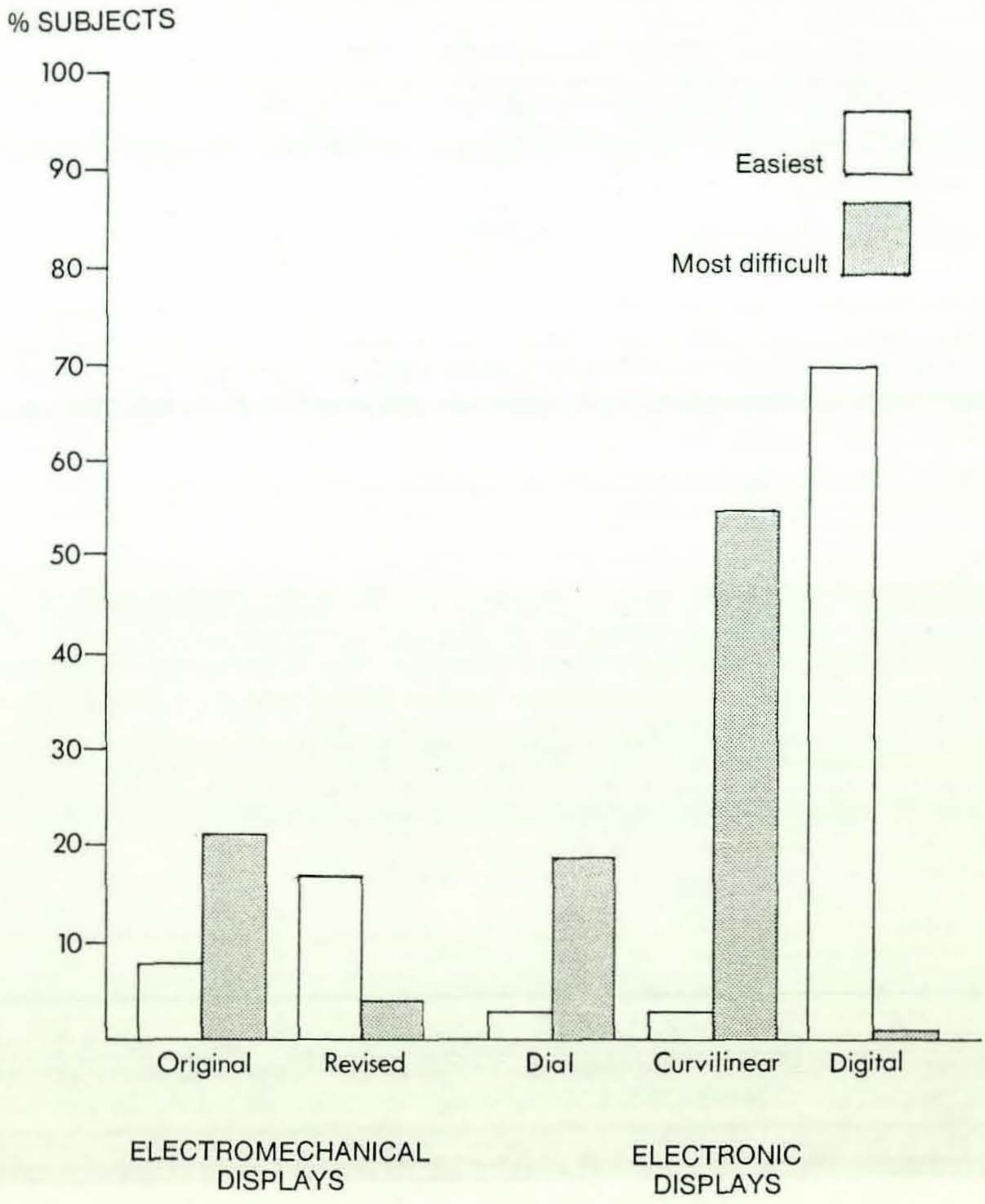


Figure 4.6 Study 1 - Which display was considered the easiest and the most difficult to tell whether the speed is within a speed limit?

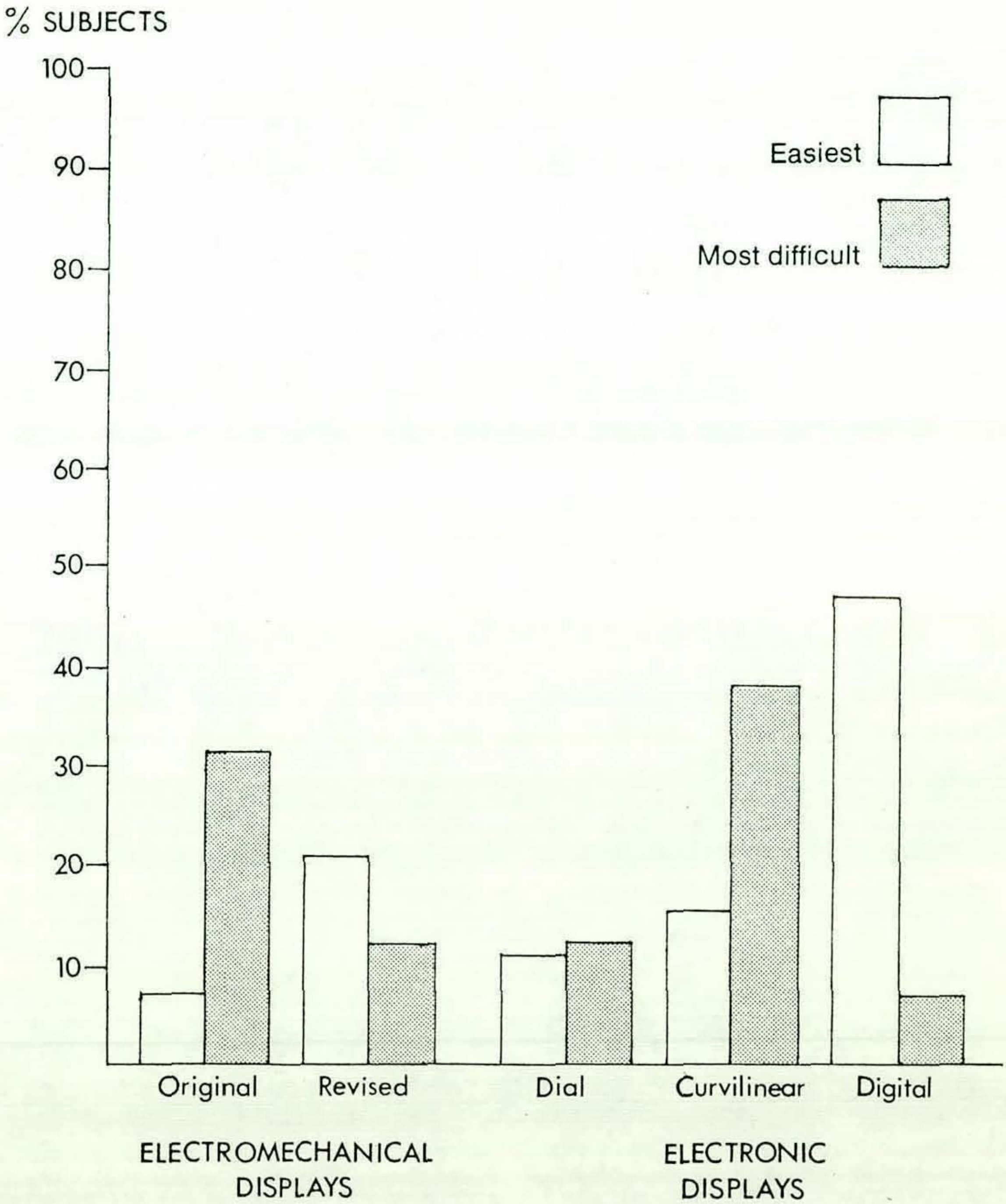


Figure 4.7 Study 1 - Which display was considered the most and the least attractive?

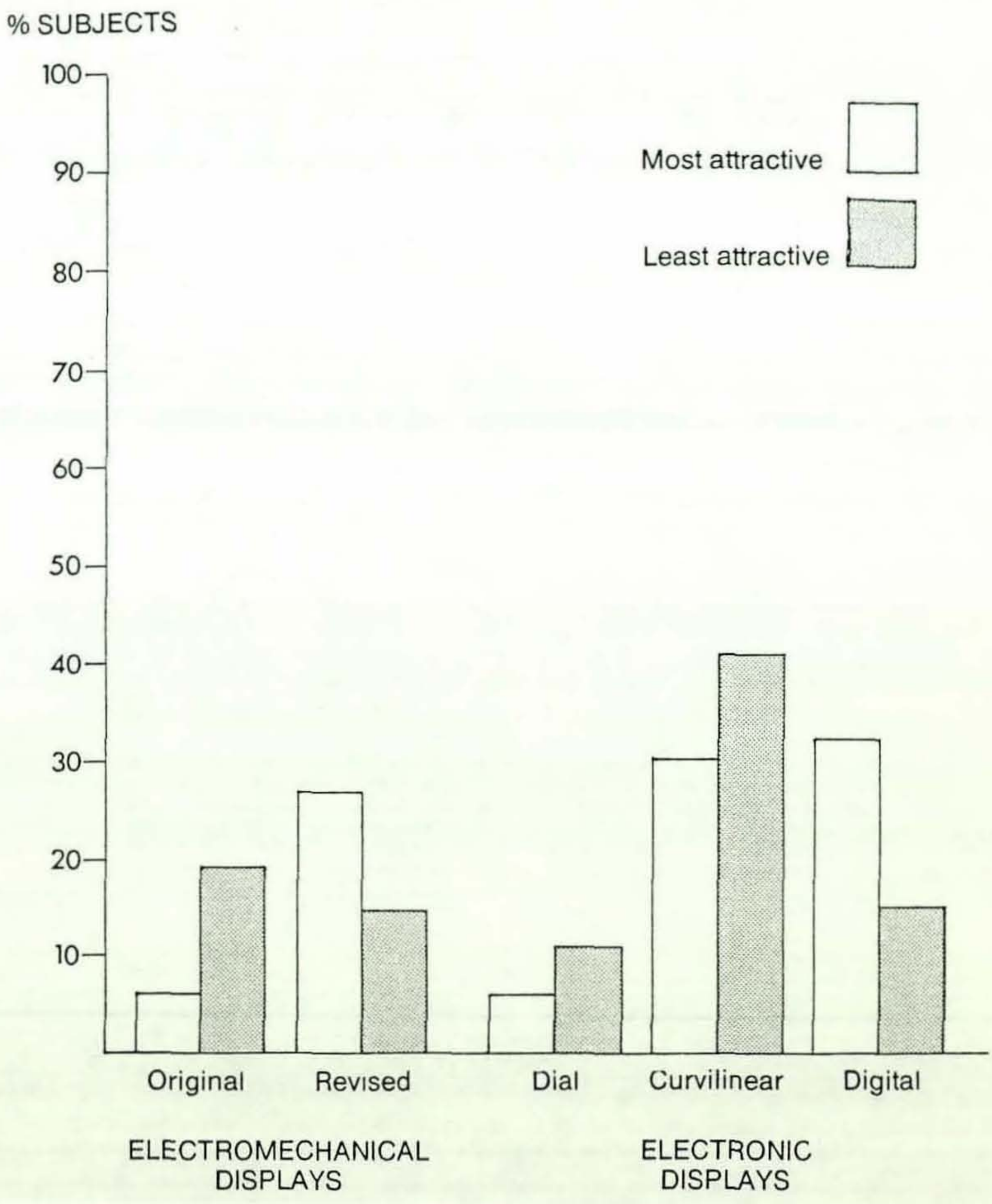
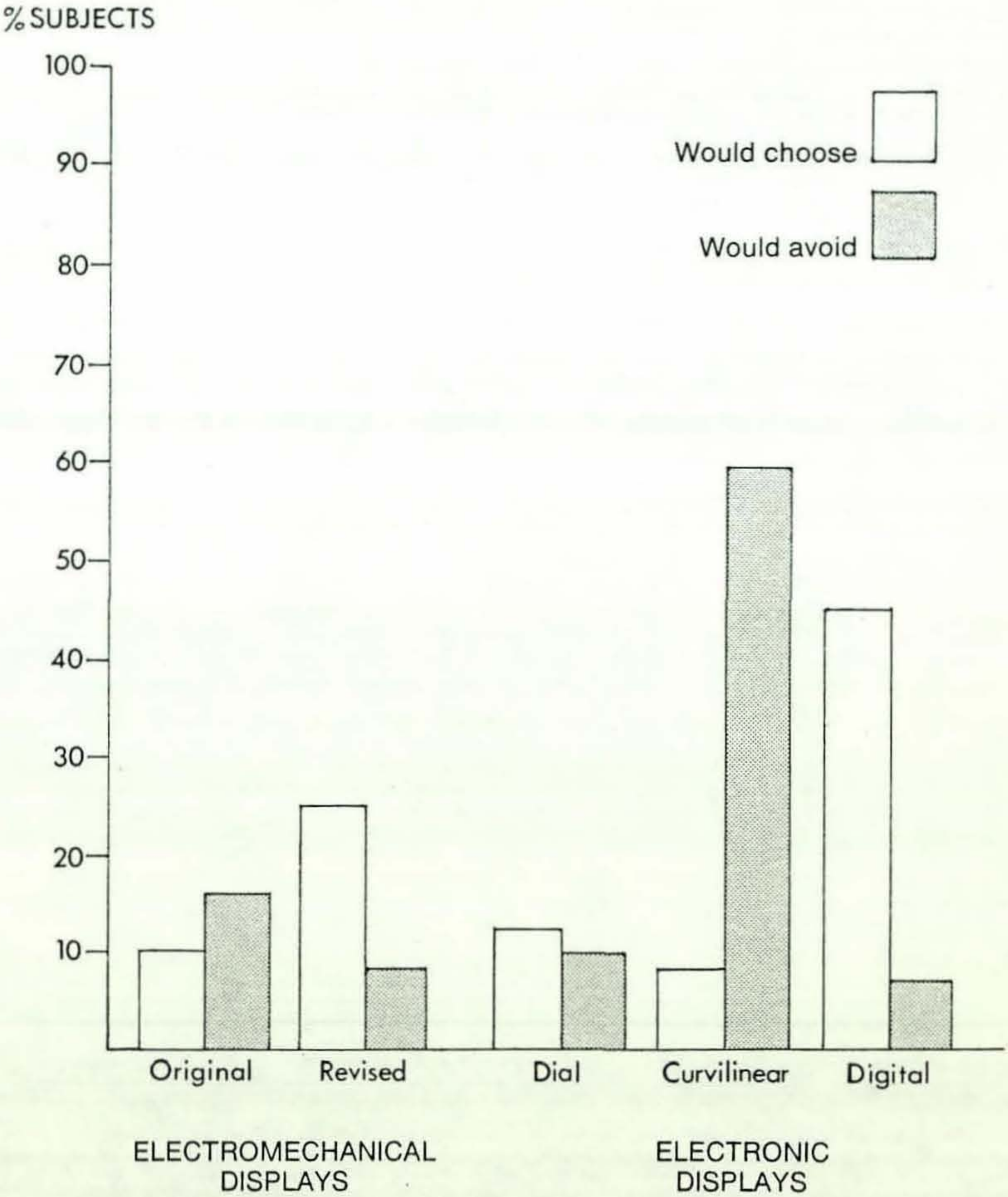


Figure 4.8 Study 1 - Which display would subjects choose and avoid for their own car?



APPENDIX 5 STUDY 2

FIGURES

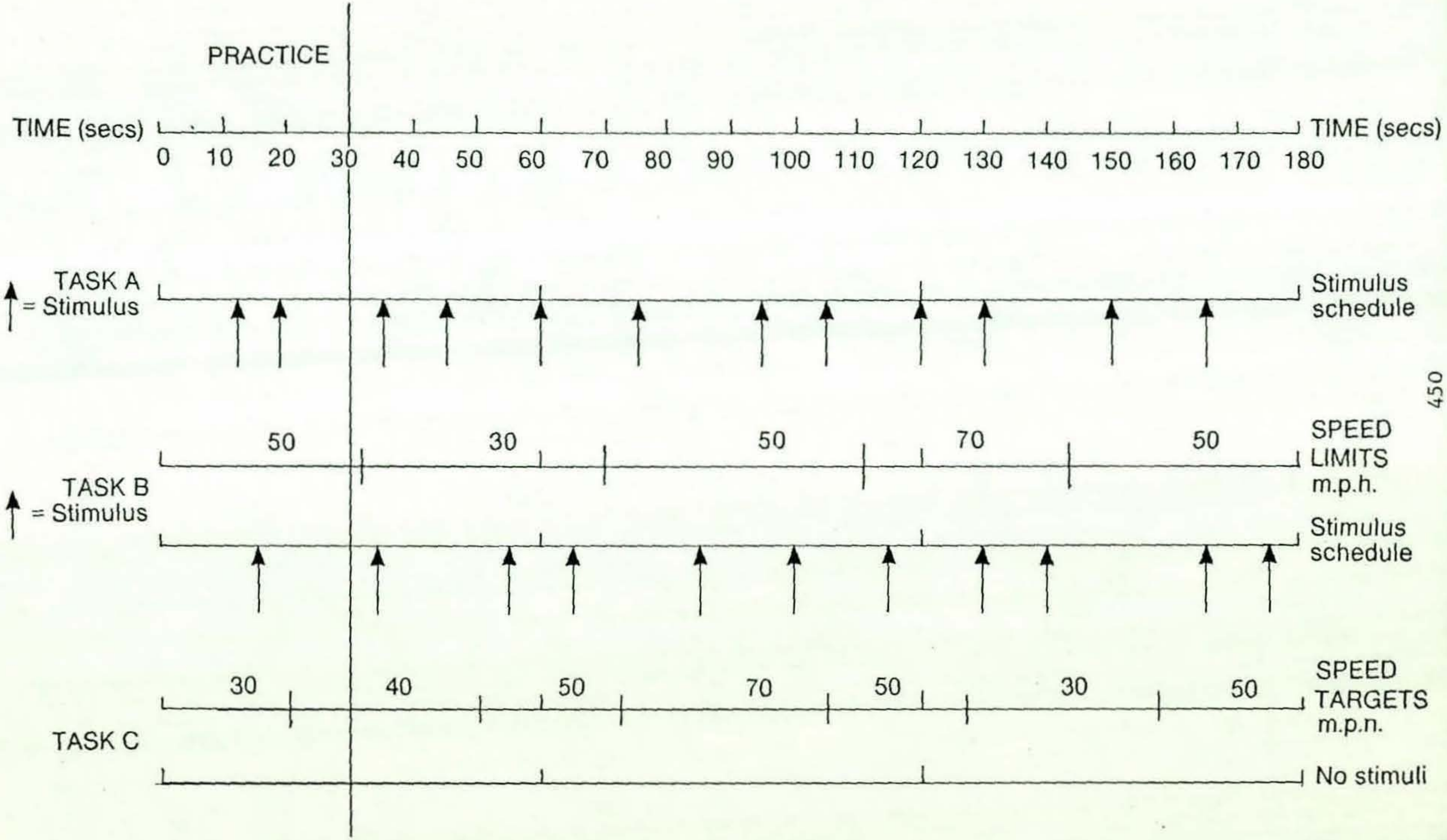


Figure 5.1 Study 2 - Specification of tasks

Figure 5.2 Study 2 - The experiment in progress

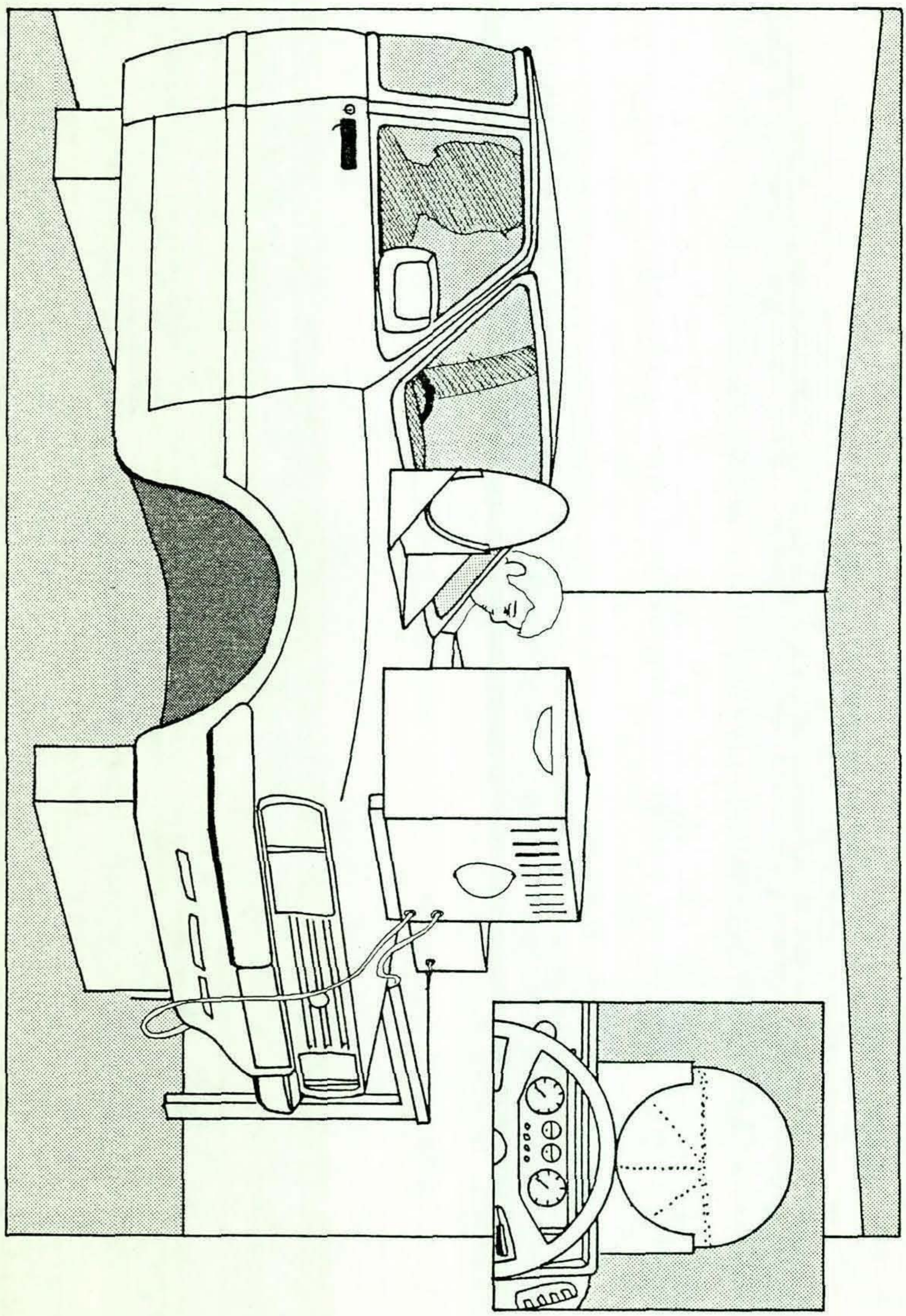


Figure 5.3 Study 2 - The percentage of correct responses made when reading the speed.

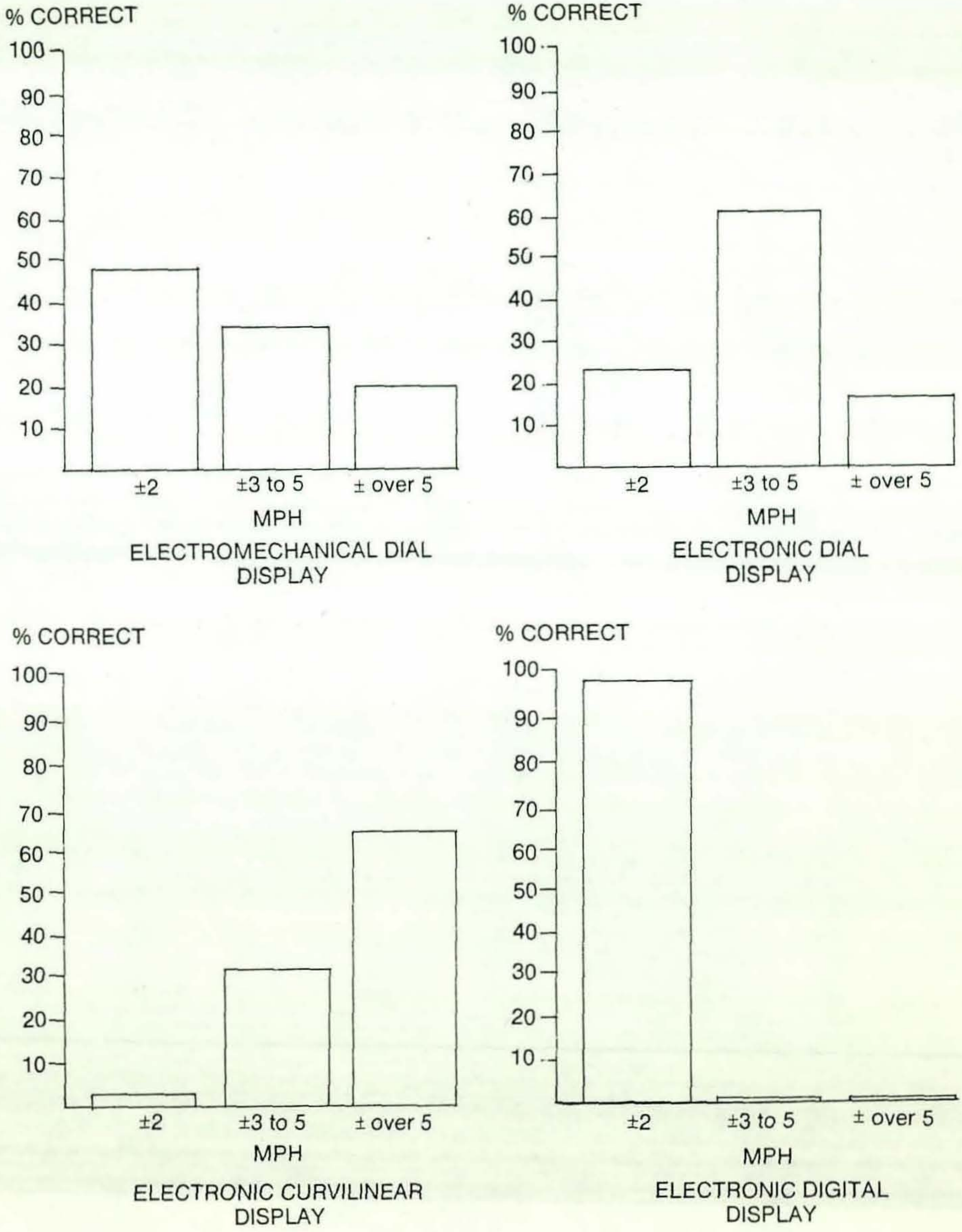


Figure 5.4 Study 2 - The percentage of errors made when deciding whether the speed is within the speed limit.

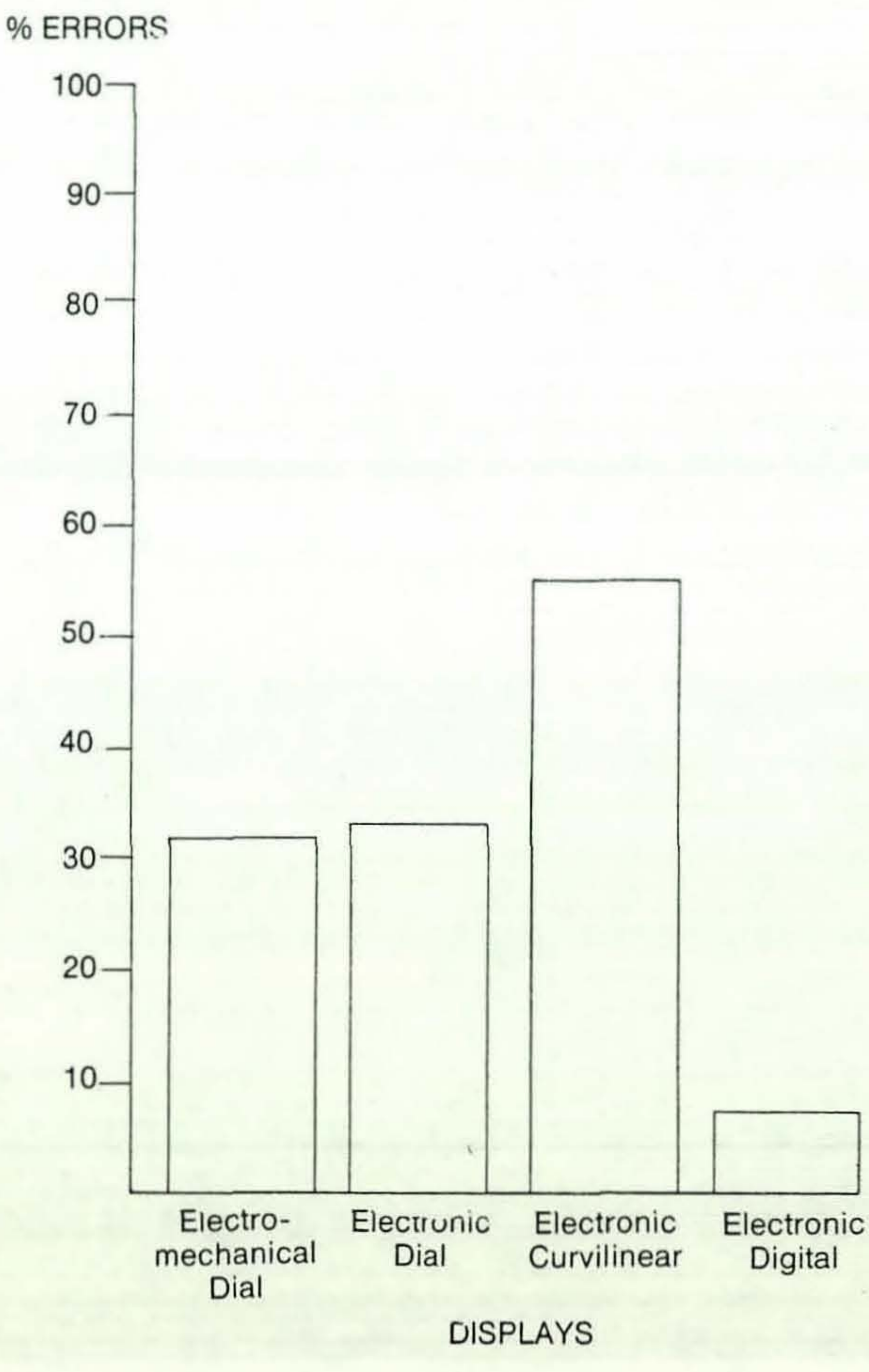


Figure 5.5 Study 2 - Which display was considered the easiest and the most difficult to read?

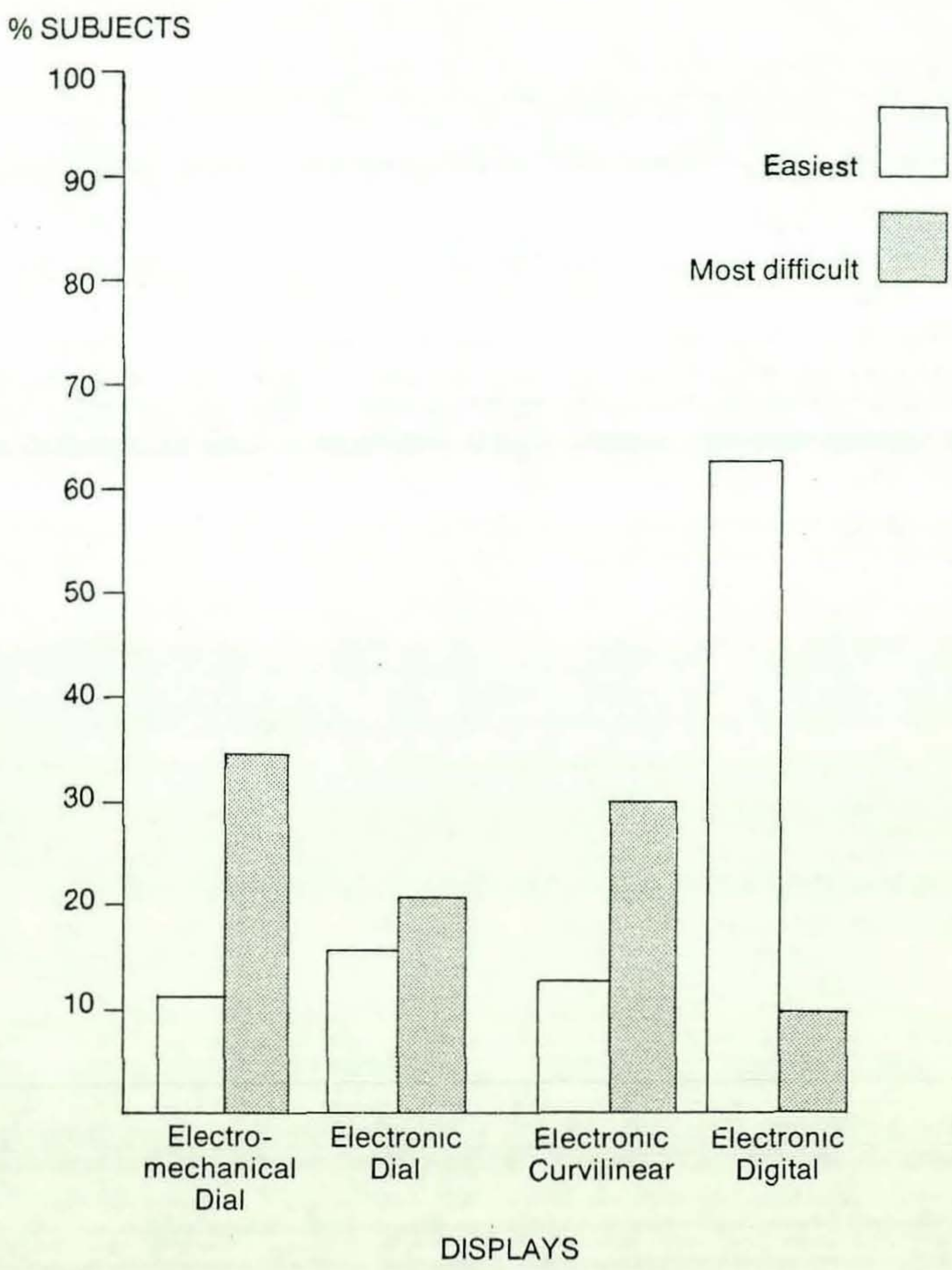


Figure 5.6 Study 2 - Which display was considered the easiest and the most difficult to tell whether the speed is within a speed limit?

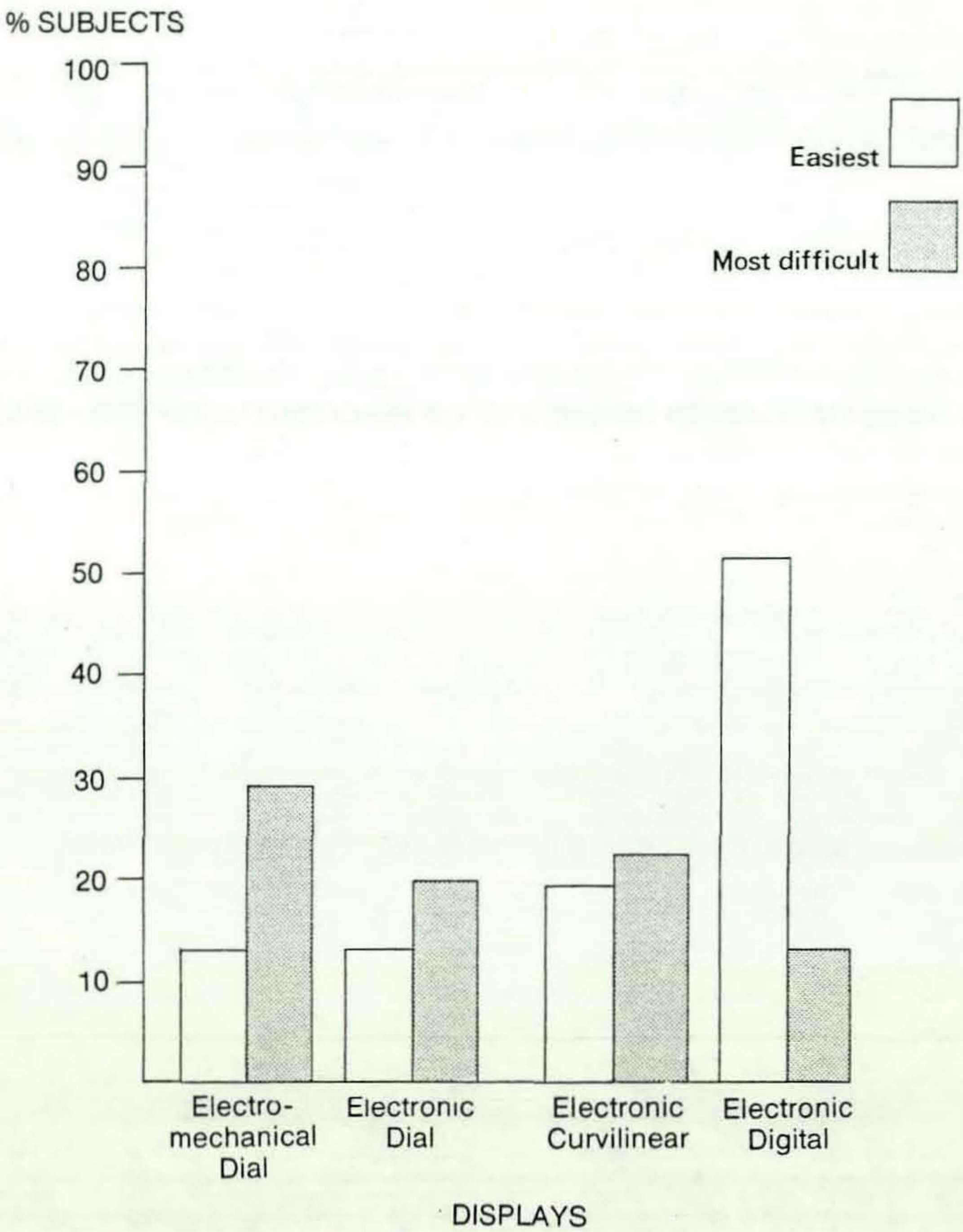


Figure 5.7 Study 2 - Which display was considered the easiest and the most difficult to use to keep to a speed target?

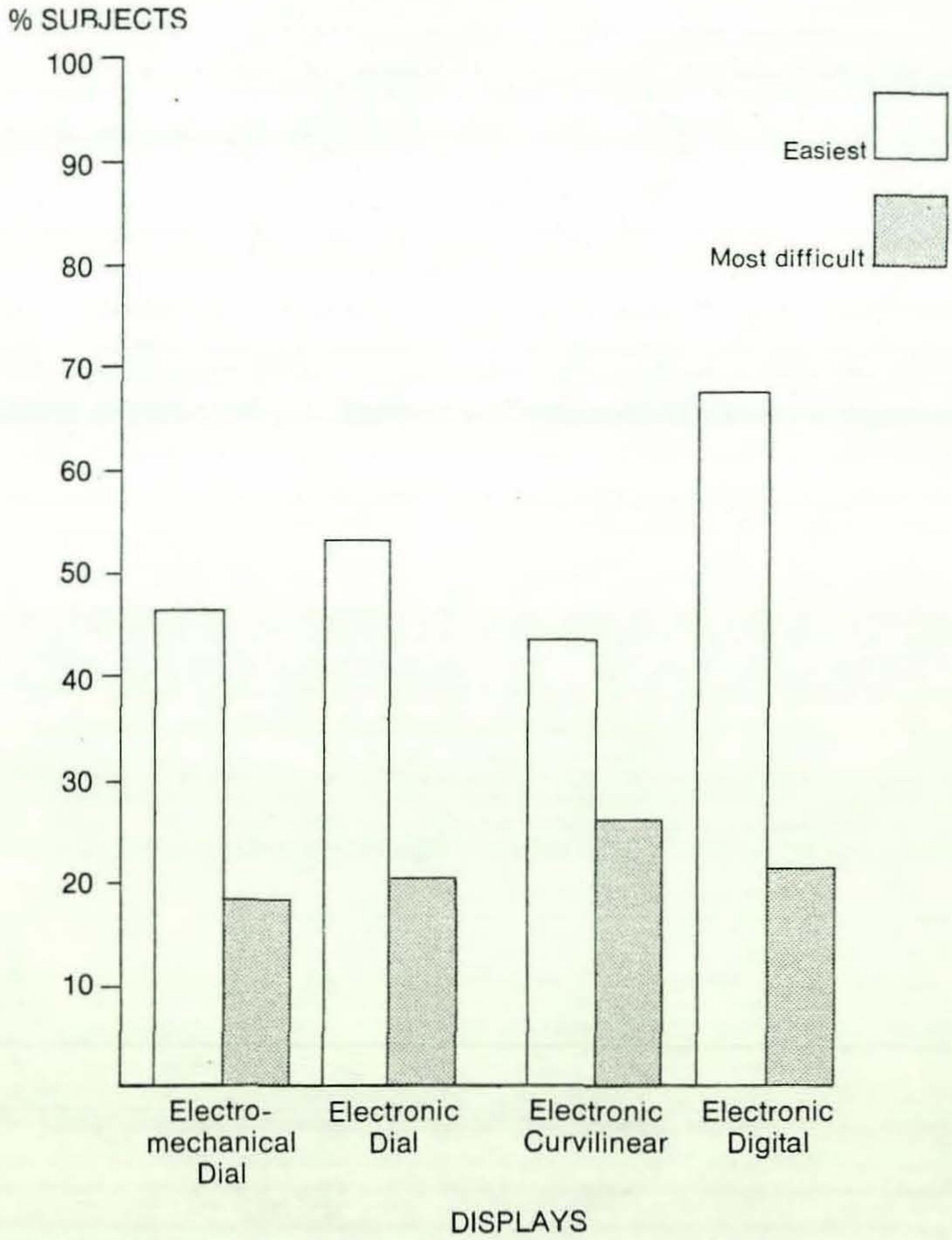


Figure 5.8 Study 2 - Which display was considered the least and the most distracting while driving?

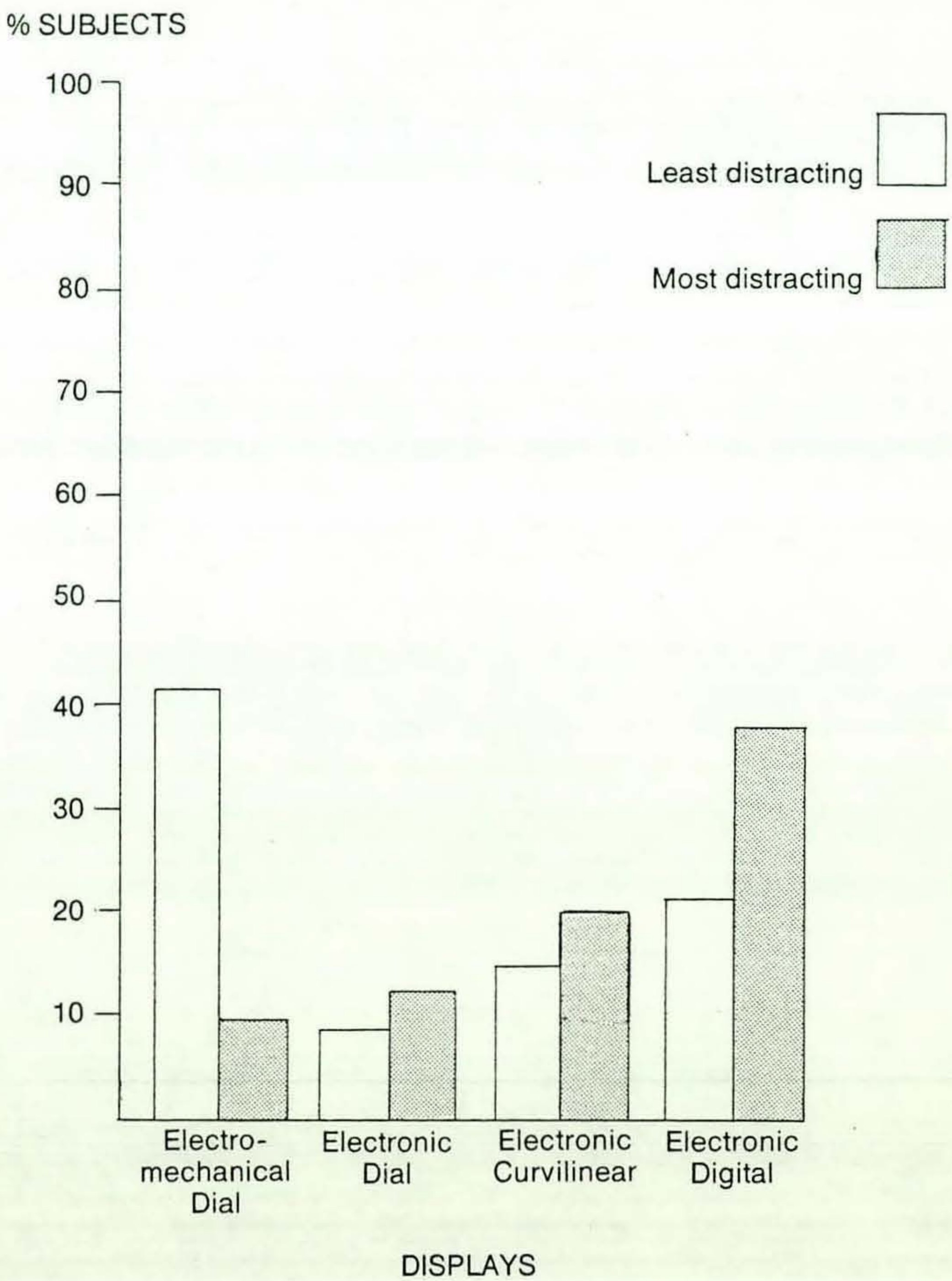


Figure 5.9 Study 2 - Which display was considered the most and the least attractive?

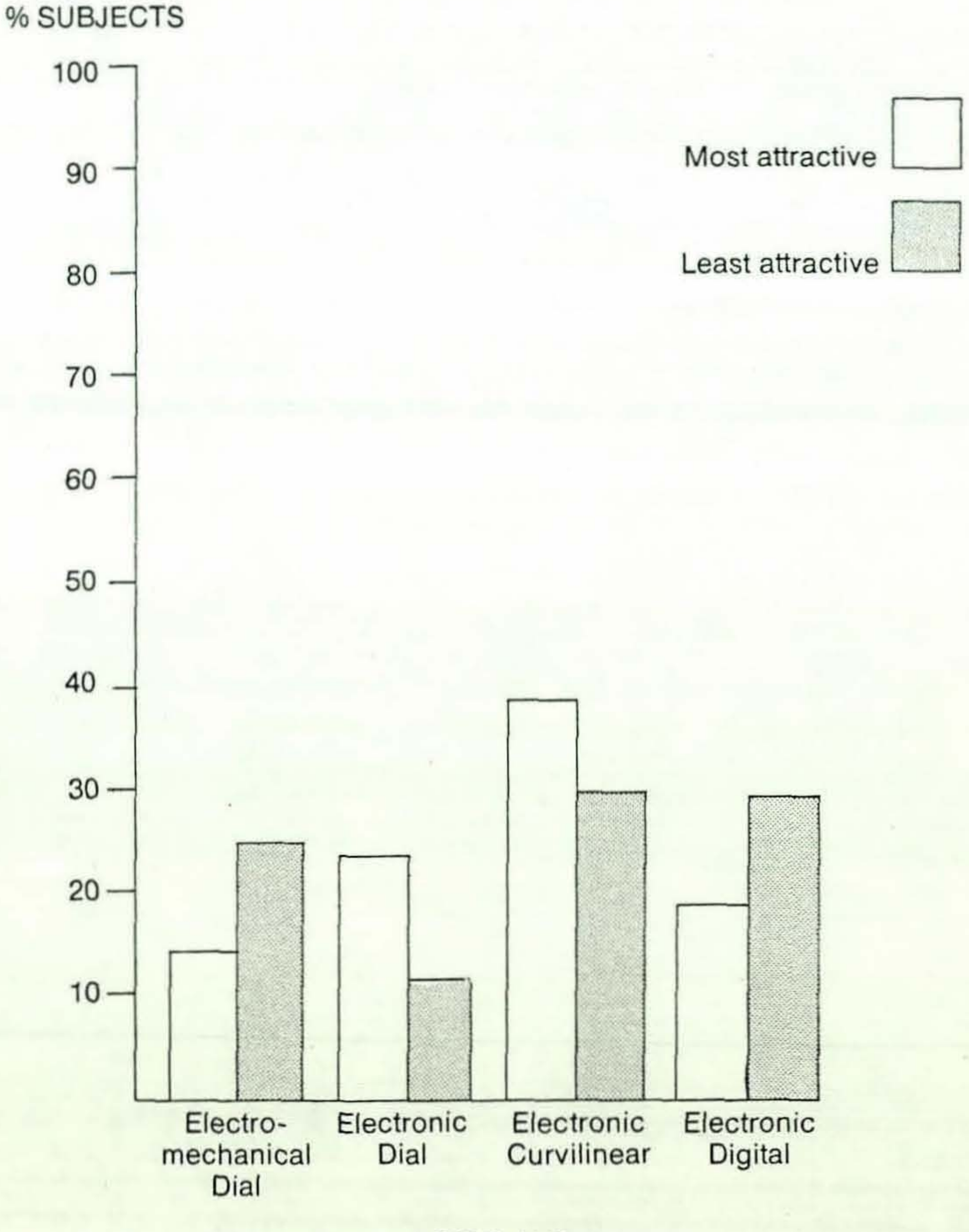
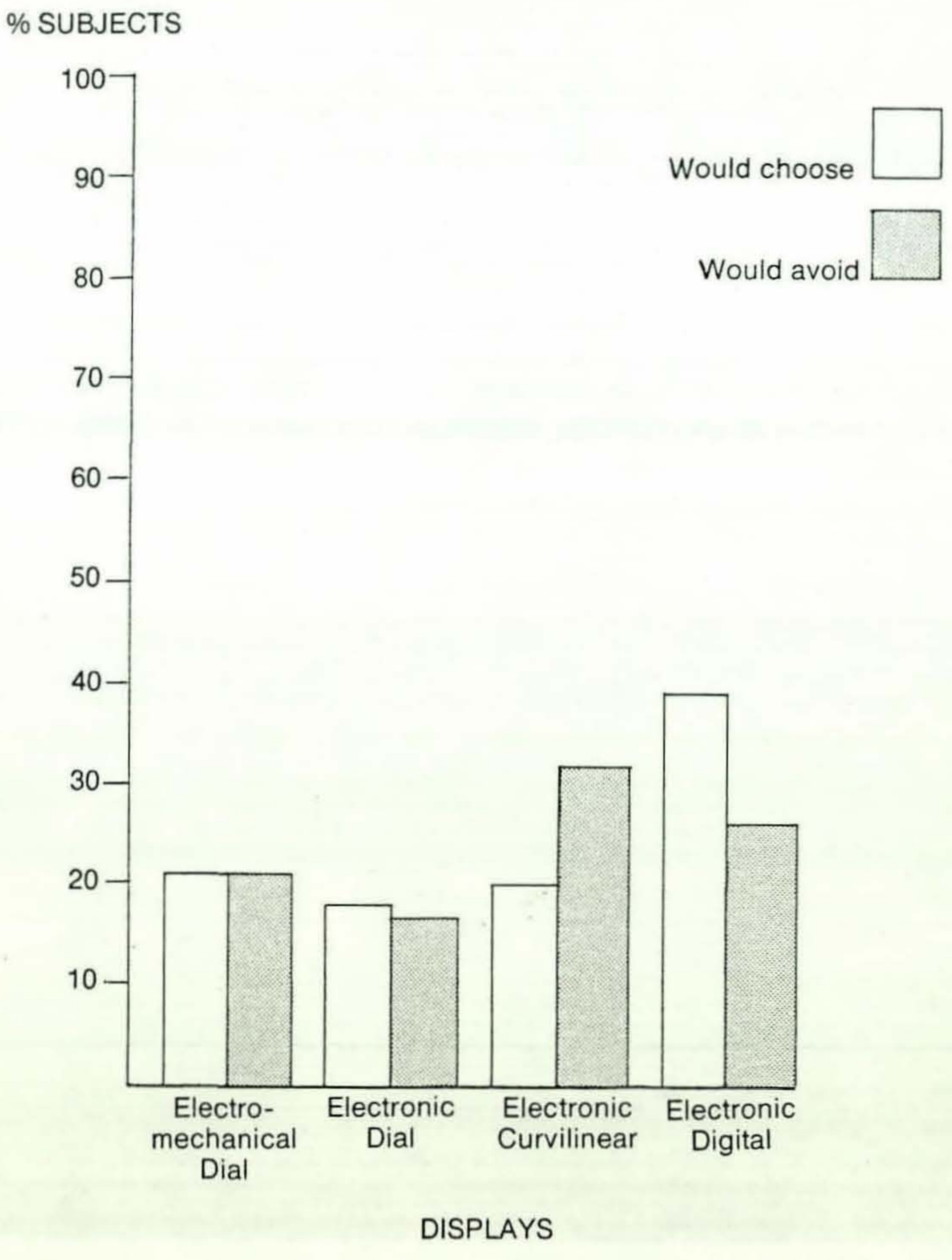


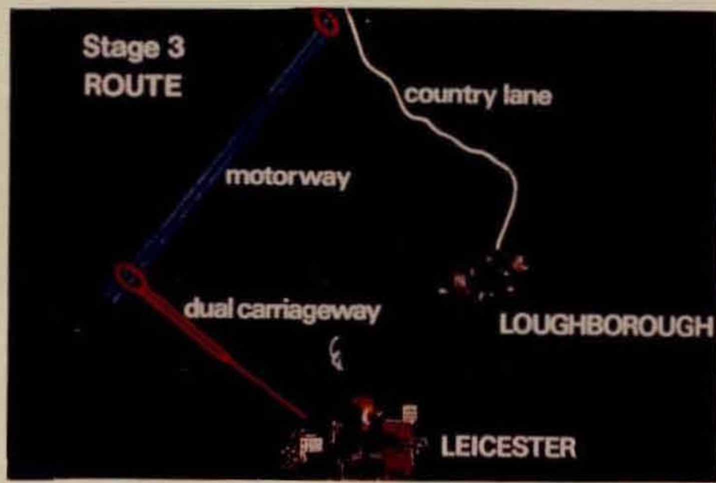
Figure 5.10 Study 2 - Which display would subjects choose and avoid for their own car?



APPENDIX 6 STUDY 3

FIGURES

DIAGRAM OF THE TEST ROUTE



EXPERIMENT IN PROGRESS

Figure 6.1 Study 3 - The percentage of correct responses made when reading the speed - DAY

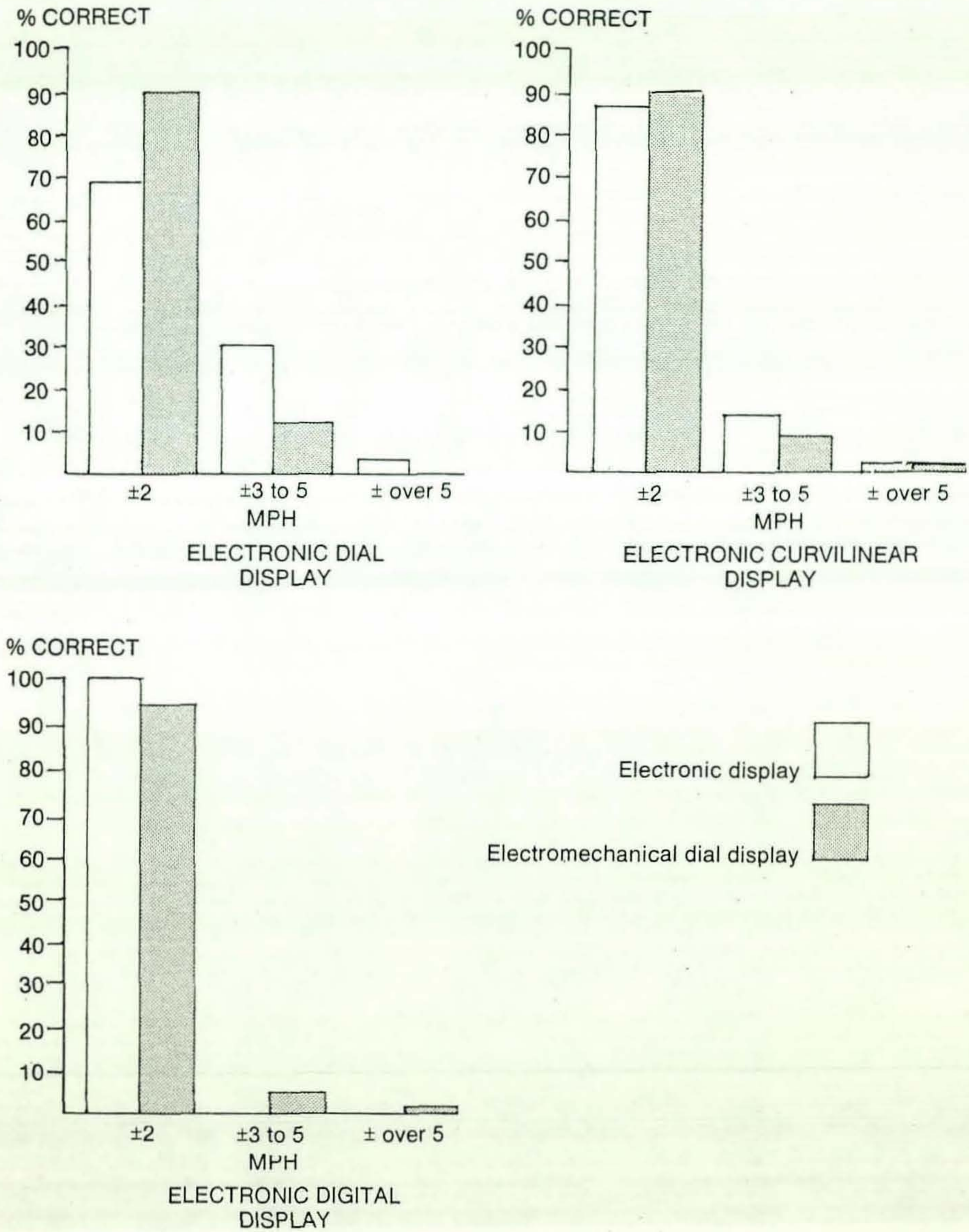


Figure 6.2 Study 3 - The percentage of correct responses made when reading the speed - NIGHT

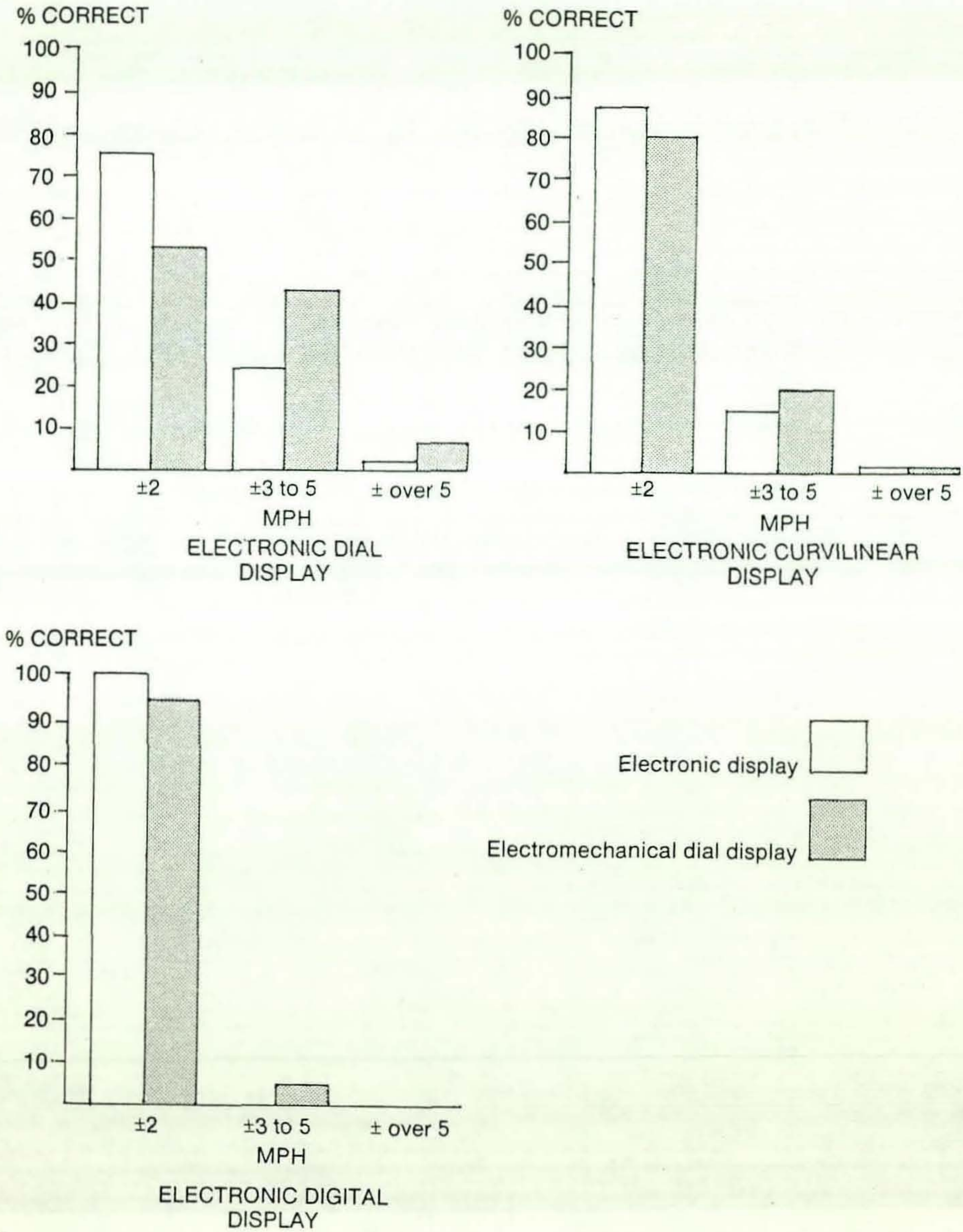


Figure 6.3 Study 3 - Which display was considered the easier to read? DAY

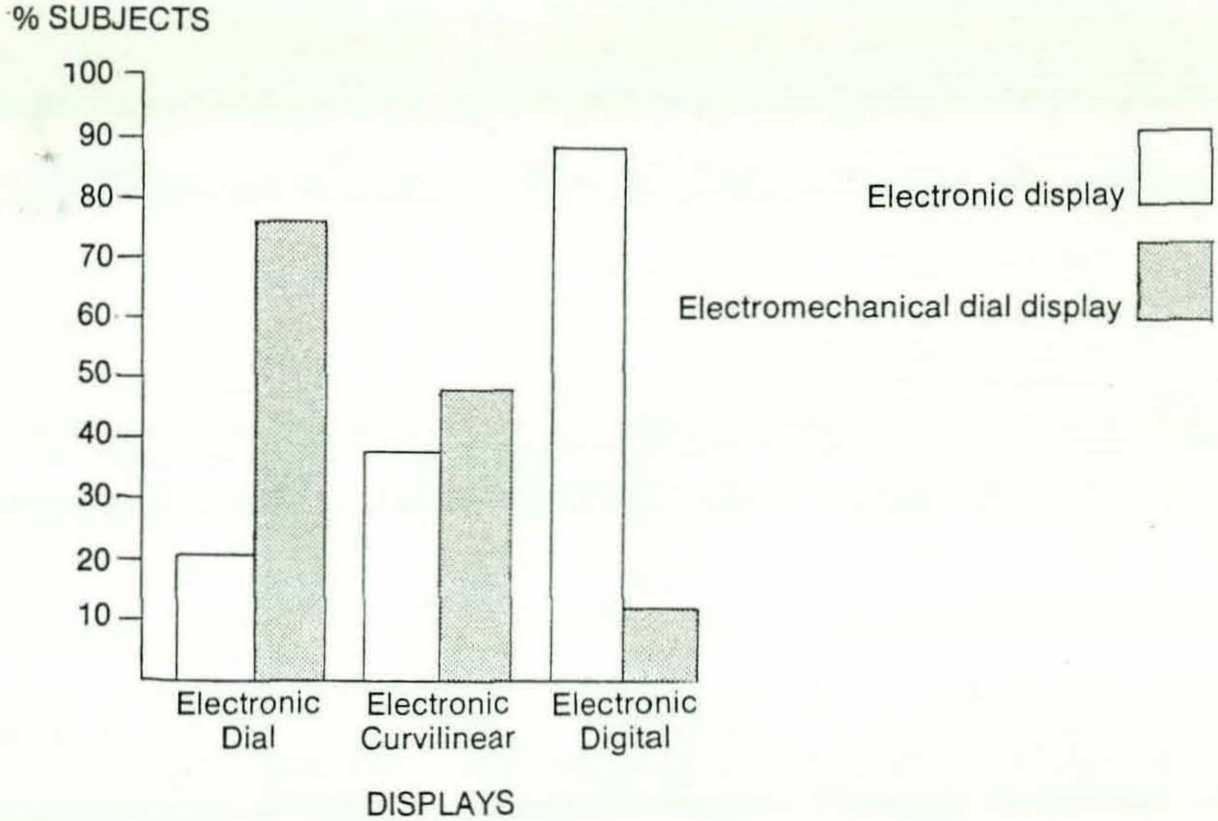


Figure 6.4 Study 3 - Which display was considered the easier to read? NIGHT

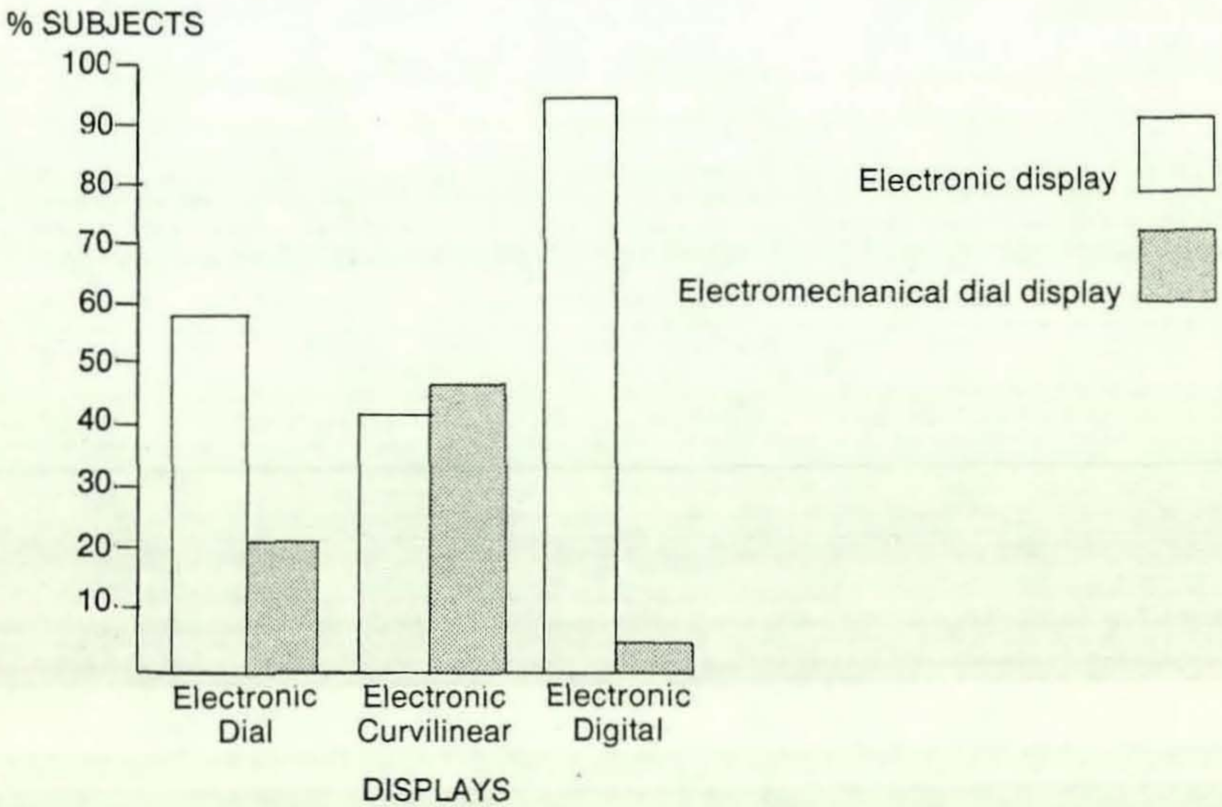


Figure 6.5 Study 3 - Which display was considered easier to tell whether the speed was within a speed limit? DAY

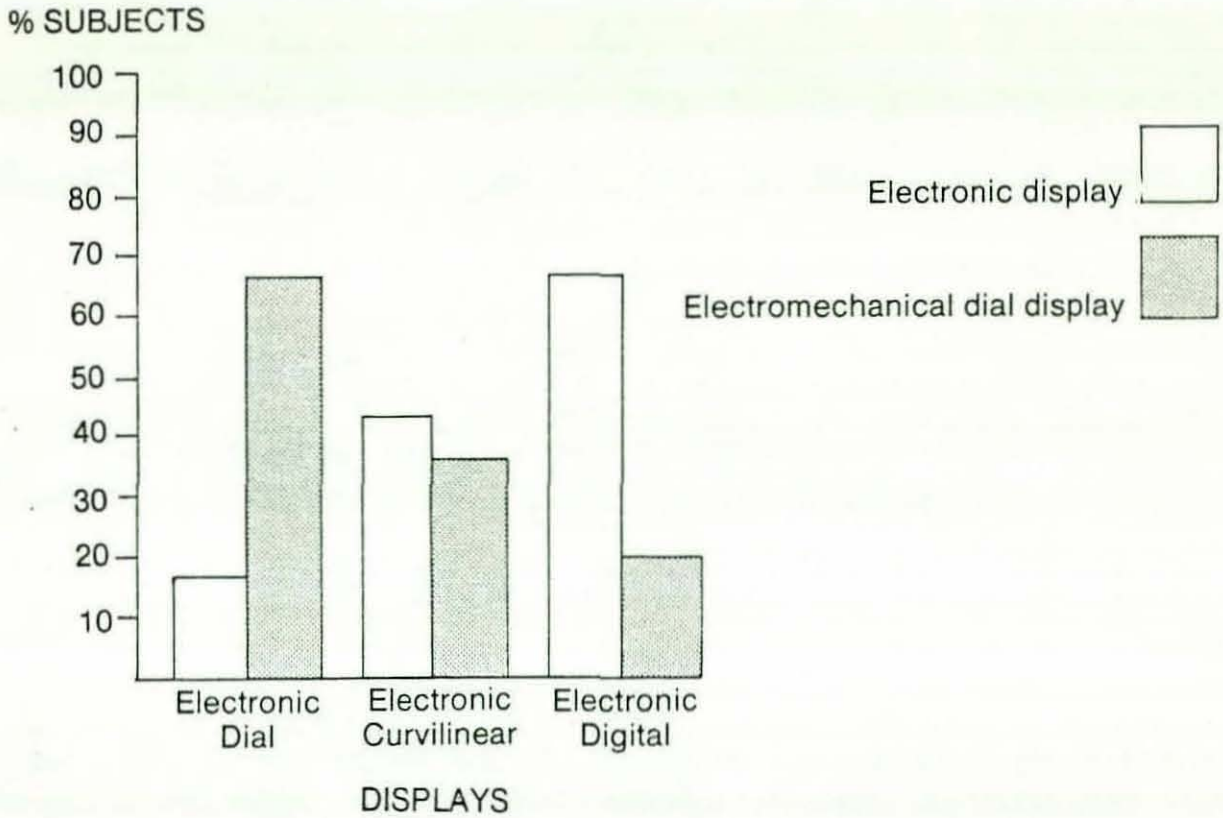


Figure 6.6 Study 3 - Which display was considered easier to tell whether the speed was within a speed limit? NIGHT

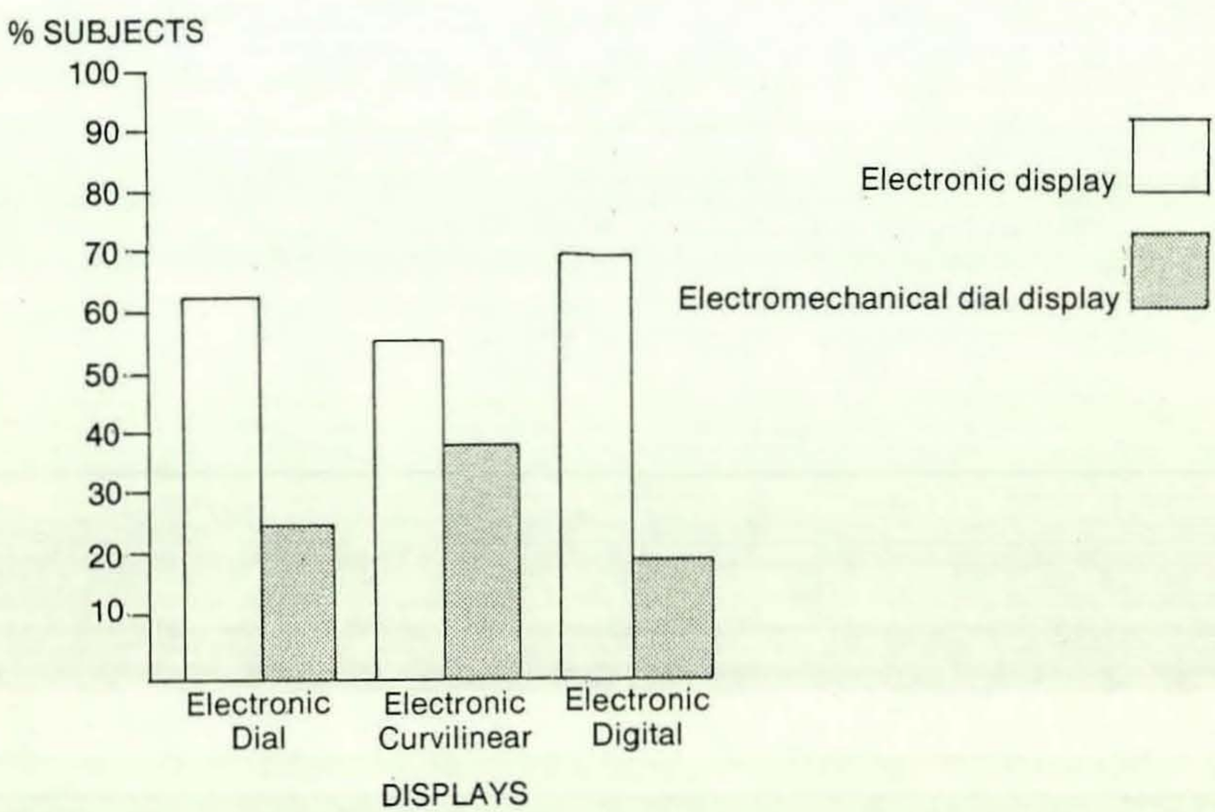


Figure 6.7 Study 3 - Which display was considered to be distracting while driving? DAY

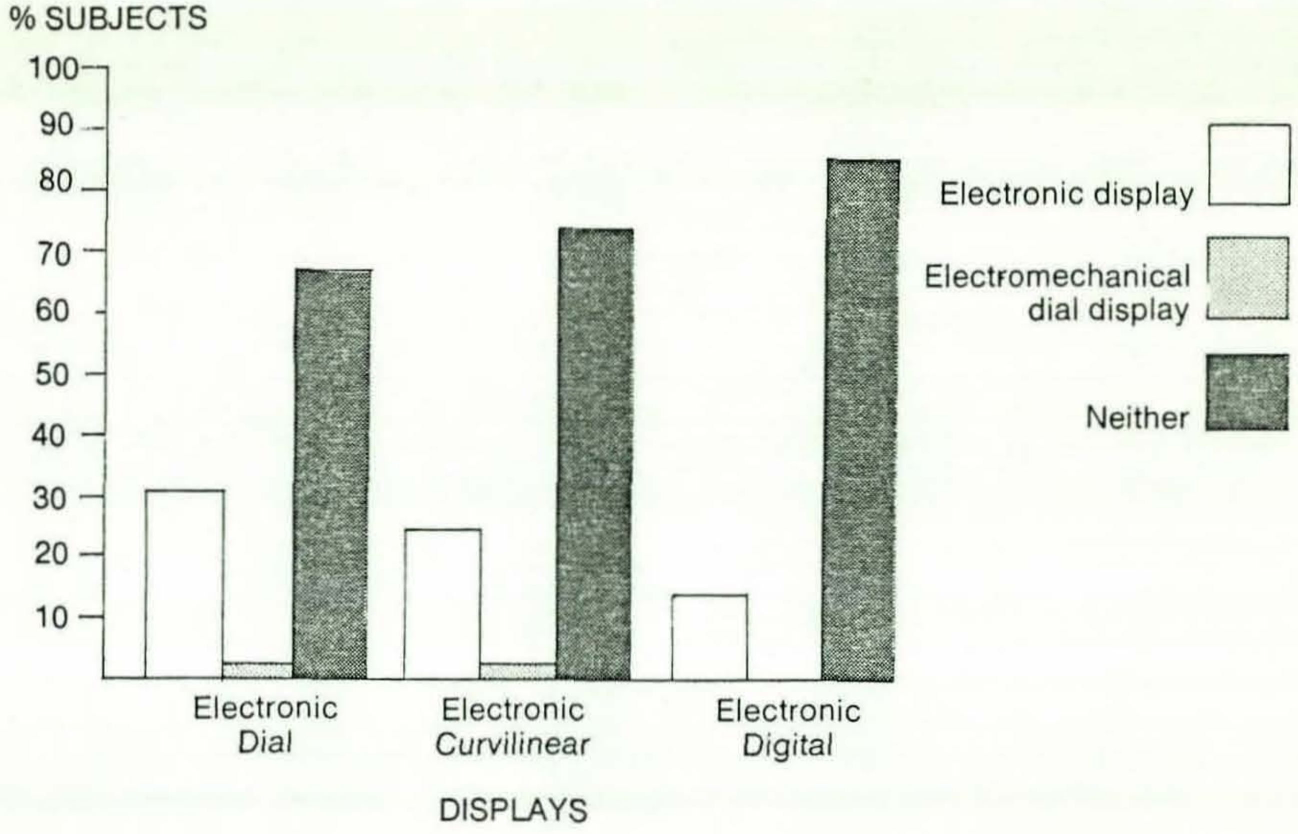


Figure 6.8 Study 3 - Which display was considered to be distracting while driving? NIGHT

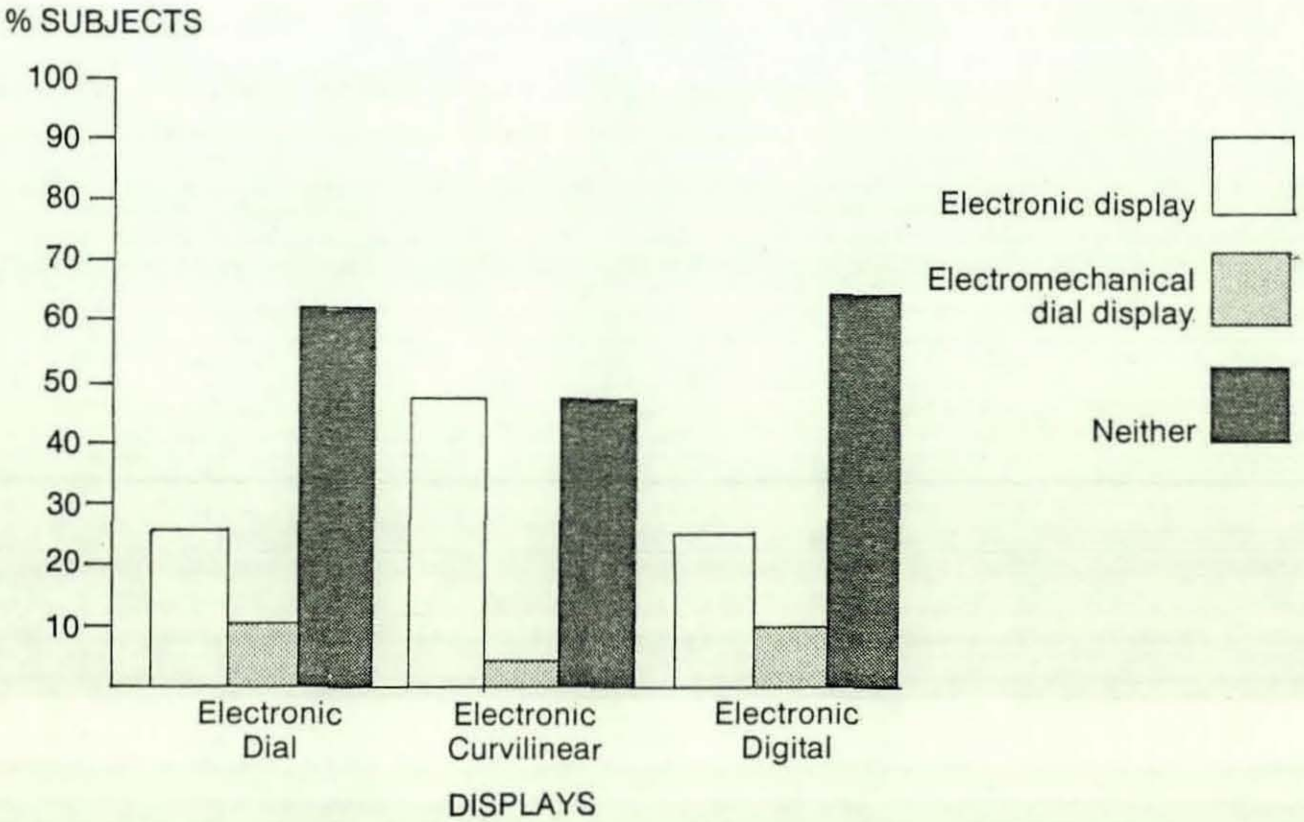


Figure 6.9 Study 3 - Which display was considered to be the more attractive? DAY

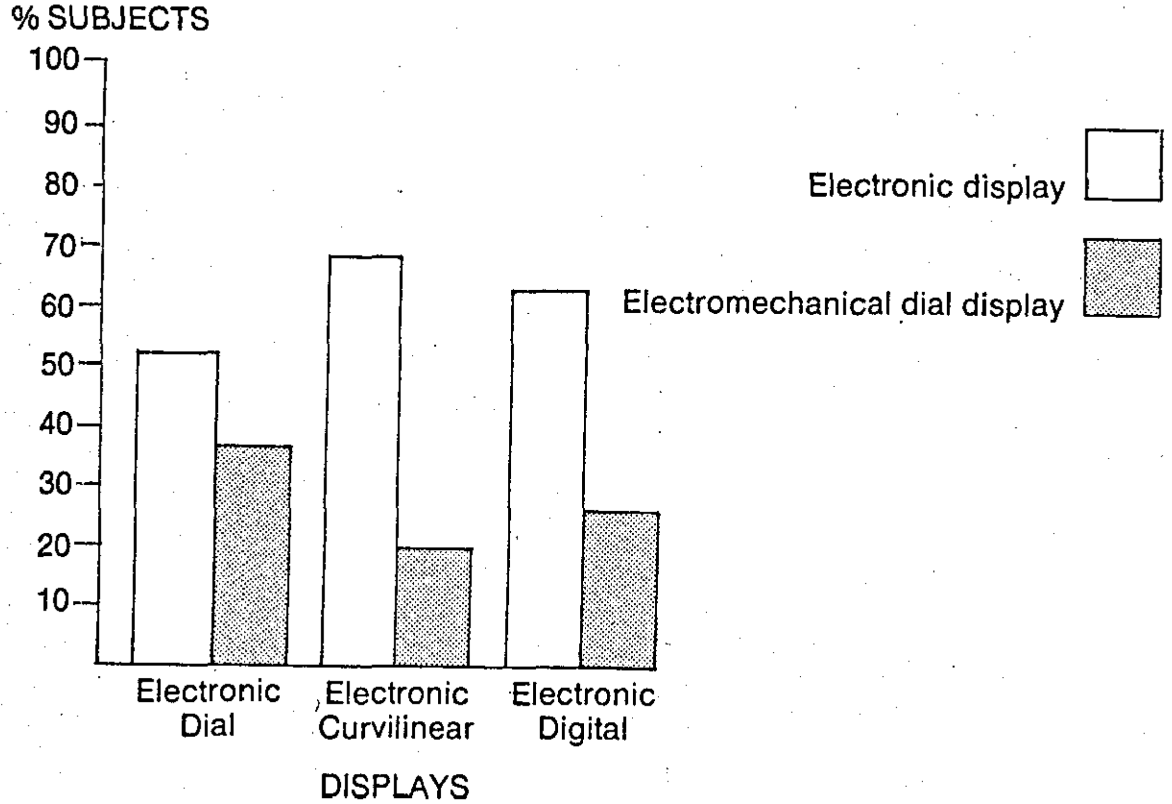


Figure 6.10 Study 3 - Which display was considered to be the more attractive? NIGHT

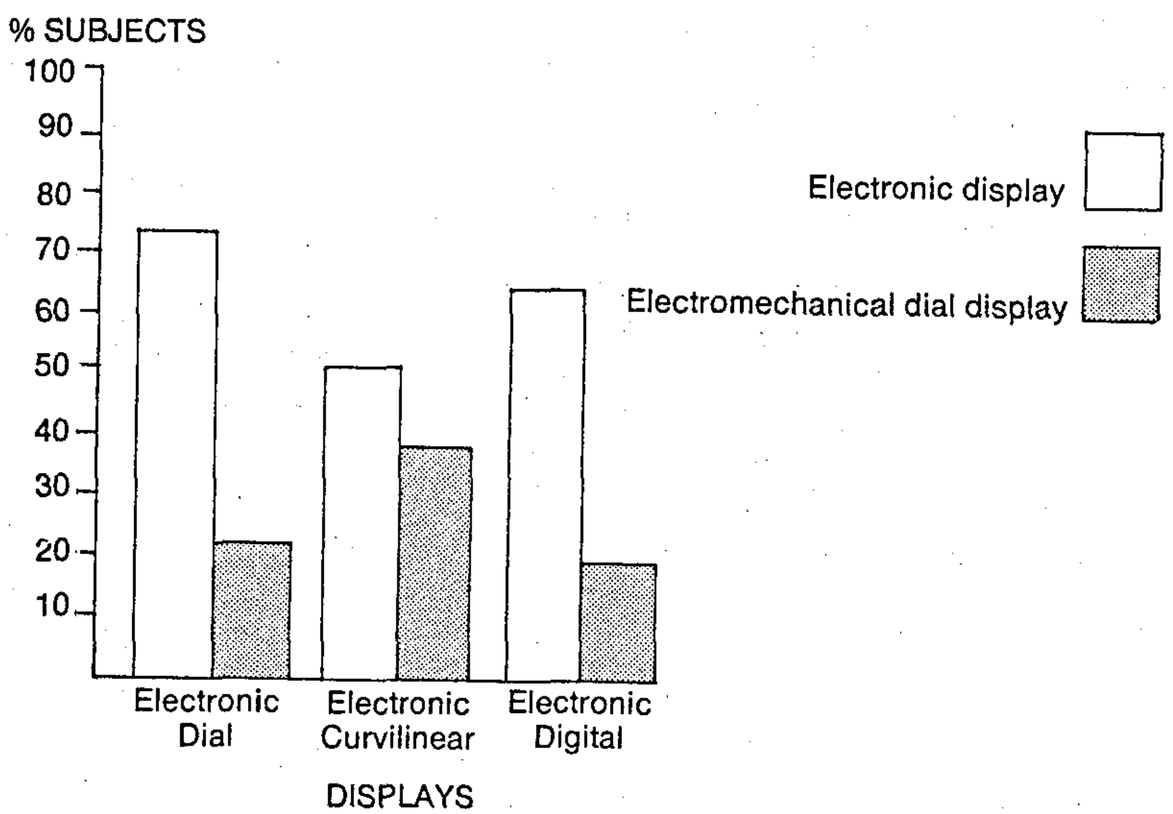


Figure 6.11 Study 3 - Which display would subjects choose for their own car? DAY

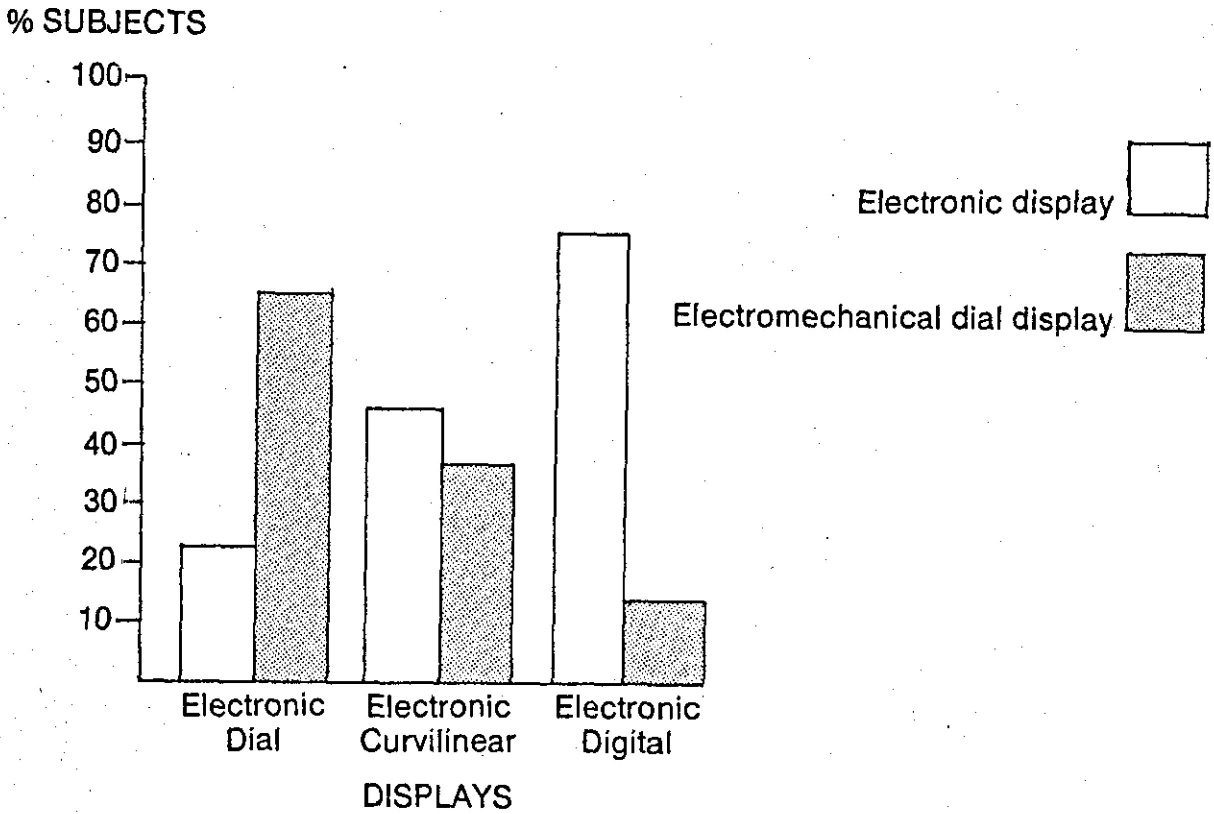


Figure 6.12 Study 3 - Which display would subjects choose for their own car? NIGHT

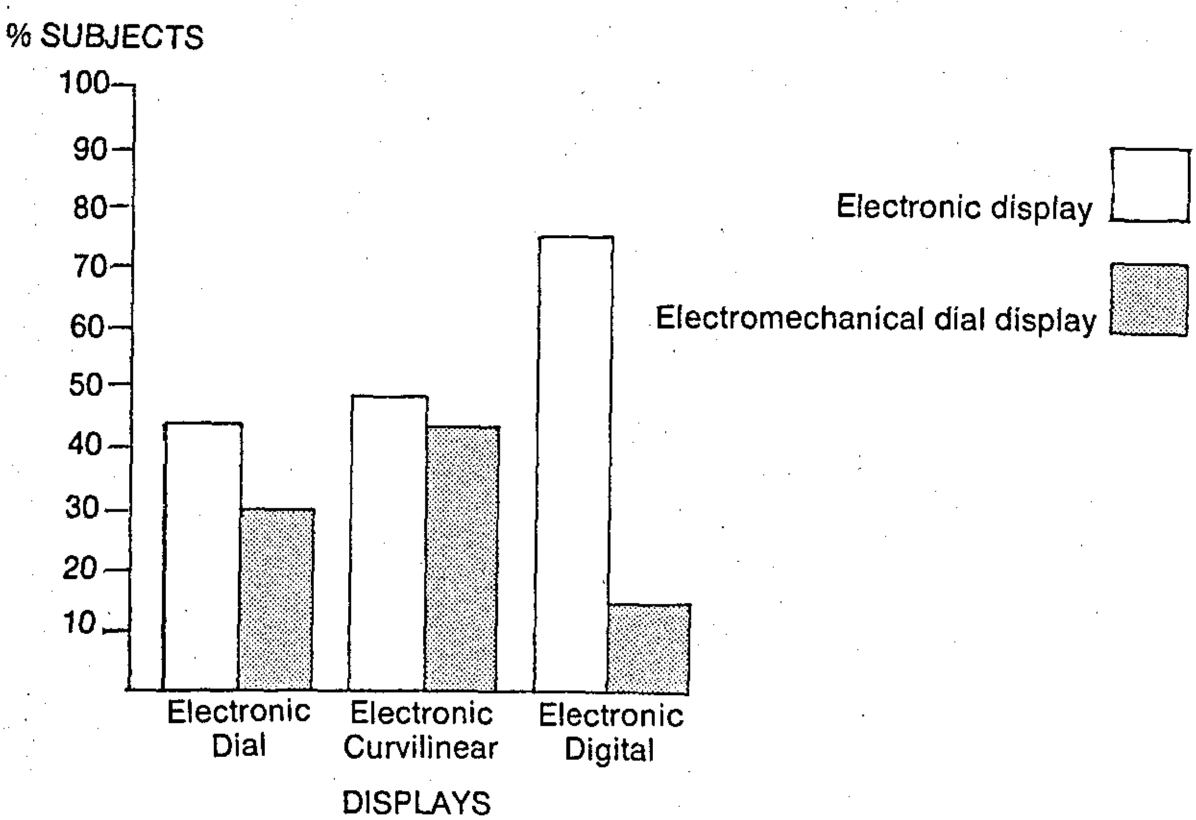


Figure 6.13 Study 3 - Which display was preferred? DAY

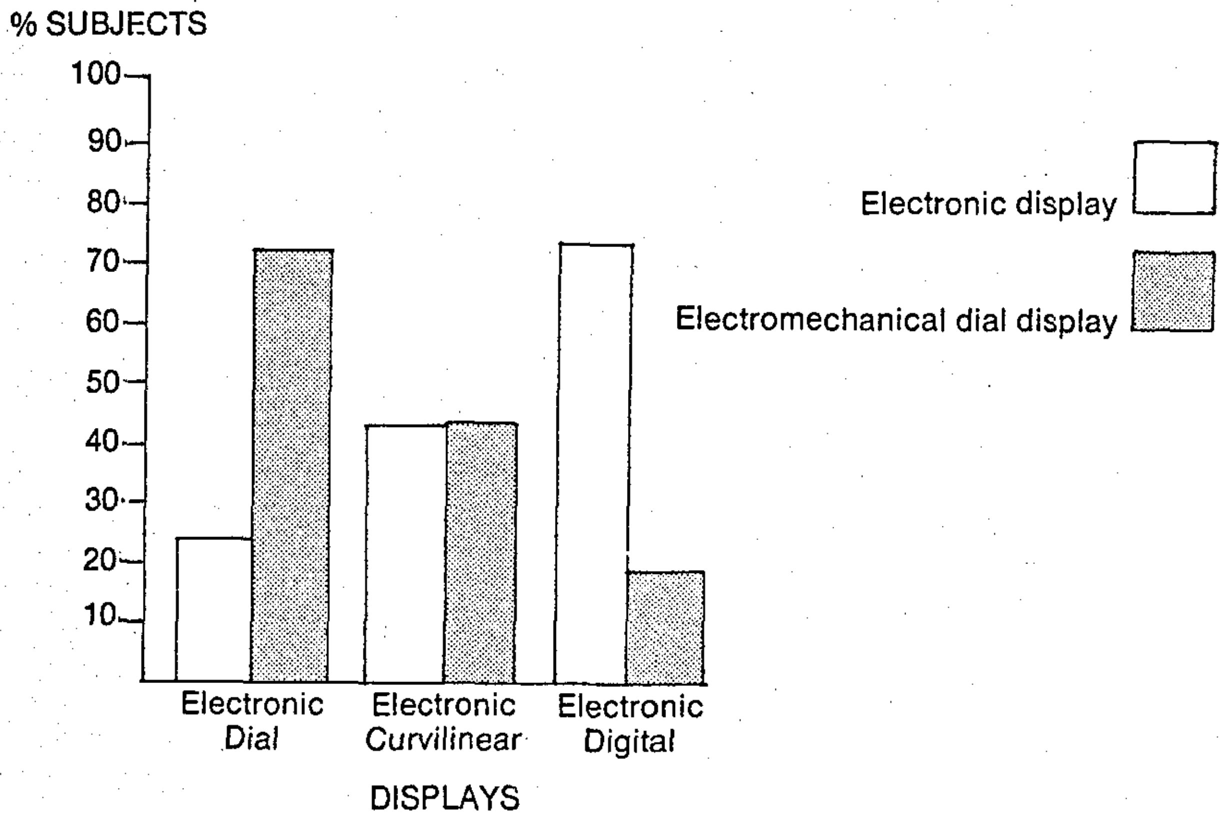


Figure 6.14 Study 3 - Which display was preferred? NIGHT.