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Daytime Conspicuity of Road Traffic Control Devices

S. E. JENKINS AND B. L. COLE

In this paper is presented a summary of the results of work carried out in Australia by the Australian Road Research Board (ARRB) and Melbourne University under ARRB sponsorship. The concept of conspicuity and how it forms part of the process of transferring information to the road user is addressed. The means by which conspicuity has been measured are described together with their strengths and limitations. An experimental program that has advanced the understanding of conspicuity and its usefulness is summarized. The major findings of the experiments are discussed in terms of their practical implications for enhancing the daytime conspicuity of road traffic control devices. The review concludes that the important variables that determine the daytime conspicuity of traffic control devices are the complexity of the background, the size of the object, and its contrast with the immediate surroundings. It was also suggested that there are two distinct components of background complexity, clutter and distraction.

The concept of conspicuity, how it can be measured, and the means by which the conspicuity of traffic control devices can be enhanced are addressed. The purpose of this paper is to present a summary of the results of work carried out in Australia by the Australian Road Research Board (ARRB) and at Melbourne University under ARRB sponsorship during the last 10 years and to draw some practical implications from the experimental studies.

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CONCEPT OF CONSPICUITY

The purpose of a traffic sign is to transfer information from the traffic engineer to the driver. In the road environment there is an enormous influx of visual information with which the driver has to contend. It is essential that priorities be allocated to this information so that the driver directs his attention to only those facets that are necessary for his purpose and safety.

The perceptual system must therefore perform a filtering action by which the majority of the visual information is shed and the important and necessary information is attended to and used. What information the driver considers important, and so pays attention to, depends on the message of the sign and its relevance to him at the time. Thus some degree of preattentive processing of all information must occur so that the important information is not discarded but progresses to the stage of consciously being used.

If the information that the traffic engineer wishes to convey to the driver is not visually prominent, legible, and comprehensible at this preattentive level of processing, its importance cannot be evaluated and it will not warrant attention. Conspicuity, then, is the attribute of an object within a visual context that ensures that its presence is noticed at the preattentive level of processing.

Engel *(1)* distinguishes between "sensory conspicuity" and "cognitive conspicuity." Sensory conspicuity is taken as the degree of visual prominence afforded a sign by its crude sensory features (brightness, color, size, legibility), which will ensure that its message content is available at the preattentive level of processing. The cognitive conspicuity of a sign arises

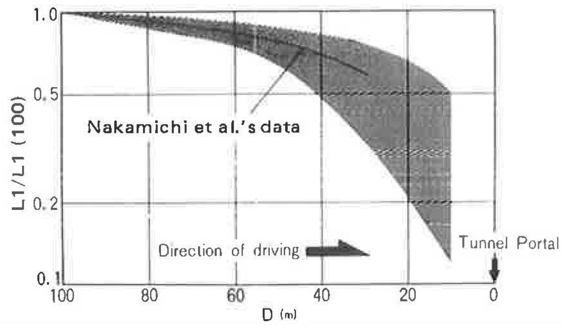

FIGURE 10 Relative variations of equivalent luminance of the standard field (L1) as a function of the distance from the tunnel (D) shown in Figure 9. The values measured at 100 m were plotted as a standard 1.0.

though luminance structures near the entrances of the tunnels differed from one tunnel to another, the general tendency of the variations in the equivalent luminance of the standard field (L1) during approach was found to be similar. In Figure 10 the relative variations of L1 are normalized at a distance from the tunnel entrance of 100 m and shown as a hatched area.

The thick curve in the hatched area in Figure 10 shows a replotting of the data by Nakamichi et al. (*5*). It can be seen that the curve they obtained represents a typical decrease in the equivalent luminance of the standard field (L1) during approach to the entrance of the tunnel (the surroundings of which consist of relatively light structures) and that this curve can be applied to most practical cases with a sufficient safety margin.

CONCLUSIONS

The following conclusions can be drawn from the investigations described:

1. By separating the effects of the surrounding field and of the central field to which the observer's fovea is adapted on the luminance difference thresholds, a method for deriving the equivalent luminance of the standard field (= previous adaptation luminance) for any complex luminance field has been developed.
2. Comparisons of the results of measuring the equivalent luminance of the standard field (for a size of 20 × 20 degrees) and the luminance in the access zone (as defined in the CIE Recommendations for Tunnel Lighting) were made and it was found that the luminance in the access zone, with an increase of a factor of 1.5, represents the equivalent luminance of the standard field (with an angular size of 20 × 20 degrees) on the access zone with sufficient accuracy for practical applications.
3. Variations in the equivalent luminance of the standard field during approach to a tunnel can possibly be classified in the future according to the luminance structures near the entrance of the tunnel. The replotted data obtained by Nakamichi et al. (*5*), however, as seen in Figure 10, can be used for most practical purposes as a first approximation of the general tendency of variations in the equivalent luminance of the standard field (L1) during approach.
4. Extensive study still needs to be done on the variations in the equivalent luminance of the standard field at actual tunnels caused by changes in daylight conditions due to season, weather, and time.

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from its meaning, novelty, or relevance and will be dependent on the psychological state of the driver, his purpose, and his expectations at the time.

A road traffic control device must meet four criteria: it must be conspicuous, its message must be legible and understood, and it must be credible to the driver who must believe what it says and that it applies to his immediate situation. If any of these criteria are not met, the message will not be registered or it will be discarded. The information will not progress past the preattentive level of processing, the driver will have no recollection of it, and any hoped for action will not happen.

METHODS OF MEASUREMENT

Inevitably the methods by which conspicuity is measured largely determine the kind of results that are obtained, so it is important that the limits and assumptions of each method be given. In the work done at ARRB and at Melbourne University two methods have been used.

The first derives from an operational definition of sensory conspicuity, proposed by Cole and Jenkins, that states that a conspicuous object is one that will, for any given background, be seen with certainty ($P > 90$ percent) within a short observation time ($t = 250$ ms) regardless of the location of the object in relation to the line of sight.

Because the observation time, if it is 250 ms or less, is too short to permit an eye movement, a conspicuous object by this definition requires no searching to be seen with certainty. The definition implies that the primary measure of sensory conspicuity is the eccentricity, the angle from the line of sight, at which the object is seen. This measure is similar to the "conspicuity area" of Engel *(2–4)*.

This method was developed in the laboratory and its validity in the real traffic situation is not certain. Indeed, it is difficult to know how such a paradigm could be transferred to the on-road situation. By this method a conspicuous object is one that is detected immediately, and it is this requirement that prevents the method from being transferred to the driving situation, where traffic control devices continually increase their angular subtense and eccentricity with time and their backgrounds continually change.

The second method was devised by Hughes and Cole *(5)*, Cole and Hughes *(6)*, and Hughes *(7)* who carried out a field trial to investigate the conspicuity of traffic control devices and disc targets in a suburban environment. They used a verbal report method that included both sensory and cognitive aspects of conspicuity and that, most important, included observer variables such as state of arousal, expectations, and level of attention.

Cole and Hughes reasoned that these observer variables must play a major role in determining whether the message of a traffic control device is acted on in the traffic situation, so they decided to manipulate the level of attention of drivers by issuing two different sets of instructions. In this way they could investigate two aspects of conspicuity: attention conspicuity and search conspicuity.

Attention conspicuity is the capacity of the traffic control device to attract attention when the driver is unaware of its likely occurrence (instruction: report all things that attract your attention). Search conspicuity is the ability of the traffic control device to be quickly and readily located by search; for example, when a driver needs a direction sign or street name (instruction: report all traffic control devices that attract your attention).

The verbal report is the end result of all levels of processing. A traffic control device may be reported because

- It is conspicuous,
- It is important to the driver at that moment, or
- Its message requires some action on the part of the driver.

A traffic control device may not be reported because

- It is inconspicuous,
- It is not credible, or
- It is so normal and accepted that it is literally unremarkable.

DETERMINANTS OF DAYTIME CONSPICUITY

The daytime conspicuity of traffic control devices is determined by their size, their contrast with the immediate surrounding background, and the complexity of the road environment.

Conspicuity can only be discussed in the context of complex backgrounds. Visibility is all that can be spoken of if the target is in a uniform background. For the term "conspicuity" to be applicable, the target must have to compete with other objects for the attention of the driver. The major problem is quantifying the complexity and defining what background objects form the population of items that can be confused with the target.

To tackle this problem directly, a series of experiments was carried out using schematic backgrounds that could be quantified yet were complex and versatile enough that they could be varied systematically along several dimensions *(8,9)*. The backgrounds consisted of a random array of discs, each simply specified by diameter and luminance. The complexity was manipulated in three ways:

- The number of identical background discs was varied from one up (density);
- The number remained constant but the size distribution was varied; and
- The number remained constant but the luminance distribution was varied.

There were three background densities such that the discs occupied 5, 10, or 15 percent of the maximum area that could be occupied by the discs, each disc subtending 72 min of arc at the subject's eye. There were three degrees of luminance variability with the number of discs kept constant throughout at 15 percent density. Thus, for the size variability experiment, there were three types of background configuration that differed in the range of sizes of the background discs but centered around 72 min of arc and a control configuration with background discs all of the same size as were used for the 15 percent background density configuration. Similarly, the luminance variability experiment had three ranges of luminances for the background discs and the same 15 percent density control configuration. Examples of the different types of background complexity are shown in Figures 1 and 2.

For each background set the target disc differed in either size or luminance. The subject's task was to locate the largest or brightest disc in the stimulus slide, which was presented for 250 ms, with the target positioned at various eccentricities.

The results are, perhaps, best summarized in two parts: whether the target was discriminated on the basis of size or of luminance.

Luminance Discrimination

The contrast in luminance between the target disc and the background discs necessary for it to be discriminated 92 percent of the time is shown in Figure 3 as a function of eccentricity (ε°) for all types of background complexity.

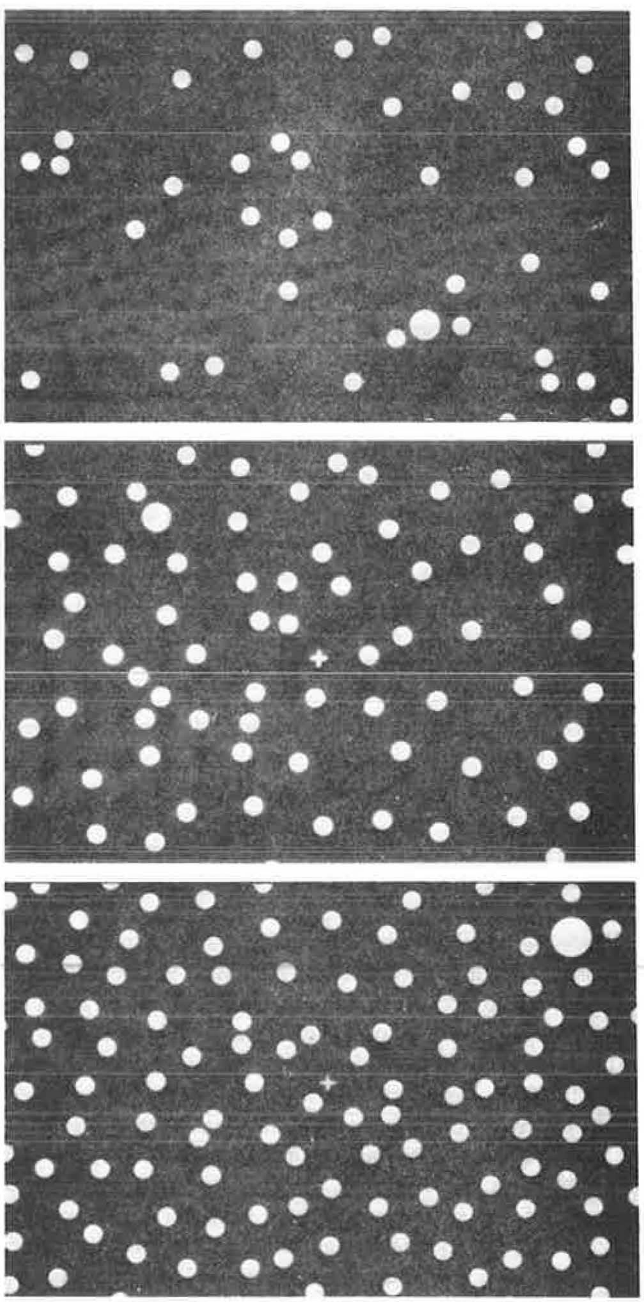

FIGURE 1 Examples of stimuli used in the experiment on varying background density *(8)*.

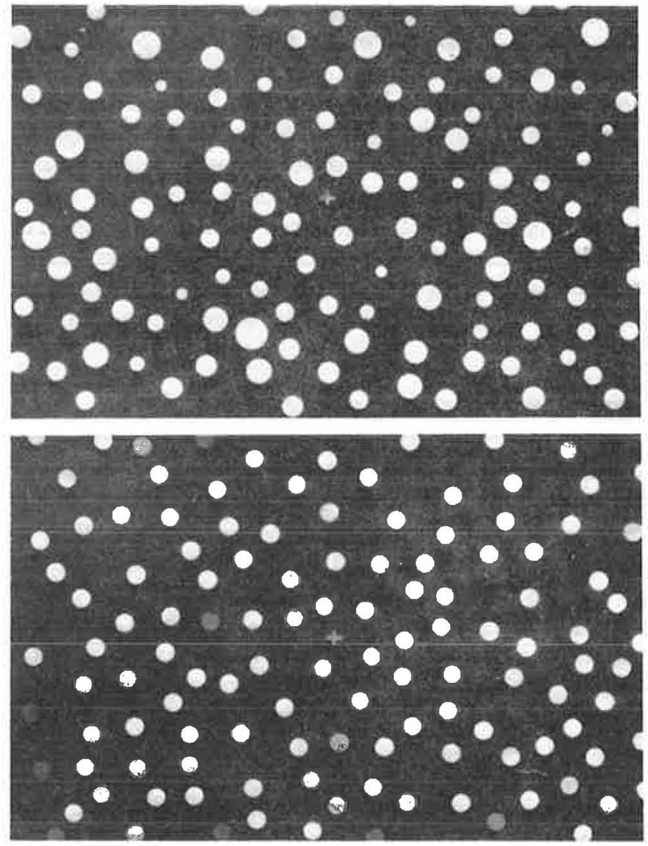

FIGURE 2 Examples of stimuli used in experiments that manipulated the variability of size *(top)* and of luminance *(bottom)* of the background elements *(9)*.

The two-disc experiment has the shallowest slope, showing that luminance discrimination on this task is the best. As the number of discs increases to 5 and 10 percent density, performance decreases, so that the target disc must have a greater luminance difference from the background discs for it to be

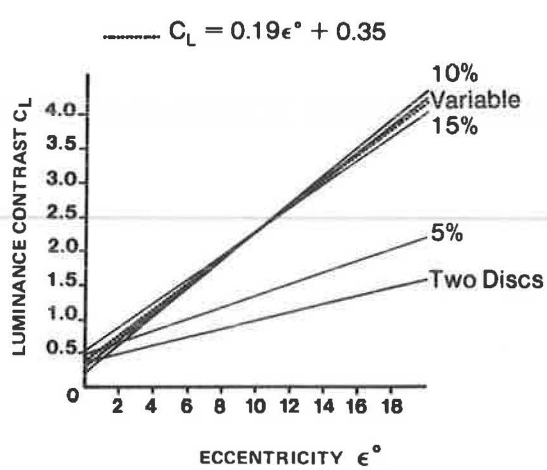

FIGURE 3 Contrast in luminance between target disc (L_T) and background disc (L_B) necessary for target disc to be discriminated 92 percent of the time as a function of eccentricity for all types of background complexity [$C_L = (L_T - L_B)/L_B$].

detected. Increasing the number to 15 percent density does not change performance by any significant amount.

The equations for luminance discrimination at the 92 percent probability level are

$$C_L = 0.06\varepsilon^\circ + 0.37 \quad \text{for two discs}$$
$$C_L = 0.10\varepsilon^\circ + 0.47 \quad \text{for 5 percent background density}$$
$$C_L = 0.19\varepsilon^\circ + 0.35 \quad \text{for 10 and 15 percent background density and variable luminance} \quad (1)$$

where $C_L = (L_T - L_B)/L_B$, L_T is the luminance of the target disc, and L_B is the average luminance of the background discs.

If the background discs themselves differed in luminance but were the same size, it was found that the degree of variability had no effect on the conspicuity of a target that differed in luminance only. In this experiment the number of discs corresponded to a 15 percent density; the background density experiment showed that at this density luminance discrimination is sufficiently poor that the variability in the luminance of the background elements would not be appreciated by the subjects unless the differences were very large. The degrees of variability of the three background distributions were not great enough to show any differential effect on target discrimination although the background reflectances ranged from 10 to 50 percent.

The reflectances of the background disc used to generate the stimulus slides represent an attempt to match those found in daytime environments. This would indicate that variation in object luminances of daytime environments will not have a large effect on target conspicuity.

Size Discrimination

The results for the size discrimination tasks were quite unexpected and are shown in Figure 4. Increasing the density of the background elements has no effect on the conspicuity of the target that differs only in size. This discrimination of the target matches that for just two discs no matter whether the background density is 5, 10, or 15 percent. The results can be adequately summarized by the equation:

$$C_S = 0.033\varepsilon^\circ + 0.10 \quad (2)$$

where $C_S = (D_T - D_B)/D_B$.

However, if the background elements themselves differ in size, the degree of variability does have an adverse effect on the conspicuity of the target that differs in size. The results from the variable size experiment can be explained using a simple model based on Equation 2.

This says that at a given eccentricity the largest background disc cannot be discriminated from other background discs if the contrasts in size are less than the threshold contrast given by Equation 2. Thus a weighted average large background disc can be described for the population at any eccentricity. Then, to be discriminated, the target disc must be of sufficient diameter that when contrasted against this average background disc it will exceed the threshold given by Equation 2. Therefore,

$$C_S = 0.033\varepsilon^\circ + 0.10 \quad (3)$$

is applicable to a wide range of backgrounds provided D_B is defined as the diameter of the weighted average of all of the largest background discs that cannot be discriminated on the basis of size at a given eccentricity.

Equations 1 and 3 give the means by which some physical attributes of a target that will ensure its conspicuity can be specified. However, to do this it must be possible to determine the population of background elements in road environments that could be confused with the target, their size distribution, and their average luminance.

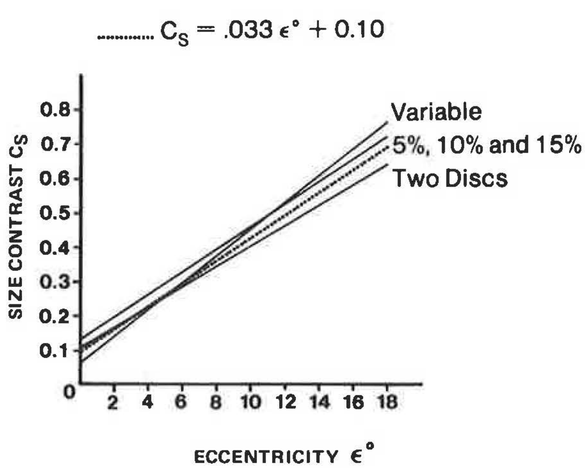

FIGURE 4 Contrast in size between target disc (D_T) and background discs (D_B) necessary for target disc to be discriminated 92 percent of the time as a function of eccentricity for all types of background complexity [$C_S = (D_T - D_B)/D_B$].

CONSPICUITY OF DISCS IN THE ROAD ENVIRONMENT

The next stage was to use road traffic scenes as stimulus backgrounds and discs of various sizes and luminances as targets. A laboratory experiment embedded a range of discs at eccentricities of 6 and 14 degrees in suburban road scenes *(10)*. A field trial also was carried out with subjects driving a fixed suburban route and using the verbal report method described previously. Along the route was placed a variety of discs that served as targets as did the traffic control devices already in place.

Because the luminances of the discs in the laboratory experiment did not match those in daytime, and the luminances in the field trial vary from hour to hour, only their reflectances where the maximum diffuse reflectance is taken as about 80 percent are referred to. Some of the results are summarized in Table 1.

The laboratory experiment showed that for a white disc with a reflectance of 80 percent to be conspicuous, it must have a diameter of 34 min at 6 degrees eccentricity and 75 min at 14 degrees eccentricity. A 75-min-diameter disc need only have a reflectance of 42 percent at 6 degrees eccentricity, but a 34-min disc must have a reflectance of 150 percent to be conspicuous at 14 degrees eccentricity (i.e., it must be self-luminous).

TABLE 1 REFLECTANCE OF DISC IN A ROAD SCENE NECESSARY FOR THE DISC TO BE SEEN WITH A PROBABILITY OF 92 PERCENT FOR TWO SIZES OF DISC AT TWO ECCENTRICITIES

Disc Diameter (min)	$\varepsilon^\circ = 6^\circ$ (%)	$\varepsilon^\circ = 14^\circ$ (%)
34	80	150
75	42	80

There were strong indications from the laboratory experiment that reflectance (or luminance) was not the primary variable but that the contrast of the disc with its immediate surroundings was. A separate experiment, again using discs and road environments, was carried out to investigate this specifically. It was found quite conclusively that contrast was the determining variable *(11)*. The background area immediately surrounding the target is, then, crucial to its detection. The traffic engineer should be made aware of the importance of sign contrast so that he may favorably locate the sign wherever possible against tree backgrounds, plain walls, or on medians. When building roads, the traffic engineer can landscape advantageously. If these options are not available, the traffic engineer may be able to supply the sign with its own background by way of a high-contrast surround. This is already done with traffic signals, and a similar treatment for signs may well be advantageous.

In the field trial, Cole and Hughes *(6)* used two sets of drivers, and each set was given different reporting instructions. This enabled two aspects of conspicuity, attention and search conspicuity, to be studied. The dependent measure was the hit rate. The discs were 300, 500, and 700 mm in diameter and had reflectance values of approximately 85, 32, and 2 percent.

The relationship between search and attention conspicuity is curvilinear and is shown in Figure 5 for each location of the disc. Obviously, search conspicuity is always greater than attention conspicuity. Directed search yielded greatest gains for targets of low attention conspicuity.

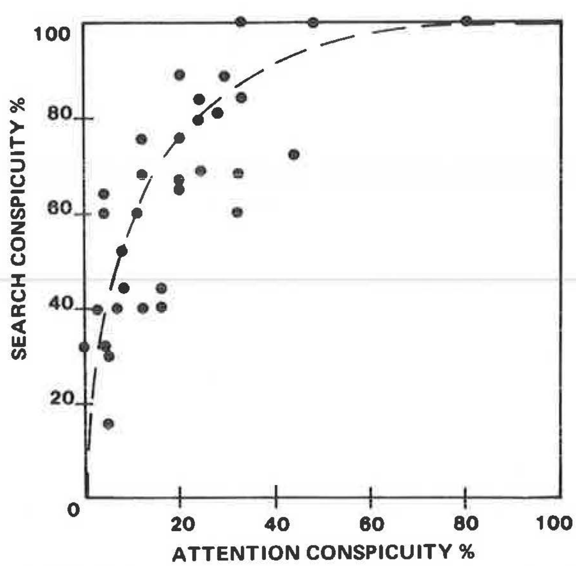

FIGURE 5 Relationship between search conspicuity and attention conspicuity for discs; each point represents the hit rate for a disc at each location *(7)*.

Cole and Hughes found that reflectance had only a small effect on conspicuity, even though the full range of diffuse reflectance was used. Size had a more dominant effect on conspicuity, but because the angular size of discs was continually increasing as the subjects drove toward them, it is more appropriate to consider their angular size when they were reported. Cole and Hughes found that the great majority of observations of the disc targets occurred at eccentricities less than 10 degrees (i.e., when the discs were more than 50 m ahead and subtended less than 1 degree).

The location of the target disc emerged as the dominant determinant of conspicuity: shopping center sections markedly reduced the conspicuity of targets compared with residential streets. Cole and Hughes argue that it is the visual clutter and not the increased task demand that reduces conspicuity in shopping centers.

CONSPICUITY OF TRAFFIC CONTROL DEVICES IN ROAD ENVIRONMENTS

The final aspect of the experimental program was to investigate the conspicuity of traffic control devices on the road in the light of what had been found in the more controlled experiments. Again, the topic was studied with the laboratory paradigm *(12)* and by the field trial *(5)*.

The laboratory study used color slides that always had at least one traffic control device situated 100 m from subject. Often, other traffic control devices were present both closer and farther away than the target traffic control device. The subjects' task was to note the types of traffic control devices that they could see and their location.

None of the traffic control devices met the operational definition of conspicuity. The detection properties of the types of traffic control devices are given in Table 2.

Size, again, was an important determinant of conspicuity, as

TABLE 2 PROBABILITY OF DETECTION OF VARIOUS CLASSES OF TRAFFIC CONTROL DEVICE FOR THE LABORATORY EXPERIMENT USING COLOR SLIDES WITH THE TARGET DEVICE AT A SIMULATED DISTANCE OF 100 m *(12)*

Traffic Control Device	Probability of Detection (%)
Railway level crossing	81
Traffic signals	76
Guide signs	76
Stop signs	62
Warning signs (symbolic)	55
Warning signs (alphabetic)	45
Children's school crossing	37
Speed restriction	31
Other regulatory signs	19
Give way	1

was edge definition. The large traffic control devices, such as railway level crossings, traffic signals, and guide signs, scored high levels of detection. It was particularly noticed that white signs did poorly. This is disturbing because most regulatory signs, which must be noticed, are white. The Give Way sign performed quite the worst of all signs; the reasons for this are not clear because it differs from other signs in several ways. It is also of some concern that children's crossings are not compellingly noticeable, although when an attendant was in view conspicuity improved.

In the field trial, Hughes and Cole noted a disturbing result: even when subjects were directed to search for traffic control devices, on average only 50 percent were located. This may be partly due to the verbal report method used, however. For example, traffic signals were reported on 14 percent of occasions, yet there was no failure to respond to them correctly. The results are shown in Figure 6 and hit rates (the proportions of discs reported) for particular classes of traffic control devices are given in Table 3.

Trends found in the laboratory studies were validated in this field trial. The more visually clustered road environments again clearly showed an adverse effect on conspicuity, the size of road signs was a significant determinant of conspicuity, and signs with color were noticed more than black-and-white signs.

Jenkins and Cole *(13)* suggested that color is not an important determinant of conspicuity and that, at best, the contribution of color is sufficient to offset the loss of conspicuity that results from the concomitant decrease of luminance. However, Jenkins *(11)* showed that contrast is a critical determinant of conspicuity and the presence of color contrast may serve to reveal an object when the luminance contrast is low. The role of color in determining conspicuity is equivocal and needs to be the focus of a directed study.

The distinction that Hughes and Cole have drawn between attention and search conspicuity provides a framework for planning a hierarchical system of road signing. It is not necessary that all traffic control devices attract the driver's attention;

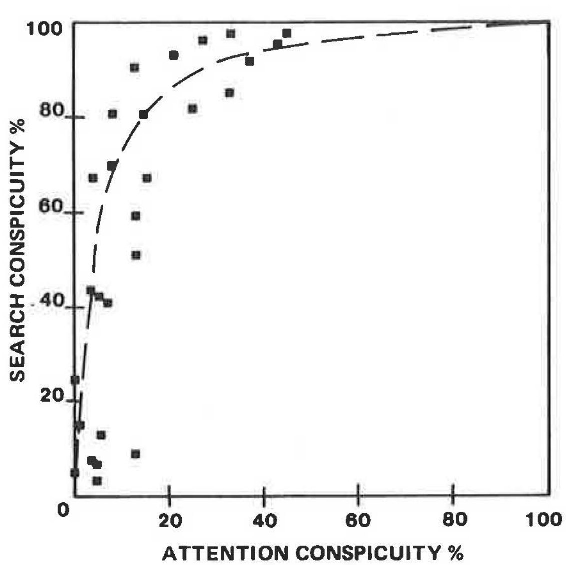

FIGURE 6 Relationship between search and attention conspicuity of traffic control devices in the field trial *(5)*.

TABLE 3 HIT RATES OF DIFFERENT CLASSES OF TRAFFIC CONTROL DEVICE FOR ATTENTION AND SEARCH CONSPICUITY OBTAINED FROM THE FIELD TRIAL *(5)*

	Hit Rate (%)	
Traffic Control Device	Attention	Search
Regulatory signs	14	68
Warning signs	23	82
Traffic signals	18	81
Direction signs		
Freeway	26	75
Other	4	8
Parking signs	0.3	6
Total	11	50

some devices need only be noticed when the driver wants them, and he will then be searching for such information.

PRACTICAL IMPLICATIONS

The practical implications that have emerged from the research so far can be summarized by six main points:

1. The important variables that determined daytime conspicuity are the size of the object, its contrast with the immediate surroundings, and the complexity of the background.
2. If a sign is to be noticed by a driver, it will be within 10 degrees of his line of sight. When the eccentricity of the sign becomes greater than this, the sign is most unlikely to be noticed at all.
3. The present size of road signs (400 to 900 mm) is sufficient to ensure that they should be conspicuous. That they are not is because their contrast is insufficient or there is a high degree of visual clutter, or both.
4. Traffic engineers should be aware of the importance of controlling sign contrast. This can be done by careful placement or by allowing a high-contrast surround to be placed around the sign, as is done with traffic signals. The dimensions of such a surround are under investigation.
5. The degree of complexity of the background is a major variable that affects conspicuity, and a means by which it can be measured must become available. Experiments have shown that subjects can rate complexity with some degree of precision, but an objective measure is preferable. It is suggested that there are two aspects of complexity:

- Clutter, where the target has to compete with other, similar objects. The effects of these similar, or confusion, elements can be countered by sign design if the confusion elements can be identified and their size distribution and average reflectance are known.
- Distraction elements, which are elements of the visual environment that are not necessarily similar to the target but will attract the driver's attention. The act of noticing irrelevant information will take time and thus increase the demand load on the driver because less time is then available for the driving task.

6. Not all traffic control devices need to attract the attention of the driver. Some devices are needed by only some of the drivers (e.g., direction signs, parking signs and the like need only be acquired when searched for). Appropriate sign design should make it possible to develop an orderly hierarchy of road signing.

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