Visual conspicuity: A new simple standard, its reliability, validity and applicability

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A general standard for quantifying conspicuity is described. It derives from a simple and easy method to quantitatively measure the visual conspicuity of an object. The method stems from the theoretical view that the conspicuity of an object is not a property of that object, but describes the degree to which the object is perceptually embedded in, i.e. laterally masked by, its visual environment. First, three variations of a simple method to measure the strength of such lateral masking are described and empirical evidence for its reliability and its validity is presented, as are several tests of predictions concerning the effects of viewing distance and ambient light. It is then shown how this method yields a conspicuity standard, expressed as a number, which can be made part of a rule of law, and which can be used to test whether or not, and to what extent, the conspicuity of a particular object, e.g. a traffic sign, meets a predetermined criterion. An additional feature is that, when used under different ambient light conditions, the method may also yield an index of the amount of visual clutter in the environment. Taken together the evidence illustrates the methods’ applicability in both the laboratory and in real-life situations.

Statement of Relevance: This paper concerns a proposal for a new method to measure visual conspicuity, yielding a numerical index that can be used in a rule of law. It is of importance to ergonomists and human factor specialists who are asked to measure the conspicuity of an object, such as a traffic or rail-road sign, or any other object. The new method is simple and circumvents the need to perform elaborate (search) experiments and thus has great relevance as a simple tool for applied research.

Keywords: conspicuity; crowding; lateral masking; visibility; visual clutter; visual search

1. Introduction: measuring conspicuity

Ergonomists and human factors specialists are frequently asked by traffic sign designers, lawmakers, advertising agencies, military involved with camouflage, website designers, etc. how conspicuous is this or that object? What is often wanted is something like a number, to allow comparative evaluations of conspicuity against a formal conspicuity criterion. However, visual conspicuity is an elusive concept, not easily expressed in simple terms. The usual answer consists of suggesting an experiment that requires placing the particular object in a situation that more or less reflects real life and have (many) subjects judge its conspicuity in one way or another. However, the results of most such studies are hard to generalise to other objects, situations and experimental tools, which means that, each time the question is asked, one must perform another experiment. What appears to be needed is a generally applicable quantitative measure of conspicuity that can be applied with ease to any object and situation, which obviates the need for experimentation and which can be used in a rule of law. It is the purpose of the present paper to report on a research programme focused on developing a method that just does that. The programme was originally initiated at the TNO-Human Factors Institute in Soesterberg at the request of the Dutch Traffic Department, who needed a simple formal rule to evaluate and formalise the conspicuity of road signs. It was later continued at the Psychonomics Department of Utrecht University in the Netherlands.

First, the definition of visual conspicuity is considered. Then, a method to measure it in a quick and easy way is explained. This is followed by a review of empirical studies designed to test the reliability, the validity and the applicability of the method in the laboratory as well as in real-life situations. The paper then shows how a standard unit or measuring conspicuity can be derived from this method. Finally, the applicability of this standard will be illustrated with some laboratory and field studies concerning various factors that affect conspicuity.

1.1. What is visual conspicuity?

The most common way in which the concept of visual conspicuity is studied is in terms of visual search. The usual procedure to measure the conspicuity of an
object is to place it against various backgrounds, at several viewing distances and in different ambient light conditions, make many images, slides, movies, etc. and then use these in visual search experiments (e.g. Scialfa et al. 2000, Ho et al. 2001, Berg et al. 2007, Tuttle et al. 2009). Alternatively, subjects may be asked to look for targets placed in (simulated) real-life scenes or just report if they noticed them accidentally (e.g. Cole and Hughes 1984, Charlton 2006). Such procedures may take time and usually require the participation of many subjects, which often causes them to be rather complex and costly (see e.g. Toet et al. 2004). In addition, the findings from such experiments cannot easily be captured in terms of a single conspicuity measurement dimension that allows comparisons between objects and circumstances.

In a sense, it is also somewhat problematic that the theoretical background of conspicuity research, being closely associated with the literature on visual search, frequently uses concepts from that literature.

The point is that in visual search much theorising has been focused on attempts to determine the properties of the target that must somehow be identified by the visual system. This has resulted in various well-known models in which feature detection plays a central role (see e.g. Treisman 1982, Wolfe 1994). Accordingly, if particular properties or features of an object are ‘salient’ enough, they cause the object to stand out from its surrounding distractors, making it conspicuous (see e.g. Itti and Koch 2000, Turatto and Galfano 2000, Bahmani et al. 2008, Gao et al. 2008, Huber et al. 2009, Rapantzikos et al. 2009, Rosin 2009, Tuttle et al. 2009).

The close association with such theories may have contributed to the oversight that conspicuity cannot really be defined in terms of object features or properties. To do so (see e.g. Isler et al. 1997, Lay 2004) is to confuse conspicuity with visibility (a confusion also often implicit in the literature on visual search). The two concepts are basically different and it is erroneous to use them as synonyms (e.g. Forbes 1972, Koornstra et al. 1997, Plainis and Murray 2002, Cottrell 2006, Porathe 2008). Visibility normally refers to the intensity or salience of an object’s features or properties, such as its colour, luminance, form, size, etc. In contradistinction, the visual conspicuity of an object refers to how well it visually stands out from its environment. Hence, conspicuity describes a relationship, the degree to which the object is visually embedded in its surrounding scene. A bright red car can be clearly visible. But that same car can be either very conspicuous (e.g. when parked in a large green meadow) or very inconspicuous (when parked in a car park with many other red cars). Hence, although the car’s features determine its visibility, they do not determine its conspicuity. Conspicuity simply is a property not of an object but of a relation. One can never derive the conspicuity of an object from its features. Instead one needs to focus on how the perceptual system deals with the interrelation between object, environment and viewing conditions. This means that an object’s conspicuity is not a fixed value. If it were it would be an object property instead of a relationship between object and environment.

Conspicuity always depends on such viewing circumstances, as the amount of visual clutter or noise in the environment, viewing distance, viewing angle and ambient light.

This is not to state that there is no connection between visibility and conspicuity, but the connection is asymmetrical. Something that is barely visible is unlikely to be very conspicuous. However, the opposite is not true. Something can be highly visible but nevertheless remain barely conspicuous, such as that bright red car in that parking area full of other bright red cars.

It is the purpose of the present paper to present a simple and easy method that captures the relational nature of conspicuity and that yields a generally valid and quantitative standard unit to express it, one that could be used in a rule of law, for example for traffic signs or railroad signals.

However, first a clarification is needed. It is well known that certain observer-related factors, such as an observer’s attentional state, may affect the outcome of a conspicuity measurement. In the literature, this has led to various definitions of conspicuity and methods to measure it. For example, there is a well-known attentional distinction between attention conspicuity – which refers to the kind of conspicuity that causes an object to draw an observer’s attention – and cognitive or search conspicuity – which refers to the conspicuity of objects that must actively be searched for (Cole and Hughes 1984, Hughes and Cole 1986). However, attentional factors are known to affect almost any perceptual phenomenon and that holds for conspicuity too. It is more convenient to speak of such factors as affecting conspicuity as intervening variables, than to assume that they define different types of conspicuity, requiring different measurement methods. A similar argument holds for factors such as the meaning an object has for an observer, what action it might provoke, etc. This is not the place to discuss all such observer-related influences (see, for some reviews, Olson 1989, Langham and Moberly 2003, Charlton 2006) because a different approach is followed here. The present view is that factors such as the observer’s actions, intentions, state of mind, etc. should not be made part of an objective and widely applicable standard of conspicuity, because it is precisely to
investigate the effects of these factors that one needs such a standard. This seems a better approach than to define different types of conspicuity, each presumably of a different nature, which invites the risk of blocking the road to a unified theory of visual conspicuity (such as suggested by e.g. Cerf et al. 2007). This is not to say that such intervening variables are uninteresting. In the final discussion of this paper, some ideas are presented as to how the influence of (at least some of) those factors may be assessed with the present measurement principles in mind.

What then is a method to measure the extent to which an object is perceived as embedded in its surrounding environment, a method that is less cumbersome than a visual search paradigm? The answer, to be found in the literature on the mechanisms of visual perception, refers to the well-known phenomenon of lateral masking. This phenomenon directly reflects the extent to which a surrounding environment impairs the perception of an object. Lateral masking is not often assumed to be important in visual search (although it should; see Wertheim et al. 2006). In the literature about conspicuity too, there are only a few suggestions that maximal gaze deviation (which is a measure of lateral masking – see below) might be used as an index of visual conspicuity (e.g. Engel 1971, 1974, 1976, Cole and Jenkins 1980, Porathe 2008). However, its reliability and validity as a quantitative measure of an object’s conspicuity have not been tested extensively, nor has it been developed to yield a generally applicable standard for conspicuity. This is what will be done in the present paper.

1.2. The phenomenon of lateral masking
The phenomenon of lateral masking can be easily demonstrated. Just write a letter, e.g. an A, on a sheet of white paper. Hold the point of a pencil slightly over the A and fixate its tip with the eyes. Then slowly move the pencil sideward, while keeping the eyes fixed on the pencil tip. The letter A thus slowly moves into the visual periphery. Continue to do so until the letter can no longer be recognised as an A. Mark the position of that maximum gaze deviation on the paper. Now write down two other letters, one left and one right of the A, leaving some space between them and the target letter A. Then repeat the procedure. It can be seen that the point where recognition of the A is lost is much less far away. If you add another letter to the left and right of the A, but more closely to it, i.e. in the spaces left open between the A and the first two flanking letters, the distance from the A where its recognition is lost becomes even shorter. This illustrates the perceptual phenomenon of lateral masking: visual stimuli surrounding an object impair the perception of that object when viewed peripherally.

Lateral masking, which in visual search research is sometimes called crowding (see e.g. Vlaskamp and Hooge 2006), thus refers to the fact that the perception of a visual stimulus (target) is impaired by the presence of other stimuli (distractors) in the visual field surrounding it. The severity of the perceptual impairment caused by lateral masking – the strength of lateral masking – is known to increase when the distractors are more closely cluttered together around the target object and also when target and distractors are positioned further away in the visual periphery (see e.g. Bouma 1970, Butler and Currie 1986, Polat and Sagi 1993, Huckauf et al. 1999). This strength is also known to increase with certain configurational factors, such as increased form correspondence between target and distractors (e.g. Egeth and Santee 1981, Estes 1982). Conversely, lateral masking may be somewhat reduced by attentional parameters (e.g. Engel 1976, van der Lubbe and Keus 2001).

A theoretical model, which predicts the strength of lateral masking, given any particular target-distractor combination, is still lacking, although some attempts have been made to describe lateral masking using such functional concepts as response competition, feature detector interaction or feature perturbation. In physiological terms, lateral masking seems to reflect some kind of interference of neural afferents stemming from adjacent retinal receptors. Some efforts have been made to link the phenomenon to receptive field sizes (see e.g. Wolford and Chambers 1983, Polat and Sagi 1993). Nevertheless, although several studies exist on factors influencing lateral masking (see e.g. Butler and Currie 1986, Kooi et al. 1994, Huckauf et al. 1999, Parkes et al. 2001, Levi et al. 2002, Tripathy and Cavanagh 2002, Cameron et al. 2004, Pelli et al. 2004), little theoretical modelling has been done on the phenomenon (but see Chen and Tyler 2002 for an attempt).

In visual search research the strength of lateral masking (crowding) is usually quantified in terms of increased search times (e.g. Krikke et al. 2000, Wertheim et al. 2006). For non-search situations, Bouma (1970) has showed that one can quantify the strength of lateral masking by measuring how far one is able to divert one’s gaze from the target object without losing the ability to perceive it as distinct from the other objects in the surrounding visual field. This basically is the method used in the example of the letter A, mentioned above. When both this method and the search times method are applied separately to identical visual search arrays, the results from both methods correlate highly (see section 2.1). This suggests that the role of lateral masking in visual search is much more
important than generally assumed and that theories that attempt to explain particular effects in visual search may well have to be adapted to include lateral masking as a central concept (see Wertheim *et al.* 2006 for details). If so, this implies that when reasoning about conspicuity, the concept of lateral masking also appears well suited to replace the more traditional concepts associated with visual search.

Accordingly, one may conceive conspicuity as describing the inverse of the degree of lateral masking exerted on an object by its environment; the stronger that masking, the less conspicuous the object. Note that this definition also reflects an empirical conceptualisation of the difference between conspicuity and visibility. The point is that, as mentioned before, lateral masking increases further away into one’s visual periphery. It thus delimits how far away one can divert one’s gaze from a target object before losing it perceptually, just as in the paper and pencil example of the letter A. Hence, one might say that the visual conspicuity of an object reflects how well it can be perceived peripherally while, in contrast, the concept of visibility corresponds to how well it can be perceived when one looks at it directly.

### 1.3. The strength of lateral masking as a measure of conspicuity

Conspicuity can thus be defined (inversely) as the extent to which the object is laterally masked by its surroundings. This implies a simple and easy way to measure quantitatively how conspicuous an object is in any laboratory or real-world situation. It is the method used in the example of the letter A above. All one needs to do is measure how far one can move one’s gaze away from the object until it cannot be seen anymore.

On the basis of this reasoning, three methods have been designed to measure this angle of maximum gaze deviation, i.e. the strength with which the environment laterally masks an object. Basically, they all consist of the same method as used by Bouma (1970): moving the observer’s gaze away from the target object until it cannot anymore be perceived or recognised. The first method is the simplest, one just looks away from the object until the deviation of the gaze is maximal and one loses sight of the target. This will henceforth be called the ‘naked eye method’. That method, however, does have some disadvantages. For that reason, two optical instruments have been designed (and patented), the so-called ‘conspicuity meters’: 1) the ‘mist-meter’ and 2) the ‘shutter meter’. All three methods will be described in the next section, including their advantages and drawbacks. After that, a number of studies are reviewed that examine their reliability, validity and applicability both in the laboratory and in real-life situations.

### 2. Measurement methods

#### 2.1. The naked eye method

The first method basically consists of just looking at the target object with the naked eye and then diverting one’s gaze sideward (or in any other direction), until the target object can no longer be perceived or recognised as different from its environment. The particular point in the environment at which one looks when this maximum gaze deviation has been reached, the so-called ‘point of maximum gaze deviation’, should be remembered. One can then, from the position of the observer’s eyes, measure the angle between the direction of the target object and the direction of this point. That angle of maximum gaze deviation will henceforth be called the ‘conspicuity angle’. The measurement of that angle can be done with a simple device (see Figure 1), consisting of a disk with a 360° scale and a rotating arrow that can, from the position of the observer, be pointed first to the target object and then to the remembered point of maximum gaze deviation. That angle thus quantifies the strength of lateral masking exerted on the target object by its visual environment. The smaller this angle, the stronger the target object is embedded in (i.e. is masked laterally by) its surroundings.

The naked eye method has been validated by showing that thus obtained visual conspicuity angles do indeed correspond closely to search times when using visual search displays (Wertheim *et al.* 2006). Identical stimulus arrays were used in two conditions. In the search condition, the target was placed at a random position within the array and search times were measured. In the conspicuity condition, the target...
was positioned at the centre of the array and, after it was pointed out to the subjects, the naked eye method was used to determine the conspicuity angle, i.e. the extent to which the target suffered from lateral masking induced by the surrounding distractors. The result showed that conspicuity angles and search times behaved in exactly the same way to a variety of factors that are traditionally known to cause well-known effects in visual search: the conjunction–disjunction difference effect, the effect of increasing the number of distractors, the effect of density, the search asymmetry effect and the effect of viewing distance. Toet et al. (1998) and Kooi and Toet (1999) also showed that with arrays consisting of simulated natural scenes with small targets imbedded, correlations between conspicuity angle obtained with the naked eye method and search times were high, ranging between 0.79 and 0.89. More recently, this same correspondence between search times and conspicuity angles has been reported with images of a natural scene (Porathe 2008). This supports the assumption, as mentioned earlier, that lateral masking largely determines visual search performance (see also Vlaskamp and Hooge 2006) and thus also determines the conspicuity of a target object, the extent to which it is embedded in its surroundings.

The naked eye method has the advantage that it is very easy to use and the visual field is not restricted. One looks at the target with both eyes, so there is no problem with the retinal blind spot. Even if the target falls on the blind spot of one eye, it will not fall on the blind spot of the other eye and thus remains visible as in normal vision. However, it has the disadvantage that the precision of the measurement depends on how precise the conspicuity angle can be measured. Another problem is that if a target object is nearby, very large and very conspicuous, this method cannot be used because the object may simply remain perceivable until it physically disappears from the visual field, i.e. until its image disappears off the retina. In other words, the method does not include a way to elevate a possible low measurement ceiling. Another disadvantage is that because of the structure of the environment, the point of maximum gaze deviation might lie at a much larger or shorter distance from the eyes than the target object. Because ocular accommodation is then different from what it was when initially looking at the target object, the retinal image of the target object could be blurred when looking at the point of maximum gaze diversion. Finally, with a featureless environment, such as blue sky or a large white wall, it is difficult to remember the exact point of maximum gaze deviation to which the pointer of the meter must be directed. These problems were the main reason for designing the optical instruments, the mist meter and the shutter meter, discussed below.

2.2. The ‘mist meter’

The first optical conspicuity meter developed was the so-called mist meter (see Figure 2). It is essentially a viewer with a 100° circular visual field. A target object can be seen together with its surrounding area through an ocular that can be adjusted for acuity if necessary. It is equipped with a small fixation mark, visible at optical infinity. Initially, this fixation mark should be positioned exactly on the target object, to be viewed at the centre of the viewer so as to allow maximum lateral masking from all sides. The fixation mark can then be moved away from the object (e.g. horizontally or in any other direction) by rotating a small hub on the instrument, to a maximum viewing angle of 50° (where it reaches the edge of the viewer’s visual field). If one looks through the instrument with one eye (keeping the other closed) and keeps the eye focused on this moving fixation point, one’s line of sight moves further and further away from the target object (just like in the example of the letter A mentioned earlier, where the fixation point consisted of the tip of the pen). One can then continue to do so until the target object can no longer be detected or recognised peripherally as distinct from its visual surroundings. At that point, one can read from the apparatus the visual angle between the direction of the target object and the line of sight. This again is the conspicuity angle.

An additional feature of this instrument is that, by rotating a partially silvered mirror inside, one can reduce all contrasts in the visual scene by a fixed...
amount, while the overall amount of light in the eye of the observer remains unaffected. This provides the impression that the scene is shrouded in mist of a particular density. This reduces the visibility of everything inside the scene by a certain fixed factor. This feature enables the measurement of conspicuity of very conspicuous objects nearby, which would, if not shrouded by mist, remain perceivable even at the maximum 50° visual angle. Thus, it can be used to elevate a possible measurement ceiling.

In several evaluation studies in the laboratory (Wertheim 1986, 1989, 1993), the conspicuity angle, obtained with this so-called ‘mist meter’, was also validated by comparing it with search times in visual search experiments. Just as with the naked eye method described above, the results showed that several factors affecting search times (e.g. the number of distractors, the colour contrast between target and distractors, disjunctions vs. conjunctions, etc.) affected the conspicuity angle in the same way. Thus, the conspicuity angle obtained with the mist meter appears indeed to be a valid index of visual conspicuity.

However, the mist feature of this instrument also has a drawback. The mist is induced by Maxwellian view in one of the light paths of the instrument. This means that the eye of the observer needs to be positioned at the precise focal point of one of the lenses inside that path. For this reason, the instrument has an ocular with a rubber eyepiece that should fit properly around the eye of an observer. Otherwise, contrast is not equal across the whole visual field, causing the mist to appear only in a section of the visual field. It takes some experience to recognise this risk of irregular mist in the visual field and to avoid it by slightly adjusting the eyepiece to fit more precisely around the eye. The measurements with the mist meter as reported below were, unless stated differently, taken with low or zero mist levels, i.e. with neglectable contrast reduction if the eye is positioned correctly.

The optics and the inclusion of this mist option also cause two other problems. First, because of the way in which the Maxwellian view is generated, flickering lights in the environment make the full-field mist flicker slightly. Thus, the instrument cannot be used to measure the conspicuity of flickering targets or of objects with flickering lights in their surrounding environment. Second, the optics cause a loss of light transmission. The diaphragm of the lenses in the system can be set at 2 or 4 mm (the latter being the maximum lens opening). But there is always a loss of light as compared with the naked eye method. Light transmission with the 2 mm opening is approximately 10% and with the 4 mm aperture it is approximately 30%. The experiments reported below all used a diaphragm aperture of 4 mm.

Another problem with this method is that one can only use one eye to look through the instrument. That means that one should only divert the gaze in a direction that does not allow the target to fall on the retinal blind spot. Thus, if one wants to move the fixation mark to the right, one must use the right eye and when the fixation mark is made to move to the left one must use the left eye. Although by rotating the optics the fixation point can also be made to move in other directions (e.g. upward or downward), one must always be careful to avoid the risk of the retinal blind spot interfering with the measurement.

2.3. The shutter meter

The so-called shutter meter (Figure 3) is another instrument designed to measure the conspicuity angle. When looking through this instrument through its ocular (adjustable for acuity), a small disc-like opening is seen straight ahead in the centre of an otherwise dark visual field. The meter should be positioned such that the target object is visible through that opening. To the observer this is like watching the target object through a small hole, as if seeing it through a long narrow tunnel. The observer can then move an internal mirror such that this tunnel, with the target remaining visible at its end, is rotated around a vertical axis at eye position in a horizontal sideward direction by a fixed amount of 1.2, 1.75, 2.5, 3.5, 5, 7, 10, 14, 20 or 28° visual angle. This moves the observer’s line of sight, i.e. the eyes, sideward at a given angle. By then pressing another button, the small hole at the end of the tunnel closes and, at the same time, a shutter briefly opens up the whole visual field (100° wide and circular) in its normal straight ahead position. The field can be preset to remain visible for either 0.5, 0.25, 1/8 or 1/16 s.

Figure 3. The shutter meter. A = button to set the deviation of the line of sight; B = button to set the duration of shutter opening; C = release button to open the shutter; D = battery chambers; E = ocular (with eyepiece attached). For further details, see text.
Since the eyes are still deviated sideward and when the shutter opens the field with the target presented straight ahead, the target with its surround is briefly seen peripherally at that preset visual angle. If the shutter is preset to open for 0.25 s or less, the visual field is seen peripherally too briefly to allow for an eye movement, i.e. to move the eyes back from their preset sideward direction. The observer then reports whether the target had been perceived. If so, the original tunnel with the target at its end is moved aside at a larger angle. This procedure is repeated until the eye is diverted to such an extent that the observer is no longer able to perceive the target as distinct from its environment, when both are briefly seen peripherally. Reducing the shutter opening time to less than 0.25 s can be used to elevate the measurement ceiling for very large conspicuous objects.

This meter does not have the drawback that the eyes must be positioned in a very precise position at the oculair to avoid Maxwellian view. It is also smaller, i.e. more easy to carry, than the mist meter. However, it also has disadvantages. First, the brief viewing time prevents proper conspicuity measurements of flickering targets. Thus, as with the mist meter, it cannot be used for such a purpose. Second, the angle at which the visual gaze is to be diverted can be set only in discrete steps, the magnitude of which increases with larger angles. In addition, the brief period in which the full visual field opens up can also be set only in discrete steps. Pilot measurements with this instrument showed that, unless the target is a highly conspicuous nearby object, shutter opening intervals of 1/8 s or shorter may cause the resulting conspicuity angles to become so small that the instrument becomes unreliable. For this reason a 0.25 s shutter time was always used in the experiments reported below. Another problem is that when the batteries that power the shutters inside the instrument become older, they gradually cause a lengthening of shutter opening times. Although this is only a small effect, it makes the shutter opening intervals less reliable if one does not frequently change the batteries. In addition, the fact that the full field opens up briefly, after the observer first has to peer through a small hole in an otherwise completely dark visual field, may cause problems with regard to light adaptation, i.e. oculair sensitivity.

The shutter meter can also be used only with one eye. Thus, just as with the mist meter, one must be careful to divert the gaze in a direction where the target will not fall on the retinal blind spot.

2.4. Criteria

It should be noted here that the measurement methods mentioned above can be used in terms of different perceptual criteria. For example, one may define the point of maximum gaze deviation as the point where one can no longer recognise the target object (recognition criterion), where one can no longer detect the target object (detection criterion), where one can no longer perceive the target as distinct from its surrounding visual stimuli (discrimination criterion) or any other perceptual criterion, e.g. the point where its colour is no longer perceivable (colour criterion). The choice of which criterion one wishes to use depends, of course, on the motivation for taking the conspicuity measure. Different criteria are likely to result in different conspicuity angles but they should not affect the rank order of conspicuity between different objects and conditions.

3. Empirical tests of the method’s reliability and validity

3.1. Experiment 1: Comparing the reliability of the three methods

To compare the three methods with regard to their measured conspicuity angles and to investigate the between- and within-subject variability of these measurements when applied at the same location to the same visual scene and target, the following study was carried out.

3.1.1. Method

The 15 participants (eight female and seven male) were all students, either paid or receiving study credits for their participation. They all had normal or corrected (lenses) to normal vision. None of the participants used spectacles and they were all naive with regard to the goal of the experiment. After a subject had completed a measurement by deviating the gaze horizontally away from the target (see Figure 4), with all three methods, there was a pause and then the measurements were repeated. This procedure was repeated 10 times. To ensure that the subjects would take their measurement with equal precision each time (instead of trying to return their gaze to a remembered point of maximum gaze deviation at a prior trial), they were told (incorrectly) that the sensitivity of the eyes may fluctuate to such an extent that the point of maximum gaze deviation is likely to be different at each trial. They were also told not to take too much time for a measurement.
and assured that attempts at extraordinary precision would not result in a more precise measurement.

3.1.2. Results and discussion

As can be seen from Table 1, there are individual differences between measurements, indicating individual differences in sensitivity for lateral masking. However, these differences are not very large, as indicated by the SD values across the individual means, which are rather small for the mist meter and the naked eye but larger for the shutter meter. On the individual level, SD values across the 10 trials are also not very high for the mist meter and the naked eye, showing that repeated measurements within subjects are rather consistent with these methods. With the shutter meter, the SD values are considerably higher, no doubt because of the fixed magnitude of the discrete steps at which the gaze can be diverted with this meter.

At group level, the conspicuity angle was not the same for the three methods. It was more or less equal for the shutter meter and the naked eye but larger for the shutter meter. On the individual level, SD values across the 10 trials are also not very high for the mist meter and the naked eye, showing that repeated measurements within subjects are rather consistent with these methods. With the shutter meter, the SD values are considerably higher, no doubt because of the fixed magnitude of the discrete steps at which the gaze can be diverted with this meter.

At group level, the conspicuity angle was not the same for the three methods. It was more or less equal for the shutter meter and the naked eye but smaller for the mist meter. The reliability of these group mean conspicuity angles is not the same for the three methods, as illustrated by Figure 5. It shows that the mist meter and the naked eye have somewhat resembling frequency distributions, although the mist meter generally yields somewhat smaller conspicuity values, whereas the shutter meter, which allows only for a few discrete conspicuity angles, provides a less reliable average value.

It is rather surprising how well the naked eye method works. The frequency distribution with this method has a quite nicely tuned symmetrical form. The scores with the mist meter are less well tuned and their distribution is shifted a little to the left, i.e. to smaller conspicuity angles. Thus, the mist meter yields somewhat lower conspicuity values. This is probably due to the difficulty of keeping the eye at exactly the same position in the eyepiece of the mist meter when taking measurements, which requires some training. As mentioned before, if this is not done perfectly, contrast can be reduced in parts of the visual field. In addition, with the mist meter light level is reduced, as light transmission through this apparatus was only about 30%.

The scattergram of Figure 6 illustrates the difference between the mean individual scores obtained with the mist meter and with the naked eye. The correlation was not very high (0.51), but this is most likely due to a rather strong range restriction, as all measurements were taken with the same stimulus array, i.e. the scores only differ with regard to the relatively small between-subject variability. When measurements are taken with many different targets, correlations between these methods are much higher (see e.g. the experiment mentioned in the final discussion, which yielded a correlation of 0.85). The slope of the linear regression line through the points in Figure 6 (forced trough the origin) was 0.75, which means that conspicuity values obtained with the mist meter were on average about 25% lower than those measured with the naked eye method.

The shutter meter appears to be a somewhat less reliable instrument to measure conspicuity, because it has quite a low resolution in terms of the conspicuity angles it can measure. However, as seen in Table 1, at group level this averages out to yield the same mean value as the naked eye. This means that the shutter meter requires a relatively large group of observers to
get a reliable measure. This contrasts with the mist meter and the naked eye method, where the low inter-subject variability implies that with these methods a few observers already allow for a reasonably reliable conspicuity average. Also, given the quite low within-subject variability with these two methods, a few subjects and a few measurements should already yield a reliable measure of conspicuity.

Thus, it may be concluded that the mist meter and the naked eye method are both methods for a quick and reliable determination of conspicuity, while the shutter meter requires more observers and more measurements to obtain a comparable reliability.

3.2. Experiment 2: A validation study

The previous study was concerned with establishing the reliability of the method. The present study investigated the validity of the method, i.e. it investigated if the strength of lateral masking does indeed reflect the level of conspicuity.

3.2.1. Method

In this study, only the mist meter was used. In an otherwise dark room, slides were projected on to a white projection screen (luminance 50 cd/m²) with one of the following six configurations:

- Configuration 1: A (black, 7.8 cd/m²)
- Configuration 2: M A M (all letters black, 7.8 cd/m²)
- Configuration 3: M X A X M (all letters black, 7.8 cd/m²)
- Configuration 4: A (red, 19 cd/m²)
- Configuration 5: M A M (A: red, 19 cd/m²; other letters black, 7.8 cd/m²)
- Configuration 6: M X A X M (A: red, 19 cd/m²; other letters black, 7.8 cd/m²)

Thus, from configurations 1–3 and from configurations 4–6, conspicuity of the target letter A should be reduced with more flanker letters. However, all black letters had a contrast with the white screen of (50–7.8)/50 = 0.844, whereas the contrast of the red A was lower: (50–19)/50 = 0.602. Since a higher contrast makes a letter stand out more from unstructured white surroundings than a lower contrast, the single black letter A in configuration 1 should be more conspicuous than the single red letter A in configuration 4. On the other hand, in configuration 6 the letter A is red and thus less embedded in its surrounding black letters than in configuration 3, where the A is also black. Hence, because of that colour difference the conspicuity of the A should be higher in configuration 6 than in configuration 3.
The arrays were viewed with the mist meter (preset at 75% contrast reduction) at 2 m distance, causing the letters to be sized $3 \times 3$. In configurations 2 and 5, inter-letter separation was $5^\circ$ and in conditions 3 and 6 it was $0.5^\circ$.

The conspicuity angle of the letter A was measured three times for each configuration by 12 naïve subjects. The whole experiment lasted approximately 20 min per subject.

3.2.2. Results and discussion

The results shown in Figure 7 illustrate that the predictions were nicely supported. The more and closer the flanker letters, the less conspicuous the target letter. Also, the black A in configuration 1 was more conspicuous than the red A in configuration 4, while the opposite holds for conditions 3 and 6, just as predicted. Interestingly, the conspicuity of the target was equal in configurations 2 and 5 and lies in between the other configurations, illustrating the presence of two opposite influences of contrast and colour that happened with these particular stimulus arrays.

Since the data are nicely in line with the specific predictions about how the conspicuity of the target letters should differ between conditions, it may be concluded that this method of measuring conspicuity is indeed valid.

3.3. Experiment 3: A conspicuity study with a simulated natural scene, using different criteria with the naked eye method

As mentioned earlier, a conspicuity measurement can be made in terms of a recognition criterion or a detection criterion. But recognition can mean different things, depending on the goal of the measurements. For example, with traffic signs it is quite important that their colours can be recognised. Thus, it needs to be known if a colour recognition criterion can indeed be used with the present method. In addition, when compared with another criterion, a colour criterion might yield a different absolute level of conspicuity, but the conspicuity effects observed should remain the same. The results from the following experiment, which was carried out as an applied project for the Dutch government, shed light on these issues. The study (Wertheim and Tenkink 2002) concerned the automatic flashing lights that are used at unmanned barrier-free railway crossings in Holland. These lights can be either red (do not cross) or white (crossing is safe, system is working properly). The questions investigated concerned the use of the lamps in those flashing lights. They could be bright red, less bright red or white. The project was intended to find out at what flicker frequency the conspicuity of the lights would be highest and what would be the optimal initial glowing time (IGT), which is the duration between the actual ignition of the light and the moment at which it reaches its maximum luminance level.

3.3.1. Method

A photograph of an approach to a barrier-free railway crossing was displayed on a computer monitor. In the image, two flashing lights were visible, positioned on the left and right side of the road close to the crossing. A large Perspex sheet was fitted over the screen of the monitor. A horizontal row of numbers, running from 0 to 22, spaced 1.14" apart was displayed on the Perspex. The first number (0) was located just below the most right of the two lights and the last number (22) was positioned at $25^\circ$ to the right of that point. The three lamp luminance/colour combinations used are shown in Table 2. The difference in luminance between the red and white lights was proportional to that in real life and the luminance of the bright red light was proportional to that of a traffic light. The proportionality consisted of all luminances (including the ambient light from the screen) being downgraded from their real-life values by a factor 100.

In the flashing conditions each pair of lights was presented either as not flashing (0 Hz) or as flashing at 0.38, 0.75 or 1.49 Hz. In the IGT conditions, IGT was either gradual (333 ms) or immediate (0 ms). In every condition, subjects were asked to move their eyes gradually along the horizontal line of numbers on the sheet of transparent Perspex, until the lights could no longer be detected or until their colour could no longer be recognised. They then reported the number that indicated their maximum gaze deviation, from which
the conspicuity angle was calculated. A total of 24 subjects participated in this study.

3.3.2. Results and discussion

As can be seen from Figure 8, irrespective of flicker frequency, the conspicuity of the red and white lights did not differ, but the bright red light was much more conspicuous, both with the detection and colour identification criterion \((p < 0.001)\). It can also be seen that there was little to be gained by increasing the flicker frequency over approximately 0.75Hz. Up to that value the slopes of the curves differed significantly from zero \((p < 0.001)\). Furthermore, the colour identification criterion yielded lower conspicuity scores than the detection criterion \((p < 0.001)\), but both criteria showed the same basic effects.

The results from the IGT conditions, shown in Figure 9, show that, with a zero IGT, conspicuity of the lights was better than with a 333 ms IGT \((p < 0.01)\), although with the colour criterion this effect was smaller than with the detection criterion. The colour and luminance differences between the three lights showed the same effects as in the frequency conditions.

The data from this study, apart from allowing the government to choose the best lamp in the automatic flashing lights of unbarred rail crossings, show that, although the measured effects are the same, detection criteria are likely to yield higher conspicuity scores than colour identification criteria. This difference in level is not surprising, given the fact that in the retinal periphery, further away from the fovea, colour perception is increasingly degraded. Consequently, colour perception gets worse with larger visual angles, which means that the conspicuity angle will be smaller if one uses a colour criterion. The results also show that when they flicker, the conspicuity of the lights increases (albeit up to a certain frequency), which nicely fits with the generally accepted

![Figure 8](https://example.com/figure8.png)

**Figure 8.** Visual conspicuity expressed in terms of conspicuity angle (eccentricity of gaze) with the naked eye method, for three lights as a function of flicker frequency with either a detection or a colour identification criterion.

<table>
<thead>
<tr>
<th>Lamp colour</th>
<th>Luminance (cd/m²)</th>
<th>Contrast*</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>13.1</td>
<td>1.31</td>
</tr>
<tr>
<td>Red</td>
<td>8.7</td>
<td>0.87</td>
</tr>
<tr>
<td>Bright red</td>
<td>26.0</td>
<td>2.6</td>
</tr>
</tbody>
</table>

*Signal luminance divided by background luminance (which was approximately 10 cd/m²).
assumption that flicker increases conspicuity (e.g. Berg et al. 2007).

However, it should be realised that this was a study carried out on a computer image and with a line of numbers present in the field of view, which in itself may have contributed to some lateral masking. Therefore, the next experiment was carried out with real-life scenes.

3.4. Experiment 4: A conspicuity study with real objects, using different methods and criteria

This study investigated if a form identification criterion also yields lower conspicuity values than a detection criterion. But the differences in conspicuity between objects with and without distractors should not be affected. Thus, a detection criterion was compared with an identification criterion, with regard to objects placed in separation, placed with one other object adjacent to it and placed with two objects placed adjacent to it on both sides. These predictions should be valid with real objects in a natural setting.

3.4.1. Method

Three groups of subjects participated. Group 1, consisting of five students, used the mist meter to measure the conspicuity of a white 5 cm high triangle chalked on the blackboard of a classroom in normal daylight circumstances. The room was filled with chairs and tables. Viewing distance was 9 m and a detection criterion was used (‘can you still detect something on the blackboard?’). Subjects then took a second measurement but with a person standing at about 50 cm aside from the triangle on the side towards which the gaze was to be diverted, i.e. observers had to move their eyes across this distracting person.

Group 2 consisted of eight students who used the shutter meter to measure the conspicuity of a 10 × 10 cm orange and white sticker (indicating a fire hose) stuck to the wall of an artificially illuminated hallway, surrounded by doors and an announcement board. They used full object identification as their criterion (‘can you still recognise the sticker as a fire hose indicator?’). Viewing distance was 8.5 m. They too measured conspicuity angles once without and once with a person standing approximately 50 cm aside from the target such that they had to move their eyes across that person.

Group 3, consisting of seven students, used the naked eye method to measure the conspicuity angle of a 10 × 10 cm white light switch with a round grey centre, placed against a white wall. Measurements were also taken in an artificially illuminated hallway but at
10 m viewing distance. Here too, the full object identification criterion was used (‘can you still recognise the target as a light switch?’). Measurements were taken first with one subject, again standing at 50 cm aside from the target object on the right, which was also the direction into which the gaze was to be moved. Then a second measure was taken with a second distractor person standing 50 cm aside from the target at the left side of the target.

3.4.2. Results and discussion

As can be seen from Figure 10, in all cases the conspicuity of the target was reduced by placing a person adjacent to the target object. When a second person was placed adjacent to the target at the other side (group 3), conspicuity was further reduced.

It is clear that adjacent objects always reduce target conspicuity irrespective of the direction of the gaze shift or of the criterion used and that this holds for real objects in a natural scene. In addition, the conspicuity with a detection criterion is higher than with an identification criterion, as expected. It should be noted, however, that in this study criterion was confounded with measurement method. But the difference between group 1 (detection criterion) and the other two groups (identification) is much larger than would be expected on the basis of just the measurement method (see Table 1). However, since different targets were used and since conspicuity is not an object property, there is no way in which predictions can be made about the conspicuity differences between the objects per se. Moreover, the groups also measured the conspicuity of their targets at different viewing distances and that could have affected conspicuity. So, in the next section the relationship between viewing distance and conspicuity will be addressed. It will then be shown how this relationship opens the way to a formal quantitative standard of conspicuity.

4. The effect of distance: the critical gap

As emphasised above, an object’s conspicuity is defined by its relation to its surrounding environment, which is affected by viewing distance. At larger distances an object becomes smaller and the amount of environment surrounding it becomes larger. However, the details of the object and the environment become smaller as well and to the extent that the scene is still seen sharply, spatial frequency increases. Thus, it is difficult to predict what happens to the strength of lateral masking exerted by the environment on the target object when viewing distance is varied.

Kooi and Toet (1999), who measured the visual conspicuity of a target stimulus within a visually cluttered image on a computer monitor, using the naked eye method, found the conspicuity angle to be reduced with larger viewing distance. However, quite surprisingly, they also found that the conspicuity angle was reduced with viewing distance in precisely such a manner that the physical distance between the object and the point of maximal gaze deviation (in the same fronto-parallel plane) remained constant. This constant distance will henceforth be termed the ‘critical gap’.

Interestingly, the constancy of the critical gap with viewing distance agrees with results from visual search experiments in which stimuli are placed on the circumference of a virtual circle. Search studies with such a display show that there is no effect on search times when the diameter of the circle is varied (Santee and Egeth 1982, Wertheim et al. 2006). Such changes in diameter mimic changes in viewing distance. The explanation is likely to be that when viewing distance is varied there are two factors that counteract each other in terms of lateral masking and, thus, in terms of conspicuity. On the one hand, there is the eccentricity factor; when a stimulus array is presented closer to the eyes, its features are projected on average further away in the retinal periphery, where their lateral masking potential is stronger. That increase of lateral masking means a decrease in conspicuity and in search studies it
should cause a lengthening of search times. On the other hand, there is the separation factor; when the same array is presented closer to the eyes, retinal separations between its features increase. That should reduce their lateral masking potential and thus cause a target object to be more conspicuous, and in search studies that should have a shortening effect on search times. Since these two factors will counteract each other, the net result of moving a stimulus array closer to the eyes is that search times remain unaffected.

It is important to note that since the critical gap is a constant, it can be used as a conspicuity measure instead of the conspicuity angle (see e.g. Alferdinck et al. 2006). That would make the concept of conspicuity independent of viewing distance. Mathematically, the critical gap can be expressed as the product of viewing distance and the tangent of the conspicuity angle (') or as illustrated in Figure 11.

\[ C = \tan(\alpha) \cdot d \]

The Kooi and Toet (1999) study, which has shown the constancy of the critical gap, was carried out with stimuli viewed on a computer screen rather close to the eyes, viewing distance being varied between 20 and 160 cm. To investigate if the independency of the critical gap from viewing distance also holds at larger distances and with more natural scenes, two studies were carried out with the mist meter and the naked eye method.

4.1. Experiment 5: Critical gap measured at larger distances

The first study was intended to investigate whether the critical gap is also constant at larger distances.

4.1.1. Method

A total of 15 students viewed the target letter ‘A’ flanked on each side by the letter ‘X’, written with white chalk on a large blackboard. The students were naive with regard to the concept of the critical gap or the hypothesis that it could be constant over distance, although they knew the concept of the conspicuity angle. Viewing distances were 9.5 and 5 m. The mist meter and the naked eye method were used. Thus, there were four conditions and each subject took one measurement per condition using the letter identification as criterion. The experiment was carried out in a classroom filled with tables and chairs, with windows letting in daylight on one side and with the lights in the room switched on.

4.1.2. Results and discussion

For all measurements the critical gap was calculated. As shown in Table 3, mean critical gap was constant across the two viewing distances. Note that although each subject took only one measure per condition, the between-subject variation was still quite small.

<table>
<thead>
<tr>
<th>Viewing distance (m)</th>
<th>9.5</th>
<th>5</th>
<th>9.5</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conspicuity angle (')</td>
<td>7.6</td>
<td>13.87</td>
<td>2.0</td>
<td>3.95</td>
</tr>
<tr>
<td>SD</td>
<td>1.4</td>
<td>3.48</td>
<td>0.7</td>
<td>1.02</td>
</tr>
<tr>
<td>Critical gap (m)</td>
<td>1.27</td>
<td>1.24</td>
<td>0.83</td>
<td>0.87</td>
</tr>
<tr>
<td>SD</td>
<td>0.23</td>
<td>0.31</td>
<td>0.29</td>
<td>0.23</td>
</tr>
</tbody>
</table>

This study showed that at larger distances than those used in the Kooi and Toet (1999) study, there is still a good constancy of the critical gap. Note that the mean conspicuity angle as measured with the mist meter was again approximately 70% of that measured with the naked eye, just as in experiment 1. However, the question still remains if this constancy of the critical gap also holds with much larger distances in real natural scenes.

4.2. Experiment 6: Critical gap measured at very large distances in natural scenes

This second study was intended to answer the question: does the critical gap remain constant even with natural objects and scenes and at very large distances?

4.2.1. Method

Three target objects were used. The first was a round black and white public clock, mounted on a high pole at the end of a large parking lot full of cars, with some trees standing behind the clock. The whole scene was in the
shadow of a high building, but under a blue sky. It was viewed with the mist meter at 183, 130, 86 and 40 m viewing distances. The second target was a blue shield the size of a traffic sign, viewed unobstructed in sunshine (the sun itself was shielded from the eyes during measurements), positioned at the end of a meadow with trees in the background. Viewing distances were 132 and 56 m. This target was viewed twice, once with the mist meter and once with the naked eye. The third target was a square piece of yellow paper (such as those used for memory notes) stuck to a tree trunk between brushes and other small trees in patches of sunshine, but viewed unobstructed at 64, 92.8, 119.25 and 154.7 m distance. This target was measured with the naked eye. Three staff members of the Department of Psychonomics served as experienced observers. They each took two measurements per condition, using a detection criterion.

4.2.2. Results and discussion
The results show that the critical gap remained constant across distance in all cases (Figure 12). This means that the critical gap can indeed be used as a measure of conspicuity that is independent of viewing distance, even at very large viewing distances and with natural scenes.

5. A formal quantitative conspicuity criterion: critical conspicuity distance for a conspicuity angle of x degrees
The constancy of the critical gap across distance is a very important finding as it makes it possible to define a quantitative conspicuity criterion: the viewing distance at which an object must still be perceivable at a given visual angle. Such a criterion can be put in a law or regulation defining a required conspicuity of any particular object, e.g. a road sign. The point is that there is now freedom to measure the conspicuity angle at any viewing distance that happens to be convenient and then calculate what is the furthest viewing distance at which that object can still be perceived at a predetermined visual angle. That maximum viewing distance will here be called the ‘critical conspicuity distance for a conspicuity angle of x degrees’ (CCDx), where the x stands for that particular prior determined conspicuity angle. In other words, CCDx is the distance at which an object has a given conspicuity angle of x degrees. It can then be seen if this is shorter or longer than required, for example, by a rule of law.

As illustrated in Figure 13, CCDx can be calculated from any conspicuity angle, if one knows the viewing distance from which that conspicuity angle happens to have been measured. It is the critical gap divided by the tangent of the predetermined criterion conspicuity angle of x degrees:

$$\text{CCD}_x = \frac{c}{\tan(x)}$$
or:

$$\text{CCD}_x = \frac{\tan(x) \cdot d}{\tan(x)}$$

As an example, assume that a rule of law is required that states that all traffic signs must be conspicuous enough to make them still perceivable for a driver at 50 m distance, even when looking at the dashboard, in which case the gaze is deviated 15° from the direction of the sign. In other words, all signs must have a \(\text{CCD}_{15}\) of 50 m. Now, one is asked to evaluate the conspicuity of a particular traffic sign against this rule of law. Suppose that for some practical reason the conspicuity angle of the sign can only be measured from a viewing distance of 30 m and it is assumed that this yields a conspicuity angle of 20°. The critical gap is 10.9 m. The sign then has a \(\text{CCD}_{15}\) of 40.75 m. In other words, one cannot stand further away from the sign than 40.75 m if one wants to be able to still
perceive it with the gaze deviated by 15°. That is much shorter than the distance of 50 m required by the rule of law. The sign’s conspicuity thus falls short of that rule and the situation must be changed to make the sign more conspicuous and then measured again to see if it reaches the required CCD of 50 m.

This example illustrates that since CCDx can be used to quantitatively evaluate the visual conspicuity of an object in terms of a predetermined requirement, it can be used as a standard measure. In the next chapter some experiments will be described that show how this standard measure can be used when investigating various effects on conspicuity both in the laboratory and in natural scenes.

6. Effects of ambient light

If a target consists of a light-emitting object, e.g. a traffic light, it should become more conspicuous at low ambient light levels (e.g. during the night), because its background (e.g. the road environment) is then less visible and the object will stand out more. Conversely, in circumstances of very high ambient light (e.g. at midday during bright sunshine) the background will be clearly visible and thus cause much more lateral masking. Thus, one can make the prediction that increased ambient light will reduce the conspicuity of a light-emitting target. Moreover, since a visually highly cluttered background should cause more lateral masking than a less cluttered one, this effect of ambient light level should be more pronounced with a highly cluttered background than with a relatively smooth background. To test these two predictions the following experiment was carried out.

6.1. Experiment 7: Effects of ambient light level on the conspicuity of car headlights in a natural scene

6.1.1. Method

One trained observer used the naked eye method (eye level at 1.7 m) with a detection criterion to measure, at a viewing distance of 100 m, the conspicuity of car headlights facing the observer. The car was positioned either on a small lane in a very large meadow (low visual clutter) or in a built-up area on a parking spot between industrial buildings (high visual clutter). Measurements were taken under different ambient light circumstances, starting at 04:30 hours (darkness) and ending at 12:00 noon (bright sunshine). The target consisted of either full or dimmed headlights and during all measurements the car’s engine was kept running (to reduce the chance of a slow reduction of headlight luminance with time, due to the battery getting low). The observer switched between the two targets after five repeated measurements to avoid too much change in ambient light between the two targets. Ambient light was measured with a diffuse lux meter directed toward the target. The conspicuity of the car lights was measured with the gaze moving in a downward direction, like a driver’s gaze that moves downward toward the dashboard.

6.1.2. Results and discussion

In the built-up area, measurements could not be taken during dusk or darkness because many lights went on in and around the buildings. These lights changed the background structure against which the car lights were seen, causing renewed lateral masking of the target, even though other aspects of the background became badly visible. Nevertheless, at the beginning of dusk (below 1000 lux ambient light) a few measurements were still taken. As shown in Figure 14, these data points (grey dots) show that the conspicuity of the car lights did indeed flatten out in the built-up area: it did not increase further with less ambient light. However, above 1000 lux, more ambient light caused the conspicuity of the car lights to decrease ($p < 0.001$) and, as expected, that decrease was stronger with the more visually cluttered environment. The difference in slopes between the meadow and the built-up area (see Table 4) was statistically significant, both with the dim and the bright car lights ($p < 0.001$).

Table 4. Slopes (linear regression coefficients) of the decrease in conspicuity with increased ambient light (in the built-up area only for data over 1000 lux ambient light).

<table>
<thead>
<tr>
<th></th>
<th>Bright car light</th>
<th>Dim car light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow (low visual clutter)</td>
<td>−0.16</td>
<td>−0.20</td>
</tr>
<tr>
<td>Built-up area (high visual clutter)</td>
<td>−0.43</td>
<td>−0.48</td>
</tr>
</tbody>
</table>

Note that this difference in slope between the meadow and the built-up backgrounds illustrates that the slope can be used as an empirical index of visual clutter in the environment. Other things being equal, the steeper the slope the more clutter in the environment.

An unexpected finding was that, although in the meadow the bright car lights were on average significantly more conspicuous than the dim ones ($p < 0.001$), with the built-up area that difference did not reach statistical significance. It is not clear why. One explanation could be that there was another factor active: local contrast. The point is that target conspicuity might suffer not only from the visibility of its background (which improves with higher ambient light), but might also be affected by the contrast...
between itself and particular features in its immediate background. But such contrast effects cannot be concluded from the present study, as ambient light levels were measured with a diffuse lux meter, which does not provide information on the luminance of specific features in the environment. To investigate the effect of contrast on conspicuity more systematically another experiment was carried out.

6.2. Experiment 8: Effect of target luminance contrast

6.2.1. Method

In the laboratory three subjects used the naked eye method with a detection criterion to measure the CCD_{10} of a very small red target light, placed against a white, wide angle screen. Again, a vertically downward gaze deviation was used. Target luminance was either 0.6 or 24.5 cd/m². A large and very strong projector was used to project ambient light evenly across the screen with a luminance that could be varied from darkness to almost daylight levels. Thus, the contrast between target and background was systematically varied in two ways: either the background luminance increased or the luminance of the target was reduced. In both cases there could be no influence of any background clutter as the background consisted only of a large empty screen.

6.2.2. Results and discussion

The results, averaged across the three subjects, are shown in Figure 15. They indicate that for these

![Figure 14](image-url)  
Figure 14. Critical conspicuity distance (CCD_{10}) values for dim and bright car headlights placed in a meadow (O; dotted regression line) and in a built-up area (●; drawn regression line through the data over 1000 lux ambient light), as a function of ambient light level. Note the logarithmic scales.

![Figure 15](image-url)  
Figure 15. Critical conspicuity distance (CCD_{10}) for a bright (▲) and a less bright (●) light-emitting target as a function of ambient background light level. Note the logarithmic scales.
light-emitting stimuli, target conspicuity (CCD\textsubscript{10}) decreased with lower contrast, either because target luminance was reduced (to become closer to ambient background luminance) or because ambient background luminance was increased (to become closer to target luminance).

These results also suggest why a large, dark backboard placed behind a light-emitting target (e.g. a traffic light) is generally assumed to enhance the conspicuity of the target. It increases the local target–background contrast without causing much increase of visual clutter (it may even shield from view some laterally masking visual clutter from the background). In the next experiment, this was tested in a laboratory setting.

6.3. **Experiment 9: Effect of a (simulated) dark backboard**

6.3.1. **Method**

This experiment was a replication of experiment 8, but with a single red slightly dimmer target light in two conditions. In both conditions, the light was placed against the wide field screen that was also used in the prior study. But in one condition a square piece of cardboard was placed in the beam of the ambient light projector in such a manner that it created a large square shadow around the target, which simulated a dark backboard. In both conditions, target conspicuity was measured in exactly the same manner as in experiment 8.

6.3.2. **Results and discussion**

As illustrated in Figure 16, without the simulated backboard, target conspicuity (CCD\textsubscript{10}) was less than with the backboard and, with the backboard, target conspicuity appeared to be reduced less steeply with increased ambient light levels than without backboard. Note that in the lowest ambient light condition, the conspicuity of the target with backboard could not be measured, as it was too dark to see the shadow backboard.

This study shows that the present method of measuring conspicuity does indeed yield a confirmation of the general assumption that a dark backboard enhances the conspicuity of a luminous object. In addition, a dark backboard seems to make the conspicuity of such an object more resistant against the conspicuity-reducing effects of increased ambient light.

6.4. **Experiment 10: A field study to compare train signal conspicuity with an a priori conspicuity requirement**

In a field study carried out for the English railway company Railtrack, the conspicuity of a number of red railroad signals was measured (Wertheim 2002). Before measurements were taken, it was decided that all signs should have a CCD\textsubscript{10} of 100 m, which means that train drivers should, at a distance of at least 100 m from the signal, still be able to detect it while their gaze is deviated by 10° in a downward direction. The 10° criterion was chosen for two reasons. First, research has shown that to look at a stimulus that is more than 10° away from the line of sight, people usually make head movements, while with smaller visual angles only eye movements are made (Sanders 1970). Thus, the 10° criterion means that drivers who look away from the signal at this angle can still see the sign without the need to make a head movement. Second, eye movement records of car drivers in normal driving situations show them to make scanning eye movements of approximately 10° (Blaauw and Riemersma 1975). The 100 m criterion was chosen by officials from Railtrack, who assumed that a distance of 100 m from a red signal is the minimum distance at which a train can still be stopped in time, given the speed of trains in that area.

6.4.1. **Method**

All measurements were taken in the train drivers’ cabin through the front window at the approximate eye position of the driver. A normal train was used. It was made to stop for measurements at the magnet that normally switches the signal’s colour (which is often much further away from the sign than 100 m).

Distance to the target signal was measured with a
precision laser distance meter. Before a signal was measured it was first put on red. For each signal, measurements were taken at different moments in time during a period of 6–8 h, starting at night or very early morning (maximum darkness) until noon (maximum ambient light level). Before each measurement, ambient light levels were measured with a diffuse lux meter through the front window next to the driver’s position in the direction of the sign. Two trained observers participated, using both the mist meter and the shutter meter (0.25 s shutter opening) mounted on tripods. The measurements were taken with the gaze deviating in a downward direction. This was done to avoid confusion with other railroad signals mounted on the same gantry to the left and right of the one being measured and because a train driver must move the gaze downward to look at the dashboard controls. An identification criterion was used (the signal should still be recognisable as the intended red railroad signal). Each measurement was taken once by two observers. Thus, there were four conspicuity measurements per signal per ambient light situation. Their average was taken as the conspicuity angle and from that average the CCD10 was calculated. In some cases, improvised backboards were also used in this study. However, for logistical and technical reasons they were much too small and were often placed asymmetrically inside the metal cage on which the signals were mounted. Thus, they did not meet the requirements of the European standard for signal backboards and, in fact, were barely visible at a distance. Circumstances in which ambient light measurements were ambiguous (e.g. viewing the signal from under a dark bridge) were avoided, as were measurements during rain (many drops of water on the windshield might interfere with target conspicuity). To avoid interference caused by other trains moving in the field of view, measurements took place only when no other trains were visible.

6.4.2. Results and discussion

Since the results of this study were confidential, only a typical result for one of the signals can be given here (Figure 17). Note that its conspicuity was reduced with more ambient light (as was the case with all signals), just as in the laboratory studies mentioned above. Moreover, in daylight, this particular signal was considerably less conspicuous than required by the predetermined rule, according to which CCD10 should not be less than 100 m. That requirement was met only in darkness. As shown in Figure 17, the improvised backboard did not improve conspicuity.

This study illustrates that the present method is quite well applicable to real-life situations and can be used to test whether or not the conspicuity of an object meets a particular criterion. In addition, the study reconfirms that the conspicuity of a light-emitting stimulus is reduced with increasing ambient light levels.

7. Summary and conclusions

The view presented in this paper is that visual conspicuity is not an object property but a perceived relationship between an object and its environment, a relationship that can be conceptualised as the extent to which an object is laterally masked by its environment. This yields a simple method that gives a quantitative measure of the visual conspicuity of an object: one only needs to measure how far one’s gaze can be diverted from the target object until it is no longer perceivable. The method is easy and quick to carry out, reliable even if one uses just one or a few observers and it allows for the setting of quantitative criteria of conspicuity, criteria that can be made into standard requirements for objects such as traffic signs, train signals, advertisements, etc. or, conversely, for such purposes as camouflage. An additional bonus of this method is that if it is applied to a light-emitting object in different ambient light situations, the change in conspicuity as a function of ambient light may provide a measure of the amount of visual clutter in the environment.

The present method also allows for making quick comparisons between objects to decide which one is the most conspicuous. An example of such a comparison...
study is given in Figure 18, which presents the CCD$_{10}$ values of 24 different designs for indoor exit signs, measured at Reading University (UK) against identical backgrounds, as obtained by just five observers with the mist meter and the naked eye method. The scores of the mist meter and the naked eye method correlated highly ($r = 0.85$).

This ease of measuring conspicuity in this way is a great advantage over the time-consuming and elaborate method of measuring conspicuity of an object by photographing or filming it in many conditions and then using these images to construct a visual search task that must be carried out by many observers. The methods described in the present paper are also likely to be more valid than when using such a search task. This is because of the present definition of visual conspicuity, according to which it is a unique relationship between the object and its environment as perceived by an observer in his or her particular viewing condition. It implies that conspicuity cannot be determined exclusively in terms of the properties of the target and the features of its environment; the observer’s viewing condition (like viewing distance or the particular angle at which a target is positioned relative to the observer) is, in fact, a third critical component.

Of course, one may also understand viewing condition to include perceptual abilities of the observer. For example, the conspicuity of a particular object, e.g. a product advertised in a shop window or on a computer monitor, may be said to be very different for young and old observers. The fact that attentional parameters are known to affect lateral masking (see e.g. Engel 1976, van der Lubbe and Keuss 2001) explains to some extent why they may also have an effect on conspicuity. As mentioned before, this issue has not been covered in the present paper, which is concerned with only the purely sensory aspects of conspicuity (although it could be argued that different criteria, such as detection or identification, reflect different attentional aspects). Nevertheless, as stated earlier, possible intervening influences of attention or other cognitive factors (e.g. expectation) may prove to be interesting topics for further research. One way to approach such an issue is to ask observers not to begin by fixating the target with the eyes and then diverting their gaze, but to begin at a greater deviation of the gaze and then move the gaze toward the target until it is noticed. One can then manipulate such attentional or cognitive factor as to what (kind of) target the observer should expect, where it is located, whether it is present or absent, etc.

The present paper has discussed three measurement methods, which all reflect the same principle of measuring maximal gaze deviation, each with its strong and weak aspects. The mist measure has a high resolution but has the disadvantage that the eye must be positioned in a precise position within the eyepiece of the optical instrument and that it cannot be used to measure the conspicuity of flashing objects. Also, given the effects of ambient light level on conspicuity, the loss of light through the optics of the instrument may cause a certain bias. The shutter meter has less resolution, especially with very conspicuous objects because the visual angle at which the eye is diverted from the target can be varied only in relatively large steps. This method may, in addition, be somewhat biased by problems of light adaptation in the eye and it too cannot be used with flashing targets. The naked eye method is a good alternative, especially since to most people no mist meter or shutter meter is available, and flashing lights are no problem. But the resolution of the naked eye method depends on the precision with which the visual gaze angle can be measured. Another advantage of this method is that there is no loss of light due to transmission through optics. On the other hand, the naked eye method may be biased with nearby objects if the specific feature in the environment, to which the eyes fixate when diverted from the target, does not lie at the

Figure 18. Critical conspicuity distance (CCD$_{10}$) values of 24 differently designed indoor exit signs, averaged across the scores of five observers, as obtained with the mist meter and naked eye method, using an identification criterion.
same viewing distance as the target. That may cause the
target image to be blurred on the retina and change spatial
frequencies in the visual field. In addition, it
lacks a feature that both the mist and the shutter meter
have: being able to elevate the measurement ceiling with
very large or highly conspicuous objects that would
otherwise still be perceivable when the eyes are deviated
maximally. It may well be a good strategy to use two of
the methods or all three of them and define conspicuity
as the average of their scores.

But whatever their differences, the three methods,
all based on the same measurement principle, have
been shown to be valid and reliable as well as very easy
to carry out, both in the laboratory and in real-life
situations. However, their main advantage is that they
can be used to calculate CCDx, i.e. visual conspicuity
as expressed as a number. This makes it possible to
provide a simple digital answer to that darn question:
‘How conspicuous is this or that object?’.

Note
1. Apart, of course, from publications that stem from the
research project reviewed here (e.g. Wertheim 1986,
Krikke et al. 2000, Wertheim and Tenkink 2002, Toet

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