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CONSPICUITY IS TASK DEPENDENT:
EVIDENCE FROM SELECTIVE SEARCH

J. Theeuwes

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Conspicuity is task dependent: evidence from selective search

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ABSTRACT

Two visual search experiments were conducted to investigate whether a highly salient stimulus difference automatically attracts spatial attention to its location. If a highly salient object captures attention even when there is no benefit for the subject to do so, this provides evidence that a highly salient object always and involuntarily attracts attention to its location. Alternatively, if the highly salient object is not treated differently compared to any other object in the stimulus field, one may conclude that the visual system does not automatically react to objects that stand out from the environment, but that the subject is able to actively filter out task relevant items. Subjects had to visually search for a horizontal target line segment positioned in either one of the 4, 8 or 16 circle or diamond form items. The direction the target line indicated (left or right) determined the response. Experiment 1 showed that an item unique in form does not automatically draw attention to its location, but that attention could actively be directed to the location of the unique item when such focussing is beneficial for the search task at hand. Experiment 2 revealed that a form change of an item during presentation of the entire stimulus field automatically seizes attention to the source of change. This study suggests that attention is only automatically drawn to an item when temporal discontinuity makes it salient. When a stimulus is highly salient only because of form differences the attention attraction property does not longer hold. Since the salient items in both experiments can be considered as highly conspicuous according to several definitions, the present results necessitate a revision of the concept of conspicuity. It shows that automatic attention attraction cannot longer be considered as a fundamental property of conspicuity.

Opvallendheid is taakafhankelijk: evidentie van selectief zoeken

J. Theeuwes

SAMENVATTING

Door middel van twee visuele zoek experimenten werd nagegaan of een groot stimulus verschil automatisch de aandacht trekt. Als de aandacht getrokken wordt door de sterk afwijkende stimulus ook wanneer dat niet voordelig is voor de waarnemer, kan geconcludeerd worden dat de aandacht zich automatisch en zonder intentie richt op de plaats van de afwijkende stimulus. Wanneer de aanwezigheid van een afwijkende niet-relevante stimulus het zoekproces niet beïnvloedt, dan kan geconcludeerd worden dat het visuele systeem niet automatisch reageert op afwijkende stimuli, maar dat de waarnemer in staat is actief taakrelevante stimuli te filteren. Proefpersonen zochten naar een horizontaal lijnsegment dat geplaatst was in één van de 4, 8, of 16 cirkel- of ruitvormen. De richting waarin het horizontale target lijnsegment wees (rechts of links) bepaalde de respons. Experiment 1 liet zien dat een item met unieke vormkenmerken niet automatisch spatiële aandacht trekt, maar dat de aandacht wel gestuurd kan worden naar de plaats van het unieke item wanneer dat voordelig is voor de visuele zoektaak. Experiment 2 gaf aan dat een verandering van vorm van het unieke item tijdens stimuluspresentatie wel automatisch de aandacht trekt. Dit resultaat suggereert dat aandacht alleen automatisch getrokken wordt wanneer de afwijkende stimulus temporele discontinuïteit heeft. Wanneer een stimulus afwijkt op grond van andere verschillen blijkt deze geen automatische aandacht trekkende eigenschappen te bezitten. Omdat volgens verschillende definities van opvallendheid, de afwijkende items in beide experimenten beschouwd kunnen worden als zeer opvallend, kan geconcludeerd worden dat de gebruikelijke definitie van het begrip opvallendheid inadequaat is. Deze studie toont aan dat het automatisch trekken van aandacht niet langer beschouwd kan worden als een fundamentele eigenschap van opvallendheid.

1 INTRODUCTION

This experimental investigation is part of a research project which is sponsored by the Road Safety Directorate of the Dutch ministry of Transport. It aims at establishing and exploring the characteristics of top-down governed visual selection in road traffic environments. Following an extensive literature review (Theeuwes, 1989a) this study investigates whether top-down directed visual selection is possible in the presence of a highly salient object.

Of all driving relevant information, about 90% is considered to be visual (Hills, 1980; Shinar, 1978). Perception is assumed to play a key role in the driver-vehicle-road system (Rockwell, 1972), and it has been estimated that as many as 45% of the accidents could have possibly be prevented if drivers would have perceived critical events immediately preceding the accident (Treats et al., 1977). In a road environment, there is an enormous influx of visual information and obviously, the appropriate sampling and integration of information is critical for the driving task. For example, through signs and other road traffic control devices the information acquisition process can be optimized. Three aspects of information transfer through traffic control devices are recognized: first, attention must be attracted; second, the symbolic or alphanumeric code used to display the message must be visible and legible; third, the message must be comprehensible (Hughes and Cole, 1984).

Attracting attention to driving-relevant objects is the most crucial process since failure to notify these objects precludes the operation of any of the other processes. The efficiency to which an object is capable of attracting attention is commonly referred to as its conspicuity (Hughes and Cole, 1984; Connors, 1975; Odeschalchi, 1960). Traffic engineers would use conspicuity in the sense of "clearly visible", "obvious", or "striking to the eye" (Cole and Jenkins, 1982). In such a view, what is noticed in the environment is solely determined by the physical properties of the objects and their background.

The present study investigates whether the presumptions about attention attraction hold in a visual search situation in which top-down strategies are viable. The question addressed is whether highly salient objects can seize attention even when there is no benefit for the subject to attend to them. If so, this implies that the automatic attention attraction hypothesis holds. If not, this would provide evidence that the visual system does not automatically react to objects that stand out from the environment, but that subjects are

able to engage in active filtering on the basis of knowledge of the stimulus input.

The concept of conspicuity has been used to refer to two different aspects. First, it refers to the degree of perceptual prominence of an object in its surroundings by virtue of crude sensory features such as differences in brightness, outline, color, size, etc. (e.g. Engel, 1977). Second, it has been applied to refer to the attention attraction consequences attributed to any object that is perceptually prominent (e.g. Jenkins, 1979). This latter property is common to almost all definitions of conspicuity (e.g. Connors, 1975; Forbes, 1939; Gerathewohl, 1954; Odescalchi, 1960), albeit in varying degrees of concreteness and differences in specific definitions. For example, it has been argued that a conspicuous object will be seen with certainty, within a short observation time (200-250 ms) regardless of the location of the target object in the visual field (Cole and Jenkins, 1980). Alternatively, Williams (1966) measured eye-movements and used the criterion of objects fixated. Similarly, Engel (1977) argued that a conspicuous object elicits an involuntary eye-movement towards it. Besides using the term conspicuity to indicate the sensory attributes that make an object salient in its environment, it is especially used to refer to the behavioral consequences of the presence of such a salient object. As indicated above, it is assumed that an inevitable consequence of the presence of a salient object is an involuntary shift of spatial attention to the location of the salient object. According to this reasoning, conspicuity plays a key role in involuntary control of selection (Engel, 1977).

However, selection is not necessarily determined by the external environment. "Set" regarded as an active, top-down process can direct attention to certain locations. The term "set" is referred to as an active process that arises from the subject's knowledge about the nature of the input he will receive (Posner, 1978). Numerous studies have shown that providing a subject with information about the location of where the object will appear affects detection speed (Posner, Nissen and Ogden, 1978), detection accuracy (Bashinski and Bacharach, 1980), and reaction time (e.g. Eriksen and Yeh, 1985; Theeuwes, 1989b). In addition, the extent to which highly salient objects can control the visual system can be reduced by actively focussing of spatial attention to a certain area (Eriksen and Hoffman, 1973; Humphreys, 1981).

The effective utilization of spatial information in directing attention in the visual field is related to selection theories that claim that attention has a spatial locus analogous to a spotlight or zoom lens (Posner, 1980; Eriksen and Yeh, 1985; Theeuwes, 1989b). According to this view, selection is analogous to setting the spot-

light to a location in the visual field. When an explicit location cue is provided, the spotlight will focus and move to the point of importance. After focussing this location, selection is thought to have occurred. This selection is clearly the result of active top-down processing directing the spotlight to a specific location. However, when it is unclear where the spotlight should go, it is kept wide, and when something seems to be happening the beam sharpens and moves to a point in space that receives detailed processing (Broadbent, 1982).

The processing in a wide mode of spatial attention can be conceived of as "pre-attentive", operating automatically, in parallel across all elements, and unlimited in capacity (Neisser, 1967). It is recognized that this pre-attentive stage of processing provides a selection of stimuli for more detailed and extensive processing that could not be performed in parallel.

The present study is concerned with the control of selective intake turning from a wide to a focussed attentional mode, while searching for a target in a multi-element stimulus field in which a highly salient item is present. Two hypotheses can be asserted. First, since pre-attentive processing is automatic and not under subject control it is possible that, pre-attentively, attention is pulled to the salient item in a bottom-up fashion. When any highly salient stimulus distinction based on a single feature causes an automatic shift of spatial attention, filtering out of a stimulus is a passive consequence of stimulation. This hypothesis is in accordance with the traditional view of conspicuity, in which a conspicuous object is not only salient but also involuntary draws attention to its location. Second, it is possible that spatial attention is not automatically shifted to the location of the highly salient item. According to this hypothesis, subjects are able to engage in active filtering on the basis of knowledge of the nature of the stimulus input they will receive, implying that attentional focussing is sensitive to top-down influences. For example, in a recent study of Yantis and Jonides (1988) it was shown that stimuli differing in color did not automatically attract attention. Jonides and Yantis (1988) conclude "that uniqueness of color is a sufficient condition for active allocation of attention to take place, but it is not sufficient to capture attention" (p 353). This study demonstrates that attentional focussing is not merely a driven process but that dependent on the task demands, features can be used to actively filter out task relevant items. Obviously, this hypothesis is not in accordance with the traditional view of conspicuity because it claims that a highly salient object does not automatically and unintentionally attract attention to its location. It claims that attention is under

voluntary control and can actively be directed to the location of the highly salient object.

In the present study, subjects searched for a horizontal target line segment pointing either to the left or right. This target line segment appeared in one of the non-relevant circle or diamond forms which were presented circularly around the central fixation point. On each trial, one form always differed from the background, i.e., a circle among diamonds or a diamond among circles. The display size was either 4, 8, or 16, consisting of a quarter, half or full circle, respectively. In one of the forms, the response requiring line segment appeared, whereas non-target line segments appeared in the remaining forms. The chance that a target line segment appeared in the salient form was the same as for any of the other forms. In a control condition, the target line segment appeared always in the salient form providing a search performance which is thought to be independent of the number of elements in the display.

The two hypotheses discussed above lead to different predictions for this situation. First, if the salient form automatically attracts attention to its location, search time for those trials in which the salient form happens to contain the response requiring line segment will be extremely fast. It should give detection times which are independent of the number of non-targets in the display, i.e., a search performance similar to the control condition. In this case directing spatial attention clearly is conceived of as a bottom up, automatic process. For trials where the target line segment appears in a non-unique form, search time is expected to increase with display size revealing a serial attentional scan.

Second, if directing spatial attention is dependent on whether such focussing to the salient form is task relevant, one expects that search is not affected by the salient form being present. For each trial, a serial search is expected showing an increase in search time with an increasing number of non-targets. In line with the conclusions of Jonides and Yantis (1988), attentional focussing is then considered to be a process that enables active filtering.

2 EXPERIMENT 1

The first experiment follows up on the Jonides and Yantis study (1988). They showed that an item, unique in color or intensity did not automatically attract attention. The present study investigates whether an item unique in form can cause an automatic shift of attention. This study includes a control condition in which form unique-

ness was always a reliable cue. In contrast to the Yantis and Jonides study, this allows a direct comparison between conditions in which the allocation of attention to an unique item is differentially related to task relevancy. In addition, it provides a essential test of whether subjects are capable of perceiving the unique element in all. In order to create a explicit manipulation of uniqueness, large display sizes were used. Finally, in order to rule out the possibility of an interaction between target- and spatial uncertainty, target uncertainty was eliminated by presenting a target on each trial. For example, in the Jonides and Yantis study, the number of errors increased with the display size implying that subjects were biased towards negative responses i.e., with increasing display size, subjects were more likely to respond "target not present".

2.1 Method

2.1.1 Task and Stimuli

The sequence of events on a trial was as follows: initially, a fixation dot ($.3^\circ$) was presented at the center of the field for 1800 msec. Five hundred msec prior to stimulus field onset the fixation dot increased in size to 2° in order to warn the subject for the upcoming stimulus field. Then, with a maximum of 5 sec, the stimulus field remained on until a response was given. The stimulus field consisted of 4, 8 or 16 elements which were centered around the fixation point in an imaginary quarter, half or full circle of 5° visual angle radius. The elements consisted of 1.4° circle or diamonds forms in which $.5^\circ$ horizontal line segments were placed. In each display, one element was unique in comparison to its background, i.e., a diamond among circles or a circle among diamonds. The horizontal line segments appearing in the forms were enclosed by two small vertical lines ($.2^\circ$). The target line segment had only a vertical line at one side. The side with the vertical line omission determined the appropriate response key (left or right). In a block of trials, the probability of a circle appearing among diamonds, or a diamond appearing among circles was equal, preventing consistent mapping. The target line segment appeared at each of the 16 locations equally often. Within these constraints, the position of the unique form in relation to the position of the target line segment was chosen at random. Fig. 1 provides two examples of display size 16.

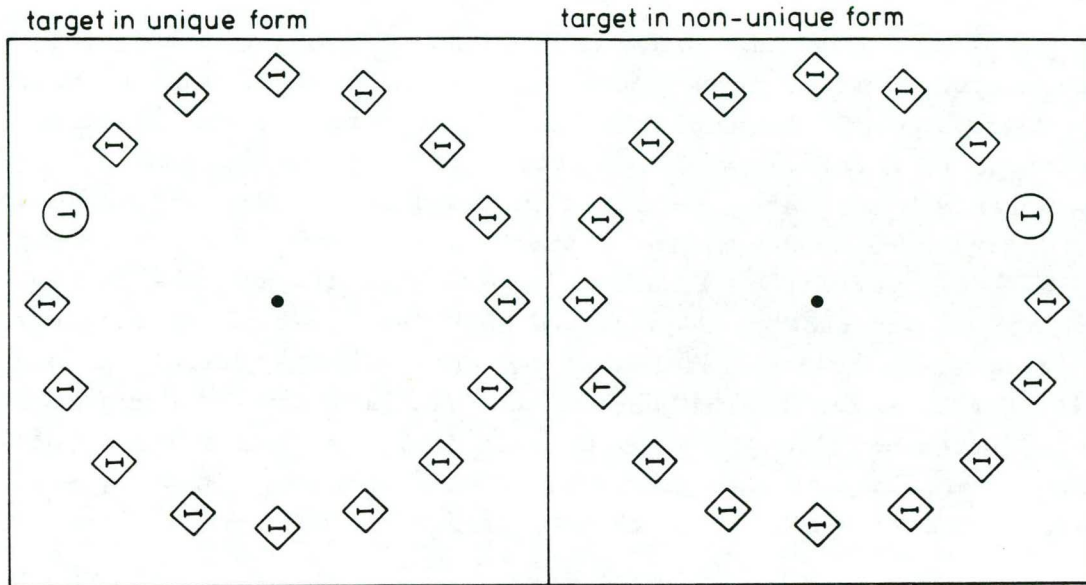


Fig. 1 Examples of display size 16. The left panel represents a typical trial in which the target line segment is positioned in the unique form (trial type "unique"), the right panel represents a typical trial in which the target line segment is not positioned in the unique form (trial type "non-unique"). Correct response for left panel is "left", for the right panel "right".

2.1.2 Apparatus

A S-R interface with external clocks (accuracy 1 msec) connected to an IBM AT-3 with video-digitiser (Matrox inc.) controlled timing of events, generated video pictures and recorded reaction time. The 45° degrees tilted response panel consisted of a left and right response key (1 x 1 cm) which were mounted 5.5 cm apart. When an error was made, a warning tone was generated by an audio generator. The stimuli appeared on a 35 x 23 cm TV-monitor (Barco, CDCT 2/51) and had a luminance of 6.7 cd/m^2 on a background of 0.02 cd/m^2 .

Subjects were tested in a sound attenuated, dimly-lit 2 x 2 x 2 m cubicle (Amplisilent) with their heads resting on a chin rest adjusted to a comfortable height. The TV-monitor was located at eye level, 115 cm from the chinrest. An intercom was used to communicate with the subject.

2.1.3 Subjects

Sixteen paid subjects participated in the experiment. Their age varied from 18 to 26 years. Eight subjects were randomly assigned to

each of the experimental and control conditions. All subjects had normal or corrected-to-normal vision and were right handed.

2.1.4 Experimental design and procedure

The design of the experiment was a two factor within-subject design (display size and trial type) with a between-subject control condition. Subjects were presented eight blocks of 192 trials each. There were two type of trials: those with the target line segment positioned in the unique form (unique), and those with the target line segment positioned in any other form (non-unique). In order to ensure that the location of the target line segment was unrelated to the position of the unique form, the target line segment appeared in each form equally often. This implies that the target line appeared in the unique form at $1/n$ trials in which n represents the display size. Table I shows the number of trials per block of each trial type for the experimental condition.

Table I Number of trials per block of each trial type.

trial type	display size		
	4	8	16
unique	16 (128)	8 (64)	4 (32)
non-unique	48 (384)	56 (448)	60 (480)
total	64 (512)	64 (512)	64 (512)

In the control condition, the unique form always contained the target line segment, implying that form uniqueness was a reliable cue for target search. An experimental session lasted approximately 20 minutes and consisted of 192 trials with a 2 minute interval after 96 trials. Each block started with 3 dummy trials. The total number of trials performed by each subject is shown between brackets in Table 1.

Subjects were run in alternating sessions. Before the experiment started subjects received instructions. They were asked to visually search for the target line segment, and press the appropriate response key with their thumbs which were resting on the response

keys. No information was provided about the relation between unique form and target line segment. The subjects were instructed to respond as quickly as possible while keeping errors to a minimum. Every error made was signalled by a warning beep. Each subject was given a practice session consisting of 192 experimental trials and 192 control trials.

In order to check whether the salient items could be considered as conspicuous, a measurement device developed by Wertheim (1986, 1989) determined the level of conspicuity. Although this measure is only one operationalization of the concept of conspicuity, one might consider this device as most promising because preliminary validation studies have shown that the measure highly correlates with other measurements of conspicuity (Wertheim, 1989). In addition, the output of the device is based upon a combination of definitions of conspicuity using a combination of both the eccentricity and subjective visibility as a dependent measure. The output of the device is the amount of contrast reduction needed to dissolve the object in its "overall" background at a specific eccentricity of viewing. The conspicuity of the unique item for each display size was measured for 20 random display configurations. Half of the measurements concerned a diamond among circles, the other half a circle among diamonds. The eccentricity under which the measurements took place was about 14° visual angle.

2.2 Results

Median correct response times were calculated for each subject for each factor combination. The mean results over subjects are presented in Fig. 2.

Separate analyses of variance (ANOVA) were performed on the experimental and control conditions, and on the comparison of both. For the experimental condition, an ANOVA with individual median response times for correct trials as cells showed a main effect of display size ($F(2,14) = 230$; $p < .001$). Neither trial type nor its interaction with display size reached significance. The results clearly show that the unique item did not cause an automatic shift of spatial attention. An ANOVA performed on the correct individual median response times in the control condition revealed a main effect of display size ($F(2,14) = 5.87$; $p < .05$). A comparison of the experimental condition in which the unique form contained the target with the control condition, showed a reliable effect of unique versus control ($F(1,14) = 38.2$; $p < .001$).

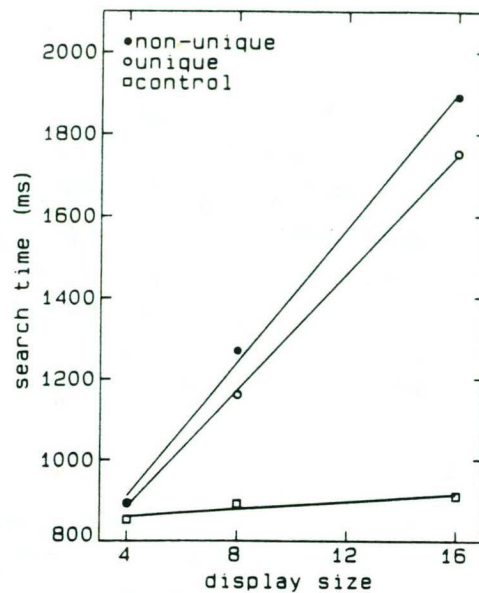


Fig. 2 Mean search time for non-unique, unique and control trials of Experiment 1 as a function of display size.

In addition, display size interacted with this factor ($F(2,28) = 76.7$; $p < .0001$). The error rates in all conditions were quite low and never exceeded 2%.

In order to determine the slopes of the search function, the individual median response time were submitted to a linear regression analysis. The increment in response time for the non-unique condition was 82.2 msec per comparison whereas the increment for the unique condition was 71.9 msec per comparison. The lack of a significant difference between the unique and non-unique function slopes ($t(44) = .96$) provides additional evidence that the unique item does not automatically attract attention. The slope for the control condition was 4.5 msec per comparison, which is only marginally different from a zero slope ($t(22) = 1.81$; $p < .10$). This finding of an almost zero slope in the control condition indicates that the form difference is highly salient and can be perceived. It implies that subjects will and can make use of this form difference when it is advantageous for their task execution.

2.2.1 Conspicuity measurement

The results of the conspicuity measurement revealed that there was no difference between a circle among diamonds or a diamond among circles. For the display size 4, 8, 16, the percentage contrast

reduction necessary to "not-see" the difference between the unique object and its background anymore averaged to 96.2, 94.6, 94.4 respectively, implying that the unique object in a display of size 4 was slightly more conspicuous. According to Wertheim (1989) an object measured at 12° visual angle needing a reduction in contrast of at least 90% before it dissolves in its background can be considered as conspicuous. The values for the present experiment are determined at an even higher eccentricity and still all values are well above the 90% contrast reduction implying that the items were conspicuous.

2.2.2 Quantitative model

The present data were fit to a simple visual search model which resembles the model proposed by Jonides and Yantis (1984). For the present experiment, a simple linear search model can be expressed as

$$RT = A + k T \quad (1)$$

in which $E(A) = \alpha$, and $E(T) = \tau$. Reaction time (RT) is a random variable expressing the time to find the target, A is a random variable expressing the base time needed for those processes which are independent of the number of comparisons to be made (e.g. encoding, motor programming, response execution, etc.). k is the expected mean number of comparisons to be made on each trial, T is a random variable reflecting the time needed to decide whether or not an item is the target. Given this model, the two hypotheses discussed earlier can be tested in a more quantitative way.

(1) *Attention attraction*. If the unique form always attracts attention, and the target line segment is located in the unique form, k will be 1 since the target is found after only one comparison. This represents a situation in which search is not affected by the display size. If the unique form attracts attention and the target line segment is located in one of the non-unique items, one can assume that search proceeds in a serial self terminating way. It should be noted that in this situation search always starts at the unique form that does not contain the target. Hence for this hypothesis, k will have two different values depending on whether the target line segment appears in the unique item.

$$\text{target unique:} \quad k = 1 \quad (2a)$$

$$\text{target non-unique:} \quad k = 1 + [(d-1)+1]/2 = 1 + d/2 \quad (2b)$$

in which d is the display size. The initial 1 in Equation 2b corresponds to the item that attracts attention and is no target. For the

present experiment $k = 3$ for display size 4, $k = 5$ for display size 8, and $k = 9$ for display size 16.

(2) *Serial self-terminating search*. When an unique item does not automatically attract attention, it is plausible to assume that search will be serial and self-terminating. Since the target appeared equally often at each location and in a random order, search will start at a random position and the mean number of comparisons will be (cf. Sternberg, 1966):

$$k = (d+1) / 2 \quad (3)$$

in which d represents the display size. For the present experiment, $k = 2.5$ for display size 4, $k = 4.5$ for display size 8 and $k = 8.5$ for display size 16.

By means of linear regression the two quantitative models were fit to the data. Table II shows a test of the attention attraction and serial search model and the variance accounted for.

Table II clearly shows that the self-terminating serial search model described above fits the data. This model accounts for 81% of the variance whereas the proportion of variance accounted for by the attention attraction model is only 24%. It should be realized that the fit of the serial search model cannot be perfect because, occasionally, subjects will miss the target while serially scanning the display.

Table II Observed and predicted mean RT for Automatic Attraction (AA) and Serial Search (SS) model for Experiment 1.

trial type	display size	observed	predicted	
			SS	AA

item	4	893	899	1144
unique	8	1161	1207	1144
	16	1752	1823	1144

item	4	893	899	1286
non-unique	8	1269	1207	1428
	16	1822	1823	1712
percent variance accounted for			81	24

In studies using target uncertainty (Jonides and Yantis, 1988), such a failure would result in an error since subjects would erroneously respond "target not present". In the present experiment a subject will continue scanning the display, resulting in a large search time which cannot be predicted by the serial search model.2.3

Discussion

The data clearly show that a highly salient item does not automatically produce a shift of spatial attention. It implies that, in a search situation, an element unique in form is not automatically examined first. These results are in agreement with those of Jonides and Yantis (1988) who showed that an item that is salient because of a difference in brightness or color does not automatically attract attention. The present study provides evidence that an item defined by a difference in form has no other status than any other item in a visual display.

The data of the control condition show that when the form difference is related to the search task, subjects will use this form difference to direct their spatial attention. The almost zero slope of the search function of the control condition indicates that subjects immediately focussed their attention on the salient form without the need for any serial search. This result indicates that the salient form can also be considered as conspicuous because by definition an object is conspicuous when it requires no search to be seen with certainty (Jenkins and Cole, 1984). The results of conspicuity measurements also indicated that the forms were highly conspicuous.

In conclusion, the experiment indicates that selection is not merely determined by stimulus input; subjects are able to engage in active filtering on the basis of knowledge of the stimulus input they will receive. The present experiment clearly shows that conspicuity traditionally defined as an object factor determining visual selection (e.g. Engel, 1977; Williams, 1966) is not correct.

3 EXPERIMENT 2

Experiment 2 was designed to investigate whether other salient stimulus properties might have attention attraction properties characteristic for conspicuity as traditionally defined. An automatic attention attracting phenomenon has been reported by Yantis and Jonides (1984). Their study showed that an item having abrupt

stimulus onset was capable of capturing attention. It was argued that this phenomenon was related to visual transient channels specialized for the detection of visual onset (Jonides and Yantis, 1988). Since it can be hypothesized that it is not abrupt onset per se but abrupt change that activates these visual channels, the present study investigates whether abrupt stimulus change is a possible candidate for automatic attention attraction. Experiment 1 showed that the unique form clearly could be perceived, but that nevertheless it was not treated differently than any other item in the stimulus field. Experiment 2 follows up on this finding, by changing the unique form into a non-unique form, 260 msec after stimulus field onset. Two hypotheses can be tested. If stimulus change has attention attraction properties and the target line segment is located in the form which is changed, time to detect the target will be independent of the number of non targets in the display. Alternatively, if the visual system is not sensitive to this change, search for the target line segment located in the form which is changed will be the same as search for the target line located in any other form.

3.1 Method

3.1.1 Task and Stimuli

The task was the same as the one used in Experiment 1 with the exception that the unique form changed to a non-unique form 260 msec after stimulus onset. Instruction to the subjects was the same as in Experiment 1.

3.1.2 Apparatus

The apparatus was the same as in Experiment 1.

3.1.3 Subjects

Sixteen paid subject who ranged from 18 to 25 years of age participated in the experiment. Eight subjects were randomly assigned to experimental and control conditions.

3.1.4 Experimental design and procedure

Design and procedure were similar to Experiment 1. There were two types of trials: those with the target line segment positioned in the unique form which is changed, and those with the target line segment positioned in any other form.

Since the conspicuity of the item is determined by a single temporal change, conspicuity could not be measured by the conspicuity device.

3.2 Results

Individual median correct response time were calculated for each factor combination. The mean results across subjects are shown in Fig. 3.

The same ANOVA as the one used in Experiment 1 was conducted on the median response times for correct responses. For the experimental condition large effects were found. For display size, $F(2,14) = 615$; for trial type, $F(1,7) = 112$; for the interaction display size $\times$ trial type, $F(2,14) = 64.9$; all p 's $< .0001$. Contrary to Experiment 1, these results indicate that search reaction time was affected by trial type. The interaction suggests that with increasing display size, this trial type effect becomes more pronounced.

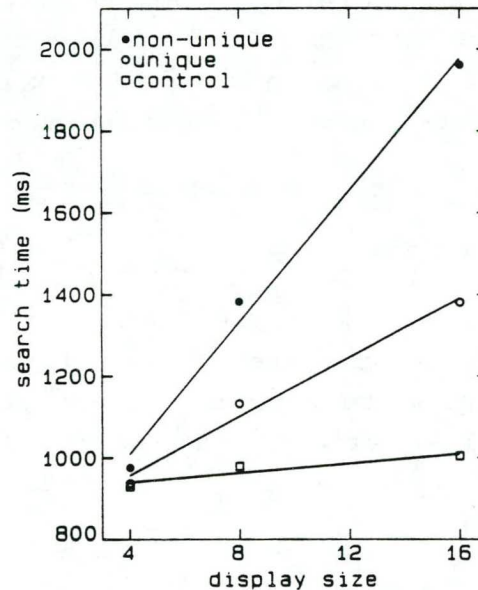


Fig. 3 Mean search time for non-unique, unique and control trials of Experiment 2 as a function of display size.

Fig. 3 shows that search time for the unique condition is much smaller than for the non-unique condition implying that the mean time needed to find the target line segment is reduced when this line segment is located in the element with form change.

For the control condition a significant main effect of display size was found $F(2,14) = 8.0$; $p < .01$. The comparison trial type unique of the experimental condition with the control condition showed an effect of unique versus control $F(1,14) = 25.1$; $p < .001$. Display

size interacted with this factor $F(2,28) = 44.2$; $p < .0001$. Again, the error rate was low and never exceeded 3%.

These results suggest that the search time function for the unique condition is equivalent to neither non-unique nor control search time function. This result is confirmed by the t-test on increments of response times. The slope of the non-unique function was estimated 86.9 msec per comparison which is significantly different from the slope of the unique search function which was 36.3 msec per comparison ($t(44) = 8.3$; $p < .001$). The slope for the control condition was 5.9 msec per comparison which is significantly different from the slope of the unique function ($t(44) = 6.1$; $p < .001$). These results imply that the stimulus change does neither induce a complete attention attraction nor a complete serial linear search.

Fitting the data to both the quantitative models of attention attraction and serial search provides a similar pattern of results. Table III shows that neither the self-terminating nor the attention attraction model can fit the data.

Table III Observed and predicted mean RT for Automatic Attraction (AA) and Serial Search (SS) model for Experiment 2.

trial type	display size	observed	predicted	
			SS	AA
item	4	938	974	1062
unique	8	1133	1210	1062
	16	1383	1682	1062
item	4	976	974	1254
non-unique	8	1336	1210	1446
	16	1961	1682	1830
percent variance accounted for			68	64

3.2.1 Search time distributions

Although it is possible to assume that the search function for unique items can be fit to a third, separate theoretical search model, it seems more likely to consider this search function as an aggregation

of both models of attention attraction and serial search. It is important to note that following the change from unique to non-unique form, nothing in the display reminds of this change. Therefore, after a failure to perceive the stimulus change a serial search of the entire display will follow.

In order to be able to test the hypothesis that the unique search function is an aggregation of the non-unique and control search function, the overall search distribution for these conditions were analyzed. Only display size 16 was analyzed because for this display size, an actual circular serial scan can be expected. In order to control for individual differences in the search time distribution, a baseline time was calculated for each subject and condition. This baseline time was the mean RT for correct responses for each individual at display size 4. Each correct RT of display 16 was divided by this baseline time. For the acquired search time index, the cumulative search distribution was computed for each of the three conditions. Fig. 4 shows the three distributions.

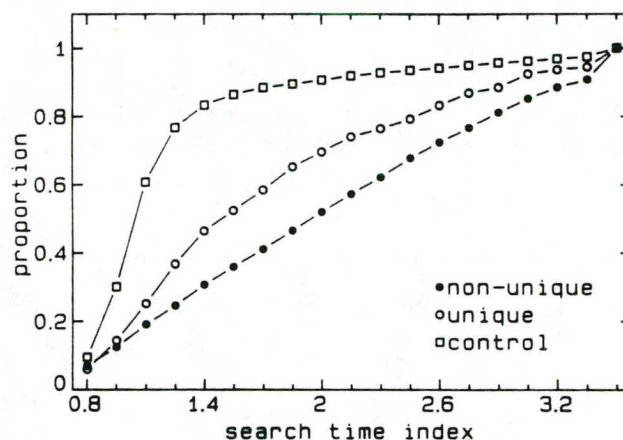


Fig. 4 Search time distribution for non-unique, unique and control trials of Experiment 2 for display size 16.

Fig. 4 reveals that the cumulative non-unique search distribution approximates a straight line implying a uniform distribution of search times. Such a result can be expected because the target line segment was randomly positioned in the stimulus field suggesting that the number of search time observations in each class interval should be more or less equal. For the control search distribution, almost 85% of all search time observations are in the first 5 class intervals implying that the target line segment is found in a single examination, immediately after stimulus presentation. Again, the

unique distribution is situated somewhere in between the two distributions.

In order to test the supposition that the unique search distribution is comprised of the non-unique and control distribution, the actual unique distribution was fitted by means of an aggregation of the observed non-unique and control distributions. Different weights were used in order to minimize Chi-square. The minimum Chi-square was found when the unique search distribution was predicted by 75% of the non-unique and 25% of the control condition distribution [χ^2 (18, $N = 250$) = 27.13, $.05 < p < .10$]. The finding that there is an almost non-significant difference between the predicted and observed unique distribution indicates that this distribution is fairly well fitted by an aggregation of the non-unique and control search distributions. Fig. 5 presents the observed and fitted cumulative search distribution.

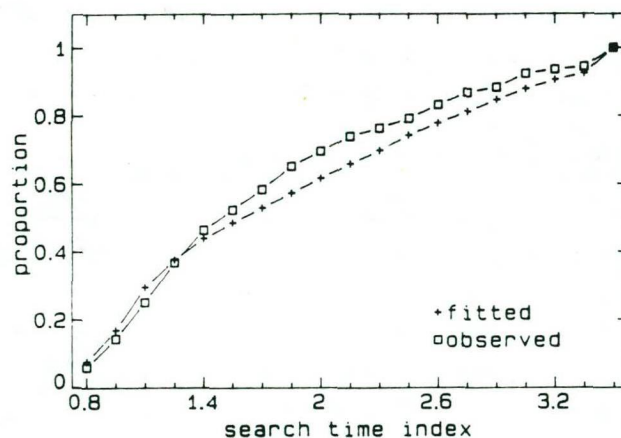


Fig. 5 Fitted and observed search time distribution for unique trials of Experiment 2 for display size 16. The fit is based on 75% of the non-unique distribution and 25% of the control distribution.

If it can be presumed that the non-unique function represents a fair estimate of serial search* and the control condition resembles attention attraction search, this analysis suggests that, at least for display size 16, in 25% of the trials attention was attracted to

* It is important to remark that the non-unique search distribution is not quite similar to a serial search because in cases when attention is drawn to the element having stimulus change attention is forced on an item in which the target line segment is not located. In these cases search starts not at a random position but always at a location where the target is not located.

the element having form change, and in 75% of the trials, search was serial.

3.3 Discussion

The data indicate that form change does cause a shift of attention to the position where the item having form change is located. This is in accordance with the acknowledgment of temporal variation as one of the object factors that constitute conspicuity (Hughes, 1983). Clearly, Experiment 2 shows that the form change is highly conspicuous and attracts attention. However, attention attraction does not always occur, and in that case, search proceeds in a serial way. A similar suggestion has been contended by Yantis and Jonides (1984) to account for the non-zero slope of the attention capturing function of abrupt stimulus onset. In their study, however, the failure to capture attention was estimated as about 10% of the trials. Our results suggests that stimulus change attracted attention in about 25% of the trials. There are several post-hoc explanations for the diminished attention attraction phenomenon. First, it is possible that subjects made an eye movement during the stimulus change. Because of saccadic suppression (Houtmans and Sanders, 1983) the change then could not have been perceived. In fact, subjects could deliberately make such eye movement or even close their eyes, in order to diminish the annoying effect of the change. Second, subjects could actively direct spatial attention to a location in the stimulus field, which would reduce attention attraction properties of elements at other places in the stimulus field (Eriksen and Hoffman, 1973; Humphreys, 1981). In all cases, it is assumed that the diminished effect is due to a reduced perception of the stimulus. Obviously, this is encouraged by the totally unconstrained search situation as used in both experiments. However, it should be realized that instructions to the subjects in both experiments were exactly the same. Therefore, the difference in search performance between Experiments 1 and 2 can only be attributed to the attention attraction properties of the item having form change.

4 GENERAL DISCUSSION

The two experiments reported here suggest that a unique item in form does not automatically draw attention to its location. When this

unique item changes during presentation into a non-unique item, attention is drawn to the source of change.

The results shed some new light on the theoretical issues outlined earlier. With respect to the concept of conspicuity, the present study shows that what is noticed is not automatically determined by the physical properties of the environment. Experiment 1 shows that an object which is conspicuous in the sense of the operational definition of Hughes and Cole (1980) only attracts attention when such attention attraction is relevant for the search task the subject is engaged in. Therefore, it is fair to claim that a conspicuous object does not necessarily attract attention. Experiment 1 shows that the conspicuous object is treated not different from any other object in the display. Though attention attraction is considered as the single most important property common to all definitions of conspicuity (e.g. Connors, 1975; Gerathewohl, 1954; Jenkins, 1979), Experiment 1 clearly shows that an object that is highly conspicuous does not necessarily draw attention to its location. Therefore, it is fair to conclude that the attention attraction property no longer holds, and can be overruled by task demands. Experiment 2 shows that some properties i.e., temporal change, still might have such attention attraction ability. Experiment 2 and several others (Jonides, 1981; Yantis and Jonides, 1984) suggest that these attention attraction properties are related to a specific class of stimulus characteristic referred to as fast temporal variation.

With respect to visual selection theories, the present study suggests that in early stages of processing, the pre-attentive system automatically extracts simple attributes like color, intensity and orientation, in parallel and across all elements (e.g. Neisser, 1967) The operation of this process is automatic, and therefore not under subject control. However, the automatic detection of the salient element does not automatically lead to a shift of spatial attention to the location of detection.

The present study shows that an element having temporal change does have this attention attraction property. Unintentionally, spatial attention is drawn to the location having stimulus change. It seems that properties of stimulus change are quite similar to abrupt stimulus onset as reported by Yantis and Jonides (1984) and Jonides and Yantis (1988).

To account for automatic early extraction of simple features, "hardwired" mechanisms are assumed that are particularly sensitive to certain attributes i.e. color, intensity, motion orientation, depth (Hoffman, 1986; Treisman, 1986). Although it is possible that early vision contains special channels tuned to certain features, the present study, together with others, (Jonides and Yantis, 1988)

suggest that channels sensitive for stimulus change are quite different from those channels sensitive for color, orientation and intensity. Activation of the former channels may lead to an automatic shift of spatial attention to the source of stimulation while, in the latter case, it does not.

One might argue that the attention attracting ability of an object is solely determined by the level of conspicuity, i.e., an object having a fast temporal change is more conspicuous than an object being unique in color, form, intensity etc. Because it is so conspicuous, there is no top-down control over the attention attraction mechanism. Whether or not an object attracts attention is determined by a quantitative difference in conspicuity. This would imply, for example, that one can make an object so bright or colorful that it always starts to attract attention. Although such an idea might be feasible, the present study together with the speculations about the "hardwired" mechanisms suggests that attention attraction is related to a qualitatively different mechanism. Some physical properties will never have attention demanding properties whereas others, as long as they are perceived, will cause a shift of spatial attention.

Obviously, this study does not exhaustively examine the role of salient features in visual search. However, it outlines a concept for the control of spatial attention when turning from pre-attentive to focal processing. It provides evidence that in a free visual search situation, an item having temporal form change automatically will be selected, independent of the goals set by the task. When a item is defined as highly salient by only form differences, selection is still under direct subject control. If the uniqueness is related to the target, subjects will actively allocate their attention to the location of the highly salient item. If there is no relation between the location of the target and unique item, the unique item receives a treatment which is not different from that of any other item.

5 CONCLUSIONS

This study provides some new insights with respect to visual sampling behavior when driving. From a road design perspective considerable research effort has been directed to ensure that drivers notice information relevant for the driving task. From this point of view, it has been argued that the main function of traffic control devices is to attract attention independent of the state of the driver. For example, Forbes (1939) defined the effectiveness of a traffic sign as the likelihood of whether a person's eye fixation would be attracted

to a particular sign. Odeschalchi (1960) argued that a sign should be made so conspicuous as to attract attention before the driver comes within reading distance of it. Conners (1975) stated that conspicuity was concerned with attracting attention to hazards when not actively searching for them. Gerathewohl (1953, 1957) considered conspicuity as "attention getting" effectiveness. Although aiming at these attention attraction properties has been prominent in traffic research, the present study suggests that this may be an inappropriate criterion for conspicuity. Objects can be highly conspicuous without the ability to force attention to the location of the object. If a conspicuous object is relevant for the task, attention can be actively directed to that location in a top-down way. Similar, if particular information is of immediate relevance to the driver, attention will be purposely directed to particular features in the road scene environment. The momentaneous need for information of the driver is considered to play a key role in this process of active directing of attention (see also Theeuwes, 1989a). Clearly, the driver is able to engage in a active filtering on the basis of knowledge of the nature of probable stimulus input. Obviously, it is not necessary that all traffic control devices attract the attention of the unalerted driver: some devices are relevant for only a small proportion of the road users engaged in a specific driving action e.g. a turning right prohibition is only relevant for drivers anticipating a right turn. However, other signals should always be noticed independent of the state of the driver, e.g. regulatory signs, traffic lights, stop signs, railroad crossings, etc. This study suggests that for these signals one should use signs having temporal variation or movement. The visual system having special feature detectors for movement and temporal variation (Hubel and Wiesel, 1959) will attract attention to its location (Yantis and Jonides, 1984).

The above differentiation refers to a similar conceptual distinction between attention and search conspicuity as recognized by Cole and Jenkins (1984). Although their studies have some methodological problems (see Theeuwes, 1989a), they also differentiate between signs being able to attract attention and signs which are noticed only when subjects actively search for them. A fundamental objection against their studies is that the difference between attention and search conspicuity might represent a response bias rather than a difference in conspicuity.

Future studies will focus on the operation of the active filtering. The present study suggests that subjects can direct their attention according to the task demands. The question whether pre-attentive processing can be tuned to the momentary task demands, especially when these are constantly changing, is still unresolved. For the

driving task situation, this question converges to whether subjects are able to search for red objects at one moment while searching for squared objects at another moment without any crosstalk or interference.

REFERENCES

- Bashinski, H.S. and V.R. Bacharach (1980). Enhancement of perceptual sensitivity as the result of selectivity of attending to spatial locations. *Perception and Psychophysics* 28, 241-280.
- Broadbent, D.E. (1982). Task combination and selective intake of information. *Acta Psychologica* 50, 253-290.
- Cole, B.L. and S.E. Jenkins (1982). Conspicuity of traffic control devices. *Australian Road Research* 12, 223-238.
- Cole, B.L. and S.E. Jenkins (1980). The nature and measurement of conspicuity. *Proceedings of the 10th Conference of the Australian Road Research Board* 10, 99-107.
- Connors, M.M. (1975). Conspicuity of target lights: The influence of color. *NASA Technical Note NASA TN-D7960*.
- Engel, F.L. (1971). Visual conspicuity, directed attention and retinal locus. *Vision Research* 11, 563-576.
- Engel, F.L. (1977). Visual conspicuity, visual search and fixation tendencies of the eye. *Vision Research* 17, 95-108.
- Eriksen, C.W. and J.E. Hoffman (1973). The extent of processing noise element during selective coding from visual displays. *Perception and Psychophysics* 11, 169-171.
- Eriksen, C.W., and Y. Yeh (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance* 11, 583-597.
- Forbes, T.W. (1939). A method for analysis of the effectiveness of highway signs. *Journal of Applied Psychology* 23, 699-707.
- Gerathewohl, S.J. (1953). Conspicuity of flashing light signals: variation of contrast. *Journal of the Optical Society of America* 43, 567-572.
- Gerathewohl, S.J. (1954). Conspicuity of flashing light signals of different frequency and duration. *Journal of Experimental Psychology* 48, 247-254.
- Gerathewohl, S.J. (1957). Conspicuity of flashing light signals: Effect of variation among frequency, duration and contrast. *Journal of the Optical Society of America* 67, 202-210.
- Hills, B.L. (1980). Vision, visibility and perception in driving. *Perception* 9, 183-216.
- Hoffman, J.E. (1986). Spatial attention in vision: Evidence for early selection. *Psychological Research*, 48, 221-229.
- Houtmans, M.J.M. and A.F. Sanders (1983). Is information acquisition during large saccades possible? *Bulletin of the Psychonomic Society* 21, 127-130.
- Hubel, D.H. and T.N. Wiesel (1959). Receptive field of single neurons in the cat's striate cortex. *Journal of Physiology* 148, 574-591.
- Hughes, P.K. and B.L. Cole (1984). Search and attention conspicuity of road traffic control devices. *Australian Road Research* 14, 1-9.
- Humphreys, G.W. (1981). Flexibility of attention between stimulus dimensions. *Perception and Psychophysics* 30, 291-302.
- Jenkins, S.E. (1979). An investigation into the nature and physical determinants of visual conspicuity. Melbourne: University Press (PhD thesis).

- Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye's movement. In J.B. Long and A.D. Baddeley (eds.), *Attention and Performance IX*. Hillsdale, NJ: Erlbaum.
- Jonides, J. and S. Yantis (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception and Psychophysics* 43, 346-354.
- Neisser, U. (1967). *Cognitive Psychology*. New York: Appleton-Century-Crofts.
- Odeschalchi, P. (1960). Conspicuity of signs in rural surroundings. *Traffic Engineering and Control* 2, 390-402.
- Posner, M.I. (1978). *Chronometric explorations of mind*. Hillsdale, NJ: Erlbaum.
- Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology* 32, 3-25.
- Posner M.I., M.J. Nissen and W.C. Ogden (1978). Attended and attended processing models: The role of set for spatial location. In H.L. Pick and E. Saltzman (eds.), *Modes of perceiving and Processing information*. Hillsdale, NJ: Erlbaum.
- Posner M.I., C.R.R. Snyder and B.J. Davidson (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General* 109, 160-174.
- Rockwell, T.H. (1972). Eye-movement analysis of visual aquisition in driving: An overview. *Proceedings of the 6th Conference of the Austrian Road Research Board* 6, 316-331.
- Shinar, D. (1978). *Psychology on the road*. New York: John Wiley and Sons, Inc.
- Sternberg, S. (1966). Figh speed scanning in human memory. *Science* 153, 652-654.
- Theeuwes, J. (1989a). Visual selection: Endogenous and Exogenous control, a review of the literature. Report IZF 1989 C-3. Soesterberg: TNO Institute for Perception.
- Theeuwes, J. (1989b). Effects of location and form cuing on the allocation of attention in the visual field. *Acta Psychologica* (in press).
- Treats, J.R., V.S. Tumbas, S.T. McDonald, D. Shinar, R.D. Hume, R.E. Mayer, R.L. Stansifer, and N.J. Castellan (1977). Tri-level study of causes of traffic accidents. Report Nr. DOT-HS-034-3-535-77 (TAC). Indiana University.
- Treisman, A.M. (1986). Properties, parts, and objects. In Boff, K.R., L. Kaufman and P. Thomas, *Handbook of pepception and human performance vol II: Cognitive process and Performance*. New York: John Wiley and Sons.
- Treisman, A.M. and G. Gelade (1980). A feature integration theory of attention. *Cognitive Psychology* 12, 97-136.
- Wertheim, A.H. (1989). Report IZF in press.
- Williams, L.G. (1966). Target conspicuity and visual search. *Human Factors* 8, 80-92.
- Yantis, S. and J. Jonides (1984). Abrupt visual onset and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance* 10, 601-621.



