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On the status of location in visual attention

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The authors propose a distinction between four issues underlying the debate on the status of location in visual selective attention. Three of them concern the representation within which attention operates. The *grouping* question focuses on whether or not this representation segments the visual field into perceptual groups. The *space-invariance* question focuses on whether it describes objects in spatio-topic or in space-invariant coordinates. Finally, the *feature-coding* question concerns whether or not it contains information about objects' non-spatial features. The last issue focuses on whether or not attention can be guided preattentively towards items possessing certain pre-specified physical properties other than location, and is referred to as the *attentional-guidance* question. A critical survey of the literature within the proposed framework is presented. Based on its conclusions, the status of location in current research is outlined, and avenues for further research are suggested.

Our visual system is limited in the amount of information it can deal with simultaneously. Thus, it is widely agreed that the perceptual analysis of the visual world takes place in two successive stages (e.g., Julesz, 1986; Kahneman, 1973; Neisser, 1967; Tsal, Meiran, & Lamy, 1995): a stage of preliminary analysis (pre-attentive stage) that is parallel and operates without capacity limitations; and a stage of more detailed analysis (focal attention) that is serial and operates only on selected parts of the visual field.

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The idea that attention operates as a spotlight (e.g., Broadbent, 1982; Eriksen & Hoffman, 1973; Posner, Snyder, & Davidson, 1980) has had a major influence on attention research. According to this model, attention can be directed only to a small continuous region of the visual field. Stimuli that fall within that region are extensively processed, whereas stimuli located outside that region are ignored. Thus, the spotlight model—as well as models based on similar metaphors, such as zoom lenses (e.g., Eriksen & St. James, 1986; Eriksen & Yeh, 1985) and gradients (e.g., Downing & Pinker, 1985; LaBerge & Brown, 1989)—endows a location (or space) with a central role in the selection process. Later theories making assumptions that depart markedly from spotlight theories also assume an important role for location in visual attention (see Schneider, 1993, for a review). These include for instance the Feature Integration Theory (FIT: Treisman & Gormican, 1988; Treisman & Sato, 1990), the Guided Search model (GS: Cave & Wolfe, 1990; Wolfe, 1994), van der Heijden's (1992, 1993) model, and the FeatureGate model recently proposed by Cave (1999; Cave, Kim, Bichot, & Sobel, 1999; Cepeda, Cave, Bichot, & Kim, 1998).

In the last two decades of the 20th century, the notion that space deserves a special status in the study of attention was repeatedly questioned. It has been challenged by two main lines of findings. Some authors contrasted space with objects, and showed that attention selects objects rather than unparsed areas of the visual field (see Driver & Baylis, 1998 and Kanwisher & Driver, 1992, for reviews). Other investigators compared location to other perceptual features, such as colour or shape, and showed that attention can be directed to properties other than location (e.g., Lambert & Hockey, 1986). However, a substantial amount of evidence in support of the idea that space is indeed special has also accumulated in recent years, within each line of investigation. Comparing space and objects, some authors showed that attending to an object entails attending to the location it occupies (e.g., Kim & Cave, 1996; Tsal & Lavie, 1988, 1993). Comparing location and other features, other investigators showed that attention cannot be directed to physical features other than location (e.g., Theeuwes, 1989). Thus, whether or not location plays a special role in selective attention remains a controversial issue.

The existing literature offers a rather confusing picture, as various aspects of the role of location have been investigated, using a very large array of rationales and tasks. The main objective of this paper is to clarify the current state of the research on the status of location in selective attention. In the first part, we distinguish between separate issues concerning how space and attention relate to each other. The second part is a selective literature review, in which the different experimental rationales used to investigate each issue are discussed, and the related findings critically surveyed. In the last part, the conclusions of the review are summarised, and directions for further research are proposed.

Current models of visual attention usually address one or several aspects of the debate on the role of location in attention, more or less explicitly (e.g., Bundesen, 1990; Cave, 1999; Cave & Bichot, 1999; Cave & Wolfe, 1990; Duncan & Humphreys, 1989, 1992; Koch & Ullman, 1985; Logan, 1996; Schneider, 1993; Treisman & Sato, 1990; Tsal et al., 1995; van der Heijden, 1993; Wolfe, 1994). As the primary goal of this paper is to provide a coherent picture of the current status of the research pertaining to this debate, we shall focus only on the empirical data that are relevant to it. Accordingly, how these models may be positioned on each issue and how they perform in accounting for the reviewed data will not be discussed.

THE PRE-ATTENTIVE STAGE

When studying selective attention, much can be learned by investigating what happens at the pre-attentive stage, i.e., before selection takes place. Two issues in particular have elicited research and are relevant to the debate on the status of location in attention. One concerns the level to which the visual field is processed pre-attentively. The second focuses on what mechanisms of attentional priority operate at the pre-attentive stage.

Pre-attentive processing of the visual field

How much visual processing is performed pre-attentively? This question has been extensively discussed within the controversy between early selection (e.g., Broadbent, 1958) and late-selection theorists (e.g., Deutsch & Deutsch, 1963). The early selection approach claims that selective attention is required for complete perceptual processing, whereas the late-selection approach assumes that selection occurs after the entire visual field has been fully perceived. Thus, late-selectionists posit that attention selects fully analysed objects. In contrast, early selectionists propose that attention operates on a more sketchy description of the visual field. Within this general framework, the dispute between the space-based and object-based models of visual attention focuses on whether attention operates within an early, spatial representation of the visual field (e.g., Posner, 1980), or whether it operates at a later stage and selects objects (e.g., Duncan, 1984). However, the dichotomy between space-based and object-based accounts of selection does not fully capture the variety of representations that may be accessed by attention.

On the one hand, attention may select areas of space with a fixed shape, independently of what objects they contain. Spotlight, zoom lens, and gradient models all posit that attention operates on such a purely spatial representation, although they differ on how flexible the size of the selected area might be.

On the other hand, attention may select objects, yet the notion of object may refer to different types of representations. Indeed, one finds that different representations are labelled as "object-based" in the literature, based on different criteria.

A grouped array of locations (e.g., Vecera, 1994) designates the locations occupied by an object. In this sense, an object-based representation describes the visual field after it has been segmented into perceptual groups according to Gestalt principles of perceptual organisation, whereas a space-based representation is unparsed. Thus, within this definition of an object, the question that distinguishes space-based from object-based accounts of attention is whether or not the segmentation of the field into perceptual groups requires attention or, to put it differently, whether all Gestalt principles or only proximity constrain the distribution of attentional resources. We shall refer to it as the "grouping question".

An object may also designate an entity which is represented independently of the location it occupies (e.g., Marr's 3D model, 1982; Vecera & Farah, 1994). In this sense, an object-based representation is one that remains unchanged whatever the object's location within the visual space. In contrast, a space-based representation represents an object differently at each different location occupied by this object. Thus, within this definition of an object, the question that distinguishes space-based from object-based accounts of attention is whether attention selects from a spatiotopic or from a space-invariant representation. We shall refer to it as the "space-invariance" question.

Because object-files (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992) are often contrasted with space-based representations (e.g., Kanwisher & Driver, 1992; Tipper, Weaver, Jerreat, & Burak, 1994), they are usually regarded as space-invariant representations. The notion of object-life refers to a temporary representation that gathers information about the object it represents and maintains that object's identity and continuity in spite of constant changes in its attributes, namely changes of location as the object moves. Note, however, that spatial constraints do play an important role in maintaining an object-file's continuity. Indeed, an object occupying different locations at different times is perceived as the same object (or object-file) only if the *spatio*-temporal characteristics of the object's states are compatible with physically plausible movement.

Finally, the notion of object may designate a combination of features at a certain location (e.g., Treisman & Schmidt, 1982). In this sense, an object-based representation is one that codes the features associated with an object in the visual field. In contrast, a space-based representation describes the visual field as featureless pieces of space. Thus, within this definition of an object, the question that distinguishes space-based from object-based accounts of attention is whether attention selects from representations that describe objects with or without their non-spatial features. We shall refer to it as the "feature-coding question".

As these distinctions suggest, simply asking whether attention selects locations or objects may be misleading, because *selection may occur within representations that are space-based in one aspect, but object-based in another*. For instance, if attention activates grouped arrays of locations, i.e., the locations occupied by objects, then selection is object-based because the selected units are locations grouped into the same perceptual whole (grouping). However, selection is also space-based because the selected locations are described in environmental rather than in object-centred coordinates (space-invariance) and the selected representation does not convey information about other properties of the object that occupies these locations, for instance, information about its colour (feature-coding). In order to characterise the representational substrate of selection, it is therefore important to clearly define which of its aspects is under investigation: grouping, space-invariance, or feature-coding. In the review that follows, the evidence pertaining to each of these three aspects will be presented separately.

Mechanisms of attentional priority operating at the pre-attentive stage

A second aspect of the pre-attentive stage that has attracted much interest concerns the factors that determine which parts of the visual field receive high attentional priority. It has been traditionally assumed that two sources of control guide attention at the pre-attentive stage (e.g., Cave & Wolfe, 1990). Stimulus-driven or bottom-up control refers to the capacity of certain stimulus properties to attract attention irrespective of task-demands (Theeuwes, 1991a, 1992). The idea that such purely stimulus-driven attentional capture exists has been increasingly challenged (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Lamy & Tsal, 1999b; Yantis & Egeth, 1999). Goal-directed or top-down control of attention refers to the ability of the observer's goals or intentions to determine which areas, attributes, or objects are selected for further visual processing. Numerous studies have demonstrated that when subjects know in advance in which location a certain object will appear, this object is responded to more efficiently. This indicates that advance knowledge of location can guide selection (e.g., Posner et al., 1980). In contrast, whether properties such as colour or orientation can guide attention pre-attentively remains controversial. In what follows, we shall refer to the question of whether advance knowledge of say, the target's colour, can help the items of the designated colour pass from the parallel to the capacity-limited stage of analysis[1] as the "attentional guidance question".

Contrasting location and other features by asking whether it is possible to attend to a specific colour, for example, or only to a specific location carries the potential for confusion. It may refer to *what* in the selected item is activated, its colour, or only its location (feature-coding). Alternatively, it may refer to *how* items are selected for further processing, i.e., on the basis of which properties, colour or only location, potential targets possessing the target property may be segregated from non-targets at the pre-attentive stage (attentional guidance). These are different issues. For instance, it is possible that one may guide attention pre-attentively towards items of the display possessing a specific colour, so they will be processed in priority (attentional guidance), but that the locations of these items rather than their colour be selected by attention (feature-coding). Several models implement this idea. For instance, FIT (Treisman & Gormican, 1988; Treisman & Sato, 1990) assumes that selection takes place on a master map of locations, which represents "*where* things are, but not *what* they are" (p. 17). Thus, the selection medium does not represent objects' colours (feature-coding). However, top-down knowledge of the target colour can guide attention towards the locations possessing the target colour (attentional guidance). The same idea is explicit in Guided Search (Cave & Wolfe, 1990; Wolfe, 1994).

With this distinction in mind, note that the use of the term "activation" in the literature is somewhat misleading. On the one hand, an item that is assigned a high level of processing priority at the pre-attentive stage (because it belongs to the target set) is said to be highly *activated* (e.g., Cave & Wolfe, 1990). On the other hand, after an item has been selected, i.e., attended to and processed, it is also said to be *activated* by attention (e.g., Vecera & Farah, 1994). In this article, in order to clearly distinguish between the two types of activation, we shall say that pre-attentive guidance of attention *tags* relevant items, thereby increasing their chances to be selected, and that attention *activates* the selected locations, features, or objects.

To summarise, we propose that the research on the role of space in

[1]Other types of top-down guidance have been investigated, for instance advance knowledge of higher-order categorical target properties (e.g., Francolini & Egeth, 1979), or advance knowledge that the target is a discrepant item within a pre-specified dimension (e.g., Treisman, 1988). Here, we shall discuss the ability only of physical stimulus properties such as colour, orientation, or shape, to guide attention.

attention addressed at least four distinct issues. On the one hand, it attempted to characterise the representation within which attention operates. Three different aspects of that representation have been studied: (1) whether or not it segments the visual field into perceptual groups (*grouping*); (2) whether it describes objects in spatio-topic or in space-invariant coordinates (*space-invariance*); and (3) whether or not it contains information about objects' non-spatial features (*features-coding*). On the other hand, research on the role of space in attention investigates how the observer's intentions may bias selection, namely whether attention can be guided pre-attentively towards objects possessing (or locations containing) certain pre-specified physical properties other than location (*attentional guidance*).

GROUPING

The grouping question is at the heart of the dispute between space-based and object-based models of visual attention. According to the space-based view, attention selects unparsed regions of the visual field (e.g., Posner, 1980). In contrast, the object-based view suggests that attention selects perceptual groups that result from the pre-attentive segmentation of the visual field via Gestalt grouping principles (e.g., Duncan, 1984). It follows that whereas space-based models predict that only proximity may constrain the distribution of attention, object-based models argue that other grouping principles play the same role. In this section, the terms "object" and "perceptual group" will be used interchangeably for simplicity purposes.

Constraints on the distribution of attention

One rationale used to address the grouping question is to examine whether dividing attention between two parts of the visual field is easier only when these parts are close to each other rather than far apart, or also when they belong to the same rather than to different perceptual groups. In a seminal study, Duncan (1984) presented his subjects with displays containing an outline box with a line struck through it. The box was either short or tall, and had a gap on either its left or right side. The line was dashed or dotted and was slanted either to the right or to the left. Subjects were found to judge two properties of the same object as readily as one property. However, there was a decrement in performance when they had to judge two properties belonging to two different objects. These results showed a difficulty to divide attention between objects, which could not be accounted for by spatial factors, as the objects were superimposed in the same spatial region (for related results, see also Baylis & Driver, 1993; Behrmann, Zemel, & Mozer, 1998; Lavie & Driver, 1996, Exps. 1–3; Treisman, Kahneman, & Burkell, 1983; Vecera & Farah, 1994; Watson & Kramer, 1999).

Another widely used experimental strategy is to study what irrelevant parts of the visual field mandatorily receive attention together with the to-be-selected, relevant part of the field: only parts that are adjacent to the attended item, or also parts that are grouped with it by any Gestalt principle, proximity playing no special role. Typically, the studies within this category used the Eriksen response competition paradigm (Eriksen & Hoffman, 1973), where the presence of distractors flanking the target and associated with the wrong response is shown to slow choice reaction to the target. They demonstrated that distractors grouped with the target (by common colour or contour, for instance), slow response more than do distractors that are not grouped with it, even when target-distractor distance is the same in the two conditions (e.g., Baylis & Driver, 1992; Driver & Baylis, 1989; Kramer & Jacobson, 1991; see also Harms & Bundesen, 1983). Banks and Prinzmetal (1976) used a visual search task and showed that a target is detected less well if it is arranged in a perceptual Gestalt with distracting elements.

Other studies provided even stronger support for the idea that proximity plays no special role by showing that it may be overridden by other Gestalt principles of grouping. Although this finding seems robust when the grouped elements occupy contiguous regions of space (e.g., Lamy, in press; Lavie & Driver, 1996), it remains controversial when they are separated by intervening elements (Baylis & Driver, 1992; Berry & Klein, 1993; Driver & Baylis, 1989; Kramer, Tham, & Yeh, 1991). Driver and Baylis (1989) used a variant of the response-competition paradigm. Subjects had to report the shape of the central letter in a five-letter display. Distant non-contiguous distractors were grouped with the target by common movement, whereas close contiguous distractors were not. Far distractors produced more interference than did near distractors. However, two failures to replicate these results were published (Berry & Klein, 1993; Kramer et al., 1991). In addition, Berry and Klein (1993) introduced a baseline condition and showed that the non-contiguous distractors produced the same amount of interference whether or not they were grouped with the target, suggesting that grouping over non-contiguous regions of the field does not affect performance.

Note that if, as the latter results may imply, grouping effects can be found only when the relevant object parts are contiguous to each other, then space does play a special role in the distribution of attention. To our knowledge, except for the unreplicated experiments by Driver and Baylis, no study to date has provided evidence that precludes this possibility. A number of investigators reported grouping effects between object parts separated by an intervening surface (e.g., Behrmann et al., 1998). However, none of these studies tested whether or not the intervening surface was also attended.

Redirecting attention within the same vs. to a different perceptual group

A second strategy used to assess whether attention selects unparsed regions of the visual field or perceptual groups is to investigate whether or not, after selecting a part of the visual field at a certain time t1, redirecting attention towards a different part at a later time t2 is easier only when the two parts are close to each other or also when they belong to the same object. The implicit assumption is that when the interval of time between t1 and t2 is short, the representation on which selection has taken place at t1 remains active and mediates selection at t2. Thus, finding that redirecting attention within the same perceptual group at t2 is easier, indicates that all the parts of the field grouped with the to-be-selected part were also attended at t1, and it is thus concluded that attention selects perceptual groups rather than unparsed locations.

Egly, Driver, and Rafal (1994) had their subjects detect a luminance change in one of the four corners of two outline rectangles. One corner was pre-cued. On valid-cue trials, the target appeared in the cued corner of the cued rectangle, whereas on invalid-cue trials, it appeared either in the uncued corner of the cued rectangle, or in the uncued rectangle. The distance between the cued location and the location where the target appeared was identical in both invalid-cue conditions. On invalid-cue trials, targets were detected faster when they belonged to the same object as the cue, rather than to the other object. Several replications were reported, with detection (e.g., Abrams & Law, 2000; Lamy & Tsal, 2000; Vecera, 1994) as well as identification tasks (e.g., Moore, Yantis, & Vaughan, 1998).

Grouping outside the focus of attention

The third strategy used to determine whether or not grouping requires attention is to study whether or not subjects perceive grouping in unattended parts of the visual field. By definition, whereas the attended part is actively processed and described in increasingly elaborate representations, unattended parts of the field remain at the pre-attentive processing level. Thus, by assessing the way the unattended visual field is represented, one may infer what processes of visual analysis are pre-attentive.

A number of experiments showed that grouping outside the focus of attention is not perceived (e.g., Ben-Av, Sagi, & Braun, 1992; Mack, Tang, Tuma, & Kahn, 1992; Rock, Linnett, Grant, & Mack, 1992), suggesting that attention selects unparsed areas of the visual field and that grouping requires attention. Ben-Av et al. (1992) showed that subjects' performance in discriminating between horizontal and vertical grouping, or in simply detecting the presence or absence of grouping in the display background, was severely impaired when attention was engaged in a concurrent task of form identification of a target situated in the centre of the screen. Mack et al. (1992) obtained similar results with grouping by proximity and similarity of lightness.

However, the dependent measure in these studies was subjects' conscious report of grouping. The fact that grouping cannot be overtly perceived when attention is engaged in a demanding concurrent task does not necessarily imply that grouping requires attention. Two arguments questioning the suitability of using dual-tasks to investigate pre-attentive processing can be found in the literature.

First, Joseph, Chun, and Nakayama (1997) found a simple feature search task—which is traditionally taken to require no attentional resources—to be impaired by the addition of a primary task with high attentional demands. They concluded that there may be "no direct route from preattentive processing to perceptual report" (p. 807), i.e., that any task requiring an overt response may have to pass through an attentional bottleneck. Based on this rationale, the results by Ben-Av et al. (1992) and Mack et al. (1992) may suggest only that overt report of grouping requires attention, and do not preclude the possibility that grouping processes take place pre-attentively. However, the validity of this argument remains an open question because Braun (1998) failed to replicate Joseph et al.'s (1997) results when subjects were experienced with similar tasks rather than naïve.

Second, Moore and Egeth (1997) argued that these results were open to memory confounds. That is, grouping processes may occur pre-attentively, grouping being perceived, yet not remembered. Moore and Egeth conducted a study with displays consisting of a matrix of uniformly scattered white dots on a grey background, in the centre of which were two black horizontal lines. Some of the dots were black and on some of the trials, they were grouped and formed either the Ponzo illusion (Exps. 1 and 2) or the Mueller-Lyer illusion (Exp. 3). Subjects attended to the two horizontal lines, and reported which one was longer. Responses were clearly influenced by the two illusions. Therefore, the fact that elements lying entirely outside the focus of attention formed a group did affect behaviour, indicating that grouping does not require attention. In a subsequent recognition test, subjects were unable to recognise the illusion patterns. This result confirmed the authors' hypothesis that implicit measures may reveal that subjects perceive grouping, whereas explicit measures may not.

Lavie and Driver (1996) used displays that consisted of two dashed lines containing two odd elements, the targets. Subjects judged whether the targets were the same or different. The authors found better performance when the targets appeared in the same rather than in different objects (Exps. 1–3). However, when a pre-cue focused attention on one side of the display (left or right), no advantage was found in the same-object condition (Exp. 4). That is, the grouping effect found under conditions of distributed attention (Exps. 1–3), disappeared when attention was focused on a small area of the field (Exp. 4). The authors concluded that "object-based selection may only operate within a spatially attended region" (p. 1250), and suggested that grouping outside the focus of attention does not affect performance. However, Lamy (in press) failed to replicate this result in three experiments.

To summarise, studies that showed no grouping outside the focus of attention used explicit measures of grouping, thus being open to memory confounds (e.g., Ben-Av et al., 1992; Mack et al., 1992; Rock et al., 1992). Using an implicit measure of grouping, Moore and Egeth (1997) did find grouping outside the focus of attention to affect performance.

Conclusion on the grouping question

In this part, we reviewed the evidence concerning whether attention selects unparsed areas of the visual field or perceptual groups. We distinguished between three different rationales used in the literature in order to address this question. This review yielded a contrasted picture. On the one hand, studies investigating what parts of the field tend to be attended to together, as well as studies testing whether or not it is easier to redirect attention within the same object rather than to a different object, offered strong support in favour of the object-based view. On the other hand, except for Moore and Egeth (1997), the few experiments investigating what is perceived outside the focus of attention suggested that grouping requires attention.

Note that in studies typically taken to suggest that grouping is pre-attentive, at least part of the relevant object (i.e., the object for which object-based effects were measured) was always attended (e.g., Baylis & Driver, 1992; Duncan, 1984; Egly et al., 1994). In contrast, in studies supporting the view that grouping requires attention, the whole object lay outside the focus of attention (e.g., Ben-Av et al., 1992; Mack et al., 1992). This difference may account for the apparent discrepancy between the two lines of findings. Finding grouping effects when part of the relevant object is attended does not necessarily entail that grouping is pre-attentive. An alternative account is that attention *causes* grouping. Specifically, attending to part of an object may cause attentional resources to be mandatorily allocated to the other parts of that object. In contrast, measuring grouping effects outside the focus of attention does allow investigating whether or not grouping requires attention.

To illustrate this point, it may be useful to draw a parallel with the question of whether or not binding features into an object requires attention (e.g., Treisman & Schmidt, 1982). Finding that illusory conjunctions occur outside the focus of attention does indicate that without attention, no binding occurs. In contrast, finding that focusing attention on one object's feature entails that its other features are also attended to does not demonstrate that binding is pre-attentive, but rather may indicate that it is the focusing of attention on an object that causes its different features to become bound together.

This analysis raises the possibility that the critical condition for finding object-based effects may be that part of the relevant object be attended to. On the one hand, this hypothesis entails that when attention is focused on part of an object, attentional resources accrue to the other parts of that object (whether these are necessarily contiguous to the attended part should be determined by further research). That is, it implies that grouping of any type affects the distribution of attention—in keeping with the object-based view, and in contrast with the space-based view. On the other hand, it also entails that if an object lies entirely outside the focus of attention, then the fact that its parts are grouped into a perceptual object does not affect performance—in keeping with the space-based view and in contrast with the object-based view. This idea is compatible with all the findings surveyed in the previous sections. Note that it can also accommodate the results obtained by Moore and Egeth (1997). In their study, both the target lines and the dots forming the illusions were black on a background of white dots, thus forming a fairly strong group on the basis of their common colour. According to the proposed hypothesis, it follows that attending to the black lines may have caused attention to propagate automatically to the illusion dots, explaining why the group they formed affected behaviour. In other words, grouping between the attended lines and the black dots, rather than grouping between the dots, may have caused the illusion to affect length judgement.

SPACE-INVARIANCE

The space-invariance question focuses on whether attention operates on a spatio-topic representation of visual objects, or whether it selects from an internal object-based representation in which the location occupied by the object plays no role. In the literature, these possibilities were usually examined separately, suggesting that selection is generally assumed to be either space-based or space-invariant but not both.

On the one hand, studies investigating whether selection is space-based manipulated only spatial factors and reasoned that if spatial effects can be found, then selection is mediated by space, and does not therefore operate on space-invariant representations. They typically used the distance manipulation and post-display probe technique described below. Some used experimental procedures that were neutral on the grouping question (e.g., Cave & Pashler, 1995; Tipper, Driver, & Weaver, 1991; Tsal & Lavie, 1993), while others specifically investigated whether the groups selected by attention are grouped-arrays of locations or spatially invariant representations (e.g., Kramer & Jacobson, 1991; Vecera, 1994; Vecera & Farah, 1994; but see Kramer, Weber, & Watson, 1997; Vecera, 1997). However, these studies all focused on whether selection is mediated by space, and will thus be surveyed together.

On the other hand, studies investigating whether selection operates on space-invariant representations usually kept spatial factors constant and compared same vs. different object conditions. They typically used moving displays.

Manipulating distance

Early studies have attempted to show that attention is directed to space by showing effects of distance on attention. The rationale was that if switching attention from one object to the other is more difficult when they are far apart than when they are close together, then these objects are not represented in a space-invariant way, attention operating within a space-based representation. These studies showed that interference effects were reduced as the distance between target and distractors increased (e.g., Eriksen & Hoffman, 1972; Gatti & Egeth, 1978), and that attending to two stimuli was easier when they were close together rather than distant from each other (e.g., Hoffman & Nelson, 1981; Skelton & Eriksen, 1976).

More recent studies showed that distance modulates same vs. different object effects. For instance, Kramer and Jacobson (1991) used the Eriksen response competition paradigm and found that the interference caused by incompatible distractors grouped with the target diminished as the distance between target and distractor increased (see also Vecera, 1994). In contrast, Vecera and Farah (1994) found no effect of distance on the distribution of attention. They used Duncan's (1984) paradigm and showed that the cost of reporting two attributes belonging to two different objects was independent of those objects' relative locations, i.e., of whether they occupied the same (together) or distant (separated) locations (Exps. 1–2). However, this finding was not replicated when stimulus eccentricities were equated in the two conditions (Kramer et al., 1997). Taken together, the results obtained using the distance manipulation support the idea that selection is space-based.

The post-display probe technique

Another method used to address the space-invariant question is to have subjects attend to an object occupying a certain location at a certain time t1 and then redirect their attention towards a different object occupying either the same or a different location at a later time t2. With this procedure, sometimes referred to as the "post-display probe technique" (e.g., Kramer et al., 1997), an advantage in the same-location condition is taken to support the idea that selection is space-based.

In the classical spatial priming paradigm, subjects are cued to attend to a certain location in the visual field. Subjects must respond to a stimulus that appears at the cued or at the uncued location. Response is faster and more accurate if the target occurs at the cued location (e.g., Posner et al., 1980). Within the framework of the spotlight model, such effects are held to show that attention is directed to space. In the target display, attention still dwells on the cued location, thus explaining the benefit at this location. However, this interpretation may not be founded when the cue is informative, because better performance may result from top-down factors. That is, subjects may attend to the cued location because they know it is the relevant location, irrespective of what the medium of representation is.

Space-based effects were also obtained when the location of the item initially attended to was not predictive of the target location. Jonides (1981) used non-informative peripheral abrupt onsets and found better performance at the location initially occupied by the abrupt onset item. Tsal and Lavie (1993, Exp. 4) showed that when subjects had to attend to the colour of a dot (its location being task-irrelevant), they responded faster to a subsequent probe when it appeared in the location previously occupied by the attended dot than when it appeared in the alternative location (see Cave & Pashler, 1995; Cave & Zimmerman, 1997; Kim & Cave, 1995, 1996, for similar results).

Following a related rationale, other authors used rapid serial visual presentation (RSVP) tasks (e.g., Broadbent & Broadbent, 1987; Keele, Cohen, Ivry, Liotti, & Yee, 1988; McLean, Broadbent, & Broadbent, 1983) or partial report tasks (e.g., Butler, Mewhort, & Tramer, 1987; Fryklund, 1975; Snyder, 1972) and showed that when subjects have to report an item with a specific colour, near-location errors are the most frequent. These results suggest that selecting an object by any of its properties is mediated by a spatial representation.

Moving displays

The experiments surveyed in the previous section investigated only whether or not attending to an object entails that its location is activated, i.e., whether or not selection is mediated by space. Object-based selection could not be diagnosed since attention was typically redirected to a representation that described a different object. "Space mediation" is thus a more adequate term than "space-invariance" to describe the issue addressed by these studies, although it should be clear that space mediation and space-invariance are two sides of the same coin. In order to determine whether attention may select also from internal object-based representations, the experimental procedure must include a condition in which the object attended to at t1 appears at a different location at t2.

The experiments that addressed the space-invariance issue by separating objects from their location via motion provided such a condition. Kahneman et al. (1992) found that the focusing of attention on an object selectively activates the recent history of that object, and facilitates recognition when the current and previous states of the object match. They found this matching process, called "reviewing", to be successful only when the objects in the preview and probing displays shared the same "object-file", namely, when one object was perceived to move smoothly from one display to the other. This finding is typically taken to show that attention selects object-files, i.e., representations that maintain their continuity in spite of location changes (e.g., Kanwisher & Driver, 1992).

Further support for the idea that attention operates in object-based coordinate comes from experiments by Tipper and his colleagues. They used the inhibition of return paradigm (Tipper et al., 1991, 1994), the negative priming paradigm (Tipper, Brehaut, & Driver, 1990), as well as measured neglect patients' performance (Behrmann & Tipper, 1994). Inhibition of return studies show that it is more difficult to return one's attention to a previously attended location. Negative priming experiments demonstrate that people are slower to respond to an item if they have just ignored it. Finally, the neurobiological disorder called unilateral neglect is characterised by the patients' failure to respond or orient to stimuli on the contralesional side of the visual field. Although early studies suggested that all three phenomena are associated with spatial locations (e.g., Posner & Cohen, 1984; Tipper, 1985; and Farah, Brunn, Wong, Wallace, & Carpenter, 1990, respectively), recent studies using moving displays showed that the attentional effects revealed by each of these experimental methods can be associated with object-centred representations.

Tipper et al.'s (1991) displays consisted of three aligned boxes (one box at the centre of the screen, flanked by two peripheral boxes). In the cueing display, one of the peripheral boxes briefly brightened, after which the central box brightened. Then, the boxes moved around the centre, 90° away from their initial location, and a target appeared in one of the peripheral boxes. Thus, the target could appear either in the cued or in the uncued box, each of which was equally distant from the cued location. Reaction time to detect the target in the cued box was longer than for the uncued box, suggesting that inhibition of return is associated with object-based representations. In another condition the boxes rotated 180°. Thus, the uncued object occupied the cued location, whereas the cued object occupied an uncued location, which allowed to measure both object-based effects and location-based effects. Although only the former effect reached significance, in similar experiments by Tipper et al. (1994), IoR effects were obtained in both the same-location and the same-object conditions.

In Tipper et al.'s (1990) study, the prime display consisted of a target (O) and a distractor (X), which appeared at the top of two of four columns present in the display. The two letters moved down the screen, disappeared behind the columns and then seemed to emerge from the bottom of the columns. Subjects had to report the locus of the target. Performance was slower when the target emerged from the bottom of the column that had occluded the ignored distractor in the prime display. Although this finding suggests that the mechanism responsible for negative priming can be associated with dynamic object-based representations, it does not preclude the possibility that space-based effects may also have been present. Indeed, the relevant condition was not included, namely the target never appeared at the top of the columns, i.e., at the locations initially occupied by the primes.

Behrmann and Tipper's (1994) experiments examined the ability of patients with left unilateral neglect to detect a target that appeared in the centre of either the right or the left circle of a barbell. In the moving condition, the left and right sides of the barbell were decoupled from the left and right sides of space by rotating the barbell 180°, while in the static condition, the two were confounded. The results revealed that target detection on the contralesional side of space was poorer than on the ipsilateral side in the static condition, and better in the moving condition. The authors concluded that attention may access object-based representations.

It is noteworthy that in the studies just reviewed, the issue of object-based attentional selection was investigated using a rather indirect route.

Kahneman et al.'s reviewing paradigm (1992) allows one to investigate under which conditions the activation of an object's previous history produces a match. However, although reviewing is triggered by attentional selection, the two are different processes, and there is no principled reason to assume that they are mediated by the same representation. Moreover, the fact that inhibitory mechanisms may be associated with object-based representations does not entail that so are excitatory attentional mechanisms. Indeed, some authors recognised that different mechanisms underlie inhibitory and excitatory components of attention (e.g., Houghton, Tipper, Weaver, & Shore, 1996). Others even questioned the idea that negative priming (e.g., May, Kane, & Hasher, 1995) and inhibition of return (e.g., Reuter-Lorenz, Jha, & Rosenquist, 1996; Terry, Valdes, & Neill, 1994) operate at the level of attentional selection.

To our knowledge, only one study used moving objects to examine directly whether attention activates space-invariant object-based representations (Lamy & Tsal, 2000, Exp. 3). This experiment was a variant of Egly et al.'s (1994) task. Subjects had to detect the presence of a target at one of the four ends of two objects, differing in colour and shape. A precue appeared at one of the four ends and indicated the location where the target was most likely to show up. In order to dissociate the cued object from its location, the two objects were made to exchange locations between the cueing and target displays, by moving smoothly, on half of the trials. Response latencies were fastest at the cued location and at the uncued location within the cued object. The results indicated that attention followed the cued object-file, while also accruing to the location initially cued.

Conclusions on the space-invariance question

We surveyed the evidence concerning whether attention operates on space-based or on space-invariance representations. We distinguished between three different rationales used in the literature in order to address this question. In studies that measured only space-based effects, using either the distance manipulation or the post-display probe technique, space-based effects were typically found. In studies that measured only object-based effects, using moving objects, object-based effects were typically found. The very few experiments where both types of effects were measured yielded mixed results. The main conclusion of this review is that the current literature does not yet provide enough constraints in order to elucidate the space-invariance issue.

First, it shows that selection is sometimes space-based and sometimes object-based, but the conditions under which each selection mode prevails remains largely unspecified. Task-relevance does not seem to determine what type of selection is used, as space-based and object-based effects were found under conditions where the critical target was as likely to appear at the cued location as at the uncued location (e.g., Cave & Pashler, 1995; Tsal & Lavie, 1993) and as likely to appear on the cued object as in the uncued object (Lamy & Tsal, 2000).

Second, a number of problems are associated with each of the experimental rationales used to investigate the space-invariant question.

The authors who used the distance manipulation strategy found that the cost of switching attention between two objects is modulated by the distance between them, and concluded that selection is space-based. However, this rationale rests on two unwarranted assumptions. The first assumption is that distance may be used as an independent variable for testing space-invariance, and the role of proximity as a grouping principle overlooked. One has to consider the possibility that when brought closer together, two perceptual groups may be perceived as a higher-order object (e.g., Duncan, 1984). In that case, distance effects may reveal only that grouping by proximity effects the distribution of attention, thus being irrelevant to the space-invariant question. The other underlying assumption is that attention moves in an analogue fashion through the visual space, with the time needed for attention to move from one location to another being proportional to the distance between them (Kramer et al., 1997). However, this idea has been challenged (e.g., Sperling & Weichselgartner, 1995).

The second experimental strategy was to measure the effects of redirecting attention towards the same vs. a different location. Response to a new object was found to be faster if this object occupied the location of a previously attended object even when space was irrelevant to the task. However, in these studies, the object initially attended (at t1) was no longer present in the subsequent display, in which attentional effects were measured (at t2). A different object typically replaced it. The findings obtained using the post-display probe technique may therefore indicate only that space-based selection prevails when the task is such that object continuity is systematically disrupted. In other words, selection may be space-based only under this specific condition, which does not abound in a natural environment.

The third rationale was to measure same vs. different object effects, using moving objects. Attending to an object was shown to entail that attentional effects remain associated with this object even if it occupies a different location, and it was concluded that selection is object-based. However, as we suggested in the introduction of this paper, space and object-file effects may not be as antithetic as is usually assumed in the literature. Accordingly, finding that attention follows the cued object-file as it moves does not necessarily argue against the idea that selection is space-based. Attention may simply accrue to the locations successively occupied by the moving object. As yet, no empirical data have been reported that preclude this possibility.

FEATURE-CODING

As was reviewed in the previous section, a number of studies suggested that attending to an object entails that this object's location is necessarily activated (e.g., Cave & Pashler, 1995; Kim & Cave, 1995, 1996; Tsal & Lavie, 1993). They showed that when subjects attend to an object occupying a certain location at a certain time t1, they are faster to redirect their attention towards a different object occupying the same rather than the different location at a later time t2. Such findings were taken to indicate that space is special, because it mediates selection. However, these experiments usually did not test the possibility that the attended object's other properties may also be activated, i.e., that attending to an object may entail that all its properties, including its location, are activated. Thus, in order to determine whether or not space deserves a special status, it is necessary to determine whether or not "feature-based" effects may also be found, i.e., whether or not subjects are also faster to redirect their attention towards an object possessing the same colour, for instance, as the previously attended object.

The relevant condition was usually not included in the design of studies investigating whether or not space is special. For instance, in Kim and Cave's (1996) study, the probe appeared in the location previously occupied either by the grouped distractor or by the non-grouped distractor. That is, the manipulation concerned the probe location. The probe was always a black dot, so it never shared the target's colour or shape. Therefore, whereas the experiment showed that attention selects from a spatial representation, it could say nothing about whether or not that representation also contains information about other features, such as colour or shape.

This issue, which we termed the feature-coding question, has usually been overlooked both theoretically and experimentally. It was incidentally touched upon in Tsal and Lavie's Experiment 4 (1993). The first display consisted of a black dot and a coloured dot (pink or blue), appearing on each side of fixation. Subjects had to detect the letter F in the two-letter display that followed, only when the coloured dot was pink. The target letter appeared either on the same or on the opposite side of the relevant dot, and its colour was either pink (same-colour) or blue (different-colour). Performance was found to be better in the same- rather than in the different-location condition, but also in the same- rather than in the different-colour condition. These results suggest that attending to an object entails that its colour is activated when colour is task-relevant, and that its location is activated even if it is utterly irrelevant to the task.

Lamy and Tsal (2000) examined the feature-coding question more systematically. In Experiment 1, location was task-relevant, whereas object features were not. This experiment was identical to the one described earlier (Lamy & Tsal, 2000, Exp. 3), except that instead of moving continuously from one location to the other, the two objects swapped positions abruptly. Performance was faster when the target appeared within the same group of locations (or object location) as the cue. In contrast, whether the target appeared in an object that had the same or different features as the cued object did not affect performance. That is, the results showed that attention selects the locations occupied by an object (grouped locations), and not its other features. In Experiment 2, the target was most likely to appear in the object possessing the cued features rather than at the cued location. Object features were therefore task-relevant, whereas location was not. Response latencies were faster when the target appeared in the object with the cued features, but also when it appeared in the same group of locations as the cue. Thus, both space-based and feature-based effects were found. The authors concluded that an object's location is attended whether or not it is task-relevant, whereas this object's other properties are attended only if task-relevant.

Conclusions on the feature-coding question

In this section, we pointed to a question that had hardly been addressed before. We argued that the space-based effects surveyed in the space-invariance section may be taken to indicate that space is special only if attending to an object entails that its location alone is activated, rather than also its other properties. Accordingly, we reviewed the very few studies that have investigated whether or not selecting an object entails activating its features (e.g., its colour and shape).

The results of these experiments suggest that space is indeed special. They showed that attending to a static object entails that its location is attended to whether or not it is task-relevant, whereas its other properties are attended to only if task-relevant. In the latter condition, subjects had to attend to the relevant feature in order to perform best. That is, if subjects had to attend to the colour red for instance, red objects were prioritised, which could explain why red objects were responded to faster. Feature-based effects were thus confounded with top-down effects. In contrast, as attending to an object entailed that its location was activated regardless of task-demands, space-based effects resulted from the fact that the selection medium represents locations. More research is needed in order to further substantiate and expand the generalisability of these conclusions, however, because the literature on the feature-coding issue is still very scarce.

ATTENTIONAL GUIDANCE

The attentional-guidance question focuses on whether top-down information, namely advance knowledge concerning a target, can help information pass from the parallel to the capacity-limited stage of analysis. This issue has been investigated with location, with primitive non-spatial features such as colour or shape, as well as with higher-order categorical properties. In this paper, we shall only discuss the ability of physical non-spatial properties to direct attention. Accordingly, the term *top-down factors* will be used in a narrow sense, to mean only *advance knowledge of a target feature*. Numerous studies have demonstrated that advance knowledge of location can guide selection (e.g., Posner et al., 1980; Theeuwes, 1989). That is, when the probable location of an upcoming target is known in advance, the object at this location is processed first. In contrast, whether attention can be guided on the basis of other stimulus properties remains controversial. That is, there is some debate as to whether knowing one of the target's attributes in advance allows one to select the objects of the visual field possessing this attribute for priority processing. This question has been investigated using three different strategies, which will be discussed in turn.

Manipulation of the availability (or validity) of advance knowledge

One experimental strategy is to use the cost-and-benefit paradigm. Valid or neutral knowledge is provided about a physical property of an upcoming target (sometimes, the procedure also includes an invalid-cue condition). Better performance in the valid-cue condition relative to the neutral-cue condition is held to show that attention can be guided by physical properties other than location.

As Duncan (1980) and Theeuwes (1993) cautioned, such a pattern of results does not necessarily indicate that the cued property can guide attention pre-attentively. They argued that experiments must be carefully designed so as to ensure that improvement in performance with advance knowledge indeed results from attentional selection, i.e., the passage from the pre-attentive to the attentive stage, rather than from post-selective processes (e.g., identification or response selection). One way to do that is to vary the number of distractors not possessing the cued property, in order to be able to ascertain that they are rejected in parallel. In several studies in which effects of advance knowledge were found, this number was kept constant (e.g., Cooper & Juola, 1990; Humphreys, 1981; Juola, Bouwhuis, Cooper, & Warner, 1991; Lambert & Hockey, 1986), making it unclear whether or not attention was guided pre-attentively towards the target elements. Duncan (1985) also argued that when the property of the target that subjects have to report (reporting attribute) and the property that defines the target set (defining attribute) are confounded, as happens with detection tasks, improvement in performance may result from the fact that subjects require less evidence to decide that the selected item is in fact the target (see also Theeuwes, 1993). He proposed that compound stimuli, in which the defining and reporting attributes are different, should be used to avoid this problem (e.g., Theeuwes, 1989).

On the other hand, the absence of facilitation does not necessarily indicate that attention can never be guided by physical features. A null effect may occur because alternative strategies are available for finding the target, and are more efficient than the use of the cue. For instance, the target may be always more salient than any of the distractors, as in feature search tasks (e.g., Müeller, Heller, & Ziegler, 1995; Pashler, 1988, Exps. 1–4). Subjects can thus adopt the strategy of looking for the most salient item in the display rather than use the cue. Another alternative strategy is for subjects to select the target by attending to its defining property (i.e., the property that defines what they are looking for; Duncan, 1985), rather than to the cued property they are instructed to attend to, if the latter allows better discriminability between target and distractors. This may always happen, as the cueing and defining properties must be distinct from each other in order for the presence or the validity of the cue to be manipulated.

Theeuwes' (1989) experiment may illustrate this point. Two shapes simultaneously appeared on each side of fixation. The target shape contained a line segment, while the distracting shape was empty. Subjects responded to the line's orientation. The target was cued by the form of the shape within which it appeared, or by its location. The cueing manipulation was effective with the location cue but not with the form cue. The author concluded that advance knowledge of form cannot guide attention. However, it may have been easier for subjects to look for the filled shape, i.e., to use the defining attribute, rather than to use the form cue. Form cueing may thus have been task-irrelevant, which would explain why it had no effect. According to this logic, using the location cue was easier than looking for the filled shape, but looking for the filled shape was easier than using the form cue. Thus, although Theeuwes' finding indicates that location cueing may be more efficient than form cueing, it does not preclude the possibility that form cues may effectively guide attention when no other, more efficient, strategy is available.

A recent series of experiments by Shih and Sperling (1996) also questioned the idea that attentional selection on the basis of non-spatial properties be possible. They required subjects to search for a digit among letters, in a task combining attentional cueing and rapid serial visual presentation (RSVP). A precue indicated the colour (or size) of the target. In Experiment 1, each array was uniform with regard to the cued dimension, and successive arrays alternated in feature value. That is, if the target was cued by colour, the six elements of the array were all green, then all red, and so on. No validity effects were found. In their Experiment 2, five elements had the same feature value on the cued dimension, and the remaining element had a different value. The target was always the odd item. Under such conditions, validity effects were found. The authors concluded that "attentional selection is made on the basis of spatial location", because non-spatial features can guide attention only if they allow spatial discrimination between target and distractors.

There are a number of problems with this conclusion. First, the idea that attentional guidance should be demonstrated when cued and non-cued elements occupy different points in time rather than in space is questionable. It implies that the competition for attentional priority that takes place between simultaneous items at different locations is equivalent to the competition between successive items at the same location. However, the way this competition is generally conceived of (e.g., Desimone & Duncan, 1995; Duncan, Ward, & Shapiro, 1994) is that, at a certain time t, attention is distributed among the different objects or locations in the field, top-down factors biasing this allocation in favour of the objects or locations with the cued attribute. Attentional resources are thought to be "locked" for a certain "dwelling time", therefore precluding immediate reallocation. That advance knowledge of colour, for instance, should affect this time-locked mechanism is in no way a necessary condition for showing that it can guide attention pre-attentively. Second, it is not clear that the critical difference between the two experiments was whether or not the cued attribute provided discriminability between *locations* rather than between *objects*. Indeed, locations and objects were confounded (they would be dissociated if different objects were superimposed, for instance). Therefore, Shih and Sperling's findings show only that a necessary condition for top-down factors to affect attentional priority is that the cued attribute be able to bias the competition between the different filled locations or objects in the field, at a certain time.

Relevant evidence in favour of the idea that attention can be guided by physical properties other than location comes from a study by Bravo and Nakayama (1992). They had subjects judge the shape of an odd-coloured target, which appeared among a variable number of distractors of another colour. In the consistent-mapping condition, the colour of the target and the colour of the distractor remained constant, whereas in the variable-mapping condition they reversed unpredictably. Performance was faster in the former condition, i.e., when the colour of the target was known in advance.

Manipulation of target and non-target set sizes

A second strategy is to manipulate the number of elements that share the cued property as well as the number of elements that do not, in a visual search task. If attention is guided by the cued attribute, then the elements with the cued attribute are passed to the second stage, in which they are scanned serially, whereas the elements without the cued attribute are rejected in parallel at the pre-attentive stage, and are therefore less likely to be "interviewed" (Duncan, 1981) at the attentive stage. Thus, search performance should deteriorate more as the cued-set size increases, than as the uncued-set size increases (because the selective process is not noiseless, it is not necessary to predict that performance be flat as the uncued-set size increases).

Finding that non-cued distractors are excluded from search, however, does not necessarily indicate that subjects segregate the display and tag the cued set for prioritised processing. First, items with the cued attribute may be searched first because they are more salient. This may happen if the cued attribute is perceptually more salient than the uncued attribute, or if the size of the cued sub-set is always smaller than the size of the uncued sub-set (e.g., Egeth, Virzi, & Garbart, 1984). Second, subjects may again use an alternative strategy and attend to the property that defines the target rather than to the cued property. Francolini and Egeth's (1979, Exps. 3 & 4) findings provide an example of how the availability of an alternative search strategy may affect performance. In Experiment 3, subjects searched for a specific letter in arrays containing black and red letters. Subjects knew the target was always red. RTs increased with the number of both red and black letters, suggesting that selectivity on the basis of colour was not possible. In Experiment 4, subjects were presented with similar arrays, but were required to *count* the red items. This time, RTs increased only with the number of red letters, and were independent of the number of black letters, indicating that selectivity on the basis of colour was possible. With the identification task, the target could be selected on the basis of either its colour or shape. In contrast, with the counting task, the task could be performed only by using the colour selection schedule.

In a number of studies, however, these problems were avoided.

Namely, salience factors were controlled for, i.e., the relative number of cued and non-cued elements was systematically varied, and the role of cued and uncued features was exchanged. These studies showed that subjects can search selectively through the cued set and ignore the uncued set, suggesting that attention can be pre-attentively guided by properties other than location (e.g., Cahill & Carter, 1976; Carter, 1982; Green & Anderson, 1956; Kaptein, Theeuwes, & van der Heijden, 1995).

Manipulation of the target's relative salience

Some authors reported that when attention is focused on a location in advance, the presence of a salient distractor elsewhere in the visual field does not impair performance (Theeuwes, 1991b; Yantis & Jonides, 1990). Investigating whether or not goal-directed allocation of attention on the basis of a physical property other than location can also override bottom-up processes is the third rationale used to examine the attentional guidance issue. The finding that search for a target defined by a known attribute is disrupted by the presence of a salient distractor is taken to indicate that advance knowledge of a stimulus property cannot guide access to the limited-capacity system, and that selection by location is special.

Theeuwes (1992) presented subjects with a variable number of items arranged in a circle. Subjects had to judge the orientation of a line located inside a target item, defined by its form (a diamond among circles). On half of the trials, the display also included a distractor unique on an irrelevant dimension (a red item among green ones). RTs were significantly higher in the distractor-present than in the distractor-absent condition. Because advance knowledge of the target's form did not enable subjects to exclude the salient distractor from processing, while it was found in other experiments that advance knowledge of the target's location does, the author concluded that properties other than location cannot guide attention pre-attentively.

Bacon and Egeth (1994) proposed that in Theeuwes' (1992) experiment, two search strategies were available: (1) the singleton detection mode, in which attention is directed to the location with the largest local feature contrast, and (2) the feature search mode, which entails directing attention to items possessing the target visual feature. Indeed, the target was defined as being a singleton *and* as possessing the target attribute. If subjects used the singleton detection mode, both relevant and irrelevant singletons could capture attention, depending on which exhibited the greatest local feature contrast. To test this hypothesis, Bacon and Egeth (1994) designed conditions in which the singleton detection mode was made ineffective. They presented either up to three identical target shapes on each trial (Exp. 2), or up to two different unique shapes in addition to the unique target shape (Exp. 3), thus ensuring that the target could not be found by simply looking for a singleton. The disruption caused by the unique distractor disappeared.

Bacon and Egeth's findings indicate that advance knowledge of a target property may guide attention pre-attentively. They also suggest that subjects rely either on a top-down strategy or on a bottom-up strategy depending on task requirements. In other words, they suggest that there is no mandatory bottom-up component in visual search, as salience affects search only when task-relevant (see Folk et al., 1992; Lamy, 1999; Lamy & Tsal, 1999; Lamy, Tsal, & Egeth, 1999; Yantis & Egeth, 1999, for related results).

Conclusion on the attentional-guidance question

This section was concerned with subjects' ability to tag elements of the field possessing a certain feature, e.g., a certain colour or shape, for prioritised processing. We distinguished between three experimental strategies used in the literature in order to address this issue. The first strategy was to determine whether advance knowledge of one of the target's physical properties improves subjects' performance when it is valid rather than neutral or invalid, as does advance knowledge of location. The second strategy was to vary the sizes of the cued and uncued sets orthogonally, in order to find out whether subjects can search selectively through the cued set and reject the uncued distractors in parallel. Finally, the third strategy was to investigate whether advance knowledge of one of the target's physical properties allows subjects to exclude a salient distractor from search, as does advance knowledge of the target's location. The results of the studies reviewed in this section suggest that object properties other than location may guide attention pre-attentively. The findings at odds with this conclusion were shown to be open to alternative explanations. In most cases, subjects could use an alternative strategy that was more efficient to perform the task (e.g., Theeuwes, 1989, 1992). The review also suggested that bottom-up and top-down factors are alternative sources of attentional guidance.

The hypothesis underlying the foregoing review on the attentional guidance issue was that finding that attention can be guided pre-attentively by non-spatial properties indicates that selection by location is not special. However, several lines of research focused on other qualitative differences between selection by location and selection by other properties. A number of authors suggested that attending to an object's location enhances the sensory quality of that object, rather than prioritising it for further processing (e.g., Egly & Homa, 1984; see van der Heijden, 1992 for a review). In contrast, Moore and Egeth (1998) presented evidence suggesting that attending on the basis of physical features other than location, e.g., on the basis of colour or size, does not directly affect the sensory quality of stimuli that possess that feature. They showed that "feature-based attention failed to aid performance under 'data-limited' conditions (i.e., those under which performance was primarily affected by the sensory quality of the stimulus), but did affect performance under conditions that were not data-limited" (p. 1296).

Moreover, in several physiological studies that compared the event-related potentials (ERP) elicited by stimuli attended to on the basis of location vs. other features, a qualitatively different pattern of activity was found for the two types of cues, which was taken to indicate that selection by location may occur at an earlier stage than selection by other properties (e.g., Hillyard & Munte, 1984; Näätänen, 1986).

These qualitative differences between selection by location and selection by other object properties are consistent with the conclusions of the previous sections. The fact that units possessing a target feature can be prioritised in parallel for further processing, but that attention eventually selects units from a spatial representation that does not represent features (at least with static displays), indeed suggests that selection by non-spatial properties involves an additional step. It suggests that features must be represented separately from the map subserving selection, but be linked to it in order for items with the target feature to be tagged. Thus, although attention activates locations directly when guided by a spatial cue, when guided by a colour cue, for instance, it does so indirectly, via a colour module.

The results reported by Nissen (1985) illustrate this point. She showed that when a target is cued by its location, the probabilities for reporting its shape and its colour are independent. In contrast, when a target is cued by its colour, the probability of reporting its shape is dependent on the probability of reporting its location. She concluded that selection by non-spatial attributes is mediated by the selection of location, and that location is the dominant form of information on which visual attention is based (see Bundesen, 1991, 1993; van der Velde & van der Heijden, 1993, for a discussion of this conclusion).

CONCLUSIONS

This paper addressed the question of whether location deserves a special status in attention. Its main objective was to provide a coherent picture of the available literature pertaining to this question. In order to do so, we proposed a distinction between four issues that are usually not clearly segregated. We referred to them as the grouping, space-invariance, feature-coding, and attentional-guidance questions. In this part, we summarise the conclusions pertaining to each issue, identifying areas of consensus and formulating new, more tightly focused experimental questions for further research.

The grouping question

The grouping question focuses on whether or not the segmentation of the field into perceptual groups requires attention, or to put it differently, on whether all Gestalt principles or only proximity constrain the distribution of attentional resources. Some studies supported the idea that grouping is pre-attentive, by showing that grouping affects the distribution of attention. Such object-based effects were typically found when attention was either divided across the display (e.g., Baylis & Driver, 1993; Duncan, 1984; Lavie & Driver, 1996, Exps 1–3) or focused on part of the perceptual group (e.g., Baylis & Driver, 1992; Driver & Baylis, 1989; Kramer & Jacobson, 1991). In contrast, perception of grouping was found to be impaired when the relevant perceptual group lay outside the focus of attention, suggesting that grouping required attention (e.g., Ben-Av et al., 1992; Mack et al., 1992; Rock et al., 1992).

In order to reconcile between these apparently conflicting lines of findings, we proposed that grouping effects may be found only if at least part of the relevant perceptual group is attended to. This idea is compatible with all the data reviewed here. However, it is important to note that it may be subserved by very different mechanisms. One possibility, which may be labelled the *grouping propagation* hypothesis, is that attention is required in order to determine grouping relations between different areas of the visual field. Accordingly, when attention is focused on a small location, it triggers an analysis of grouping links with neighbouring elements, the locations that are more grouped with the attended location receiving more attention. This in turn allows attention to be allocated to further locations grouped with the attended location, according to the same mechanism. When attention is divided across the display, each location receives enough attention for grouping relations to be calculated, thus explaining why grouping effects are found under these conditions. This entails that grouping requires relatively little attentional resources.

A second possibility, which may be labelled the *grouping gradient* hypothesis, is that grouping is pre-attentive but interacts with attention in a gradient-like manner. That is, when attention is focused on a small area, attentional activation peaks at the attended location, other locations being allocated attention in direct relation to how strongly they are grouped with the attended location. Accordingly, grouping outside the focus of attention does not have any effect on behaviour. When attention is divided across the display, attention selects the locations occupied by the relevant object, all the locations of which are equally activated.

These mechanisms are very different from each other as, most critically for the present purpose, the former implies that grouping requires attention, whereas the latter implies that it does not. The fact that they are both consistent with the various findings reported in the literature suggests that the empirical questions addressed by previous research were generally too broadly defined to determine whether or not grouping is pre-attentive, and whether space indeed plays a special role in the relation between grouping and attention. For instance, investigating the time-course of object-based attention could be particularly useful in order to discriminate between the different accounts.

The space-invariance question

The space-invariance question focuses on whether attention operates on a spatio-topic representation of visual objects, or whether it selects from an internal object-based representation in which the location occupied by the object plays no role. The findings reported in the current literature suggest that selection may be both space-based and object-based. However, this conclusion remains rather vague as only very few studies (Vecera & Farah, 1994, but see Kramer et al., 1997) have investigated the conditions under which each mode of selection prevails.

In this review, we pointed to the fact that studies using static objects supported the space-based view, whereas studies using moving objects supported the space-invariant view. The only two studies measuring both effects simultaneously yielded conflicting results. Because space-based and object-based effects were measured under very different conditions, the current state of research on the space-invariance issue does not allow one to determine whether or not space plays a special role.

On the one hand, attention was found to follow moving objects and space-based selection was observed only under the very specific condition in which the attended object disappeared abruptly and was replaced by a new object. As this situation does not reflect the way objects usually behave in natural environments, one may conclude that selection is generally object-based, and that space-based selection constitutes only a special case.

On the other hand, the fact that attention follows the object as it moves is compatible with the possibility that attention accrues to the location it occupies successively. Thus, the evidence that is usually taken to support the idea that attention selects space-invariant representations is open to an alternative interpretation that favours the space-based view. In order to test this possibility, further research could measure attentional effects along the trajectory followed by a moving object. If selection is object-based then performance should be no different when a probe appears at locations that have been occupied by the attended object during movement, and at other locations outside this object's trajectory. If selection is space-based and attention selects the locations successively occupied by the moving object, then an advantage should be observed in the former condition.

The feature-coding question

As was shown in the previous section, attending to an object that happens to be at a certain location entails that this location is activated, as subjects respond faster to a new object appearing subsequently at that location. Does this finding indicate that selection is mediated by space or does it simply suggest that selecting an object entails that all its properties, including its location, are activated? In order to answer this question, one must determine whether the same phenomenon is observed with other object properties. That is, does attending to an object that happens to be red, for instance, entail that the colour red is activated? This is the focus of the feature-coding question. Our review of the literature indicates that, in contrast to the results obtained in the location dimension, attending to an object entails that its non-spatial properties are activated only if these properties are task-relevant. As a consequence, feature-based effects may result from top-down influences rather than reflecting properties of the representational medium of selection.

Attentional-guidance

The attentional-guidance question focuses on whether advance knowledge of a target's non-spatial properties can help information pass from the parallel to the capacity-limited stage of analysis. Our review of the literature yielded three main conclusions.

First, it showed that attention can be guided by non-spatial properties. The fact that items with a target property can be pre-attentively segregated for further processing entails that selection takes place in at least two stages. When top-down information about the target is available, the first selection mechanism tags elements of the display that match the target property. Such tagging confers higher processing priority to the potential targets, but it does not interface with the response system. That is, no response can be emitted based on the priority map that results from top-down factors. A second, serial selection mechanism, referred to as focal attention, must come into play. This mechanism selects potential targets serially, by order of priority.

Second, this review suggested that selection by location is none the less special, as several lines of findings converge to suggest that selection by location may occur at an earlier stage than selection by other properties.

Finally, an increasing amount of data points to the fact that, rather than jointly contributing to determine attentional priority, bottom-up and top-down factors are alternative sources of attentional control. Thus, bottom-up and top-down activation levels do not converge on one common representation in which they are summed into a final activation index as is usually assumed (e.g., Cave & Wolfe, 1990; Wolfe, 1994). This suggests that search based on top-down information and search based on bottom-up information are subserved by different representations.

Taken together, based on the conclusions of the present review, we may speculate that at least three different types of representations or maps participate in the process of visual selection, depending on task-demands: a top-down selection map, feature maps, and a discrepancy or bottom-up selection map.

The top-down selection map subserves selection based on top-down factors. The current state of research does not yet allow us to define precisely the nature of the units that make up this map. They may be either locations or spatio-temporal units, and the preliminary results pertaining to the feature-coding question suggest that these units do not include information about the non-spatial properties of the objects they represent. The conclusiosn that emerged from the grouping section, namely that grouping effects are found only if at least part of the relevant perceptual group is attended to, do not yet provide enough constraints to determine whether the top-down selection map is segmented into groups, or whether attention is required for grouping relations to be calculated.

When attention is directed by a spatial cue, this selection bias affects the top-down selection map directly, whereas when it is controlled by a non-spatial cue, a less direct route is adopted. Indeed, the review on the attentional guidance issue suggested that selection by location is more efficient and occurs at an earlier stage than selection by other properties. The fact that units possessing a target feature can be tagged in parallel for further processing but that attention eventually selects units that do not represent features, as was shown in the feature-coding section, also suggests that selection by non-spatial properties involves an additional group of representations, the feature maps. That is, selection by a non-spatial feature takes place within the same top-down selection map as does selection by location but via the relevant feature module(s).

Finally, a discrepancy map, or bottom-up selection map, that codes the relative salience of each element present in the field—i.e., how different it is from its neighbours—is accessed when task-requirements involve searching for a salient item. That is, selection based on top-down factors and on bottom-up factors occur on separate maps. This conclusion stems from the finding that bottom-up and top-down factors do not affect search jointly. Instead, only one search mode is used, depending on task demands. The finding that selection by feature is not the preferred strategy when selection based on salience or on location information is available is easily accounted for by the fact that this selection mode involves an additional step.

There has been considerable empirical research and controversy on the role of location in attention. This review offers a new classification that may facilitate the interpretation of existing findings as well as indicate which areas are particularly in need of further research.

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