Guiding attention in a dynamic environment

Pinto, Y.

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Guiding attention in a dynamic environment

ACADEMISCH PROEFSCHRIFT

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door

Yaïr Pinto

geboren te Groningen

promotor: prof.dr. J.L. Theeuwes
copromotor: dr. C.N.L. Olivers

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Introduction

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"A picture says more than a thousand words". This proverbial saying is especially true when it comes to memory. As anyone familiar with computers knows, storing a picture really takes up the equivalent space of an entire book. Therefore, if humans would retain every image they have seen, the brain would soon be flooded with information. To retain what is important, and discard what is not, a selection has to be made. This selection procedure corresponds to what we subjectively experience as attention. In general, we can consciously remember only what we attend to (Becker, Pashler, & Anstis, 2000; Landman, Spekreijse, & Lamme, 2003). Thus, attention can be viewed as the gatekeeper. Information that does not get passed this gate essentially disappears into oblivion.

As an important cognitive function, attention has been extensively studied since the 1950's (for an overview see Pashler, 1998, or Driver, 2001). A key question in attention research is which factors drive selection. What makes you attend to one object and not the other? Theories essentially distinguish between two types of factors: factors relating to the observer, and factors relating to the stimulus. Factors generated by the observer are referred to as top-down factors. Goals of the observer (such as looking for rectangular objects) are an example of a top-down factor. The color, the shape, or the speed of an object are stimulus properties, and these are referred to as bottom-up factors. For example, imagine you are looking for your friend in a busy train station. You know he is wearing a red sweater, and therefore you decide to look for anything red. In that case, if you attend to a red item, this is because of your search goal. This then would be top-down driven attention. Conversely, in the same situation, a loud bang would catch your attention, even though you did not look for loud bangs – thus providing an example of bottom-up driven attention.

Is attention essentially top-down or bottom-up driven? Three general theoretical frameworks have emerged: The relative bottom-up model, the absolute bottom-up model and the top-down model. We will first outline what these theories encompass, and what empirical evidence supports them. We will then review two different visual settings, involving dynamic displays and dynamic changes between displays, and how well these theories fit the data found in these situations.

Visual search

In all cases, an important (though of course not the only) measure of attention is performance in a visual search task, and the search slopes it produces. In a visual search task, a participant looks for a target item among distractor items. The search slope is the increase in reaction time as a function of the number of items in the display. The search slope obtained in visual search depends on the task. If participants can immediately distinguish the target from the distractors, the number of distractors does not affect reaction times. However, if participants cannot attend the target immediately, they will have to shift their focus from item to item, causing reaction times to be longer if there are more items. For instance, when participants search for a square among circles, the number of non-target elements (circles) does not affect reaction times. Therefore, in this case the search slope is flat, and search is considered to be efficient. Note that in this example, the square is also referred to as a singleton (Pashler, 1988). Singletons denote any item that is unique along a certain dimension (in this case, the square is unique with respect to the shape dimension). Conversely, when participants search for a 2 among 5s (i.e. alarm clock numbers), the more 5s there are, the longer it takes. Thus, such a task produces a positive search slope, and is referred to as inefficient search. Treisman and Gelade (1980) based their influential Feature Integration Theory (FIT) on the striking finding that only objects that carry a unique feature yield efficient search. FIT argues that this distinction occurs, because attention is necessary to bind features. Therefore, if the target does not carry a unique feature, each object in the display has to be attended to determine which *conjunction* of features makes up the target (e.g. 2s and 5s are conjunctions of the same line segments). Although Treisman and Gelade's theory is not undisputed, the important point is that discovering which search tasks yield efficient search can be revealing about the role of attention in visual processes.

In addition to search efficiencies, search asymmetries are also an important tool for studying the role of attention. Search asymmetries are said to occur when the search for stimulus A among stimuli B is more efficient than the reverse case. For instance, it is easier to find an orange object among red objects than vice versa. Similarly, a Q among O's is more efficiently found than an O among Q's. Treisman and Gormican (1988) hypothesized that search asymmetries reveal the presence or absence of a basic feature. Thus, a Q can be easily found among O's because the target has an added feature. In the reverse case, the O is lacking a basic feature, and since it is easier to detect the presence of a feature than its absence, the O is more difficult to find. Similarly, according to this notion, the orange target can be detected by searching for added "yellowness". Again this theory is not undisputed, but the main point is that in addition to search efficiencies, search asymmetries can also be telling about how attention influences perception. Particularly, search asymmetries seem to show that it is easier to detect the presence than the absence of a feature (see: Wolfe, 2001 for an overview of research on search asymmetries). As such, search asymmetries are a tool to investigate what constitutes a feature. For instance, Kristjánsson and Tse (2001) argued that “bumpiness” is a basic features based on search asymmetries.

Relative bottom-up model

According to the relative bottom-up model, attention is primarily driven by stimulus properties. However, according to this model stimuli in isolation do not determine where attention is allocated, but stimuli in comparison to surrounding stimuli determine where attention goes. Particularly, in the spatial domain, stimuli that *differ* sufficiently on a dimension from other stimuli (i.e. contain a unique feature relative to the background, whereby feature-contrast has to be local) attract attention (Nothdurft, 1993; Itti & Koch, 2000, 2001). So a red object surrounded by other red objects does not draw attention, but this same object surrounded by green objects does. One important line of research supporting the relative bottom up model is the work of Theeuwes (1991; 1992). In his experiments participants searched for a diamond among circles (or vice versa). All elements were green, but on some trials one of the non-target objects (i.e. a circle when participants searched for a diamond) was red (see Figure 1.1). Participants were aware that the red item was never the target, and that they should ignore this potentially distracting item. Nonetheless, when a red distractor was present, search times to find the target increased, indicating that participants could not ignore the red item. This phenomenon is referred to as *attentional capture*. Thus, if certain items attract attention, even though you do not want to attend to these items, attention is said to be captured. The Theeuwes’ studies provide an example of this attentional capture, since attention goes to an item that is never the target, and thus that participants (presumably) do not want to attend (but see Bacon & Egeth, 1994). Another example of attentional capture are the studies of Yantis and Jonides (1984), and Jonides and Yantis (1988), which we will discuss more elaborately later on. Here it suffices to state that in these studies attention also goes to an object that is hardly ever the target (and thus that participants do not want to attend).

In contrast to the spatial domain, in the temporal domain stimuli that are the *same* as previous stimuli appear to draw attention. Research supporting the claim that temporal comparisons determine where attention goes was performed by Maljkovic and Nakayama (1994; 1995; 1996). In their study participants searched for an object with a unique color, e.g. one red diamond among several green diamonds or vice versa. When the target color on the current trial was the same as the color of the target on previous trials, participants responded faster. This occurred even when the current target color was the same as the target color seven trials back, although the conscious recollection did not go further back than one trial. Furthermore, when the target color switched every second trial, and participants were made aware of this, participants were still faster on repetition trials than on switch trials, even though they knew that a switch would come. Maljkovic and Nakayama’s studies indicate that if a stimulus is the same as a previously observed stimulus, it attracts attention, irrespective of the search goals of the participant.

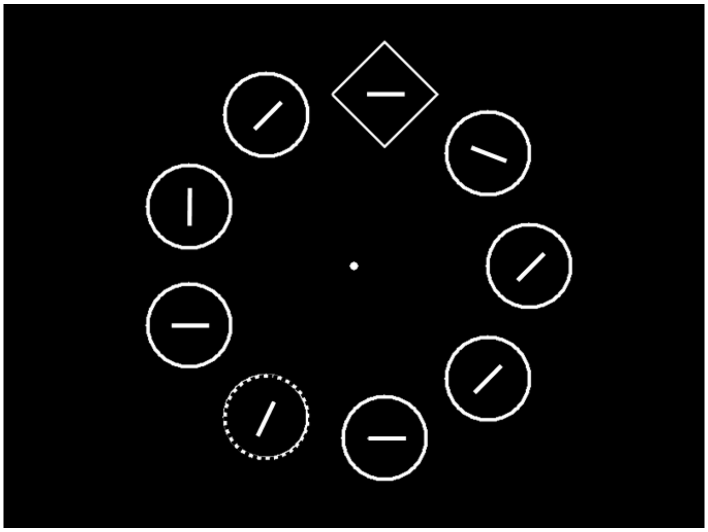


Figure 1.1. Example of a display used by Theeuwes (1992). In his experiment the figures were green and the background was white. The dotted line indicates a red object. In this example participants searched for a diamond (and reported the orientation of the line inside it), while a distractor (the red circle) was present.

Absolute bottom-up model

The absolute bottom up model agrees with the relative bottom up model in the sense that attention is essentially driven by stimulus properties. However, the absolute bottom up model suggests that specific *types* of unique stimuli summon attention not the fact that one element is a singleton (i.e. that the element is different from all elements in the display). According to the prevalent versions of these theories, the most important ‘attention-grabbing’ stimuli are dynamic objects. Supposedly, from an evolutionary viewpoint, dynamic stimuli indicate potential danger, such as the appearance of a predator, or the sudden looming of an obstacle on our path. Therefore we are inclined to attend to these stimuli. Classic evidence for this model comes from work done by Yantis and Jonides (1984) and Jonides and Yantis (1988). In their studies participants first viewed a display only consisting of figure eights. After some time these figure eights turned into letters. Participants then searched for a certain letter among distractor letters (e.g. an H among P, E and S, see Figure 1.2). The number of distractor letters varied from trial to trial. The more distractor letters were present, the longer it took participants to find the target, indicating that a letter had to be attended before participants knew whether it was the target or not. On some trials, one of the letters was presented with a sudden onset. Most of the times, this sudden onset was not the target, and therefore participants had no incentive to attend to this object. Nevertheless, when the sudden onset happened to be the target, reaction times became independent of the number of distractor letters, indicating that the sudden onset was always attended first. Importantly, this result was only found for sudden onsets. For instance, in the same set-up, when the target sometimes had a unique color, participants were no more efficient in finding it. Yantis and Jonides' research suggests that not all properties attract attention. Onsets do, but unique colors do not. In a similar line of research, Franconeri and Simons (2003) suggested that other dynamic properties such as looming and motion also capture attention. They hypothesized that features capture attention as long as they denote something ecologically relevant.

In this context it is important to mention the study of von Mühlenen, Rempel, and Enns (2005). According to von Mühlenen et al., the key factor is not the dynamic features that are involved, but the *timing* of the dynamics. For instance, they showed that stimuli that captured attention according to Franconeri and Simons, only did so when they changed when everything else was static. That is, when an object loomed at the moment that the search display appeared (i.e. the figure eights turned into letters) then the looming object did not capture attention. However, when it loomed before the search display appeared (as was the case in the study of Franconeri and Simons), then it did capture attention. Similar results were found for objects with a unique color. When an object acquired a unique color before or after the appearance of the search display (i.e. when it was the only changing object) it captured attention. However, when the object acquired the unique color during onset of the search display it did not capture attention. This led von Mühlenen et al. to argue that temporal factors (in addition to spatial factors) are essential for attentional capture. The most effective stimulus is unique in both dimensions, that is, it undergoes a change during relative calm. Von Mühlenen et al.'s notion could be considered to support the relative bottom-up model, since it suggests that comparisons (in both the temporal and spatial domain) are essential for attentional capture.

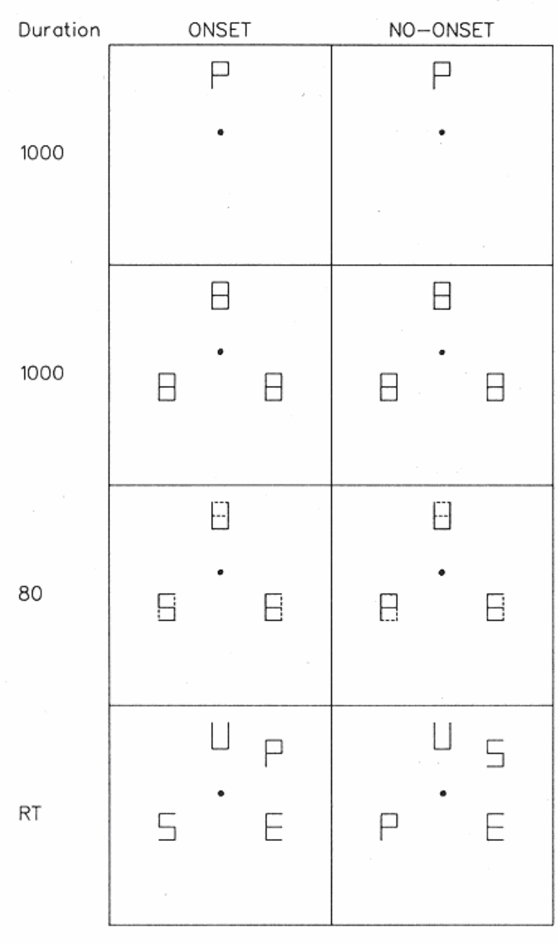


Figure 1.2. An example display as used by Yantis and Jonides (1984), taken from their manuscript. In this example participants reported the presence of the letter P, which could appear as an onset, or on the place previously occupied by a figure eight.

Top-down model

The third influential model is the top-down model. This view states that attention is primarily driven by factors relating to the observer, such as search goals and internal preferences. Again, there are several studies supporting this theory. Folk, Remington and Johnston (1992) presented participants with a search display in which they either had to find a target that appeared with a sudden onset, or a target that carried a unique color. The target could appear in one out of four locations. Before the search display was presented, a cue was shown on one of these locations. The cue appeared 150 ms before the search display, and could either be a sudden onset or a uniquely colored item (see Figure 1.3). This cue was not predictive of where the target would appear, and participants were made aware of this (and were thus instructed to ignore the cue). Folk et al. found that the cue only affected reaction times when it was from the same category (onset or unique color) as the target. That is, when participants searched for an onset, a uniquely colored cue could appear anywhere without affecting reaction times. However, an onset cue speeded responses if it appeared on the target location, and slowed responses when it appeared somewhere else. The same pattern held when participants searched for a uniquely colored target (in that case uniquely colored cues did, but onset cues did not affect their reaction times). Folk et al. concluded that features only attract attention if they match the search goals of the subject.

Bacon and Egeth's (1994) study corroborated this hypothesis. They suggested that in Theeuwes' earlier-mentioned studies participants were distracted because the distractor essentially met their search goals. According to Bacon and Egeth, since participants searched for a unique form (i.e. a diamond is unique among circles), they may have searched for anything unique, rather than for diamonds specifically. Since a red object among non-red items is also unique, this then caused them to attend to this distractor. To avoid that participants adopted such a search strategy, Bacon and Egeth construed displays in which several targets were present. For instance, participants indicated the orientation of a line inside a diamond, and then were presented with a display containing three diamonds (and several circles, see Figure 1.4). In such a search display, there are no unique objects, and therefore unicity cannot be a search goal. Bacon and Egeth varied the number of targets from trial to trial, so that on a small portion of the trials there was only one target. They found that under these conditions, when one of the distractors carried a unique color, it did not affect search times, even when there was only one target. Bacon and Egeth took this as evidence that what was previously considered to be proof of bottom-up capture of attention, was in fact another example of top-down driven attention (but see Theeuwes, 2004). Another important study taken to support the theory of top-down control of attention was performed by Yantis and Egeth (1999). In their study participants performed a difficult search task, for instance involving a vertical bar target among tilted bar distractors. Search was aided when the target carried a unique color, but only if color and target coincided frequently. That is, color information was only used, when on most trials the item with the unique color was the target. This suggests that attending to a salient feature, such as a unique color, is under top-down control. People only do this when they see it as beneficial. Thus, knowledge about the target influences where attention goes, again indicating that top-down settings (in this case search knowledge rather than search goals) determine the allocation of attention.

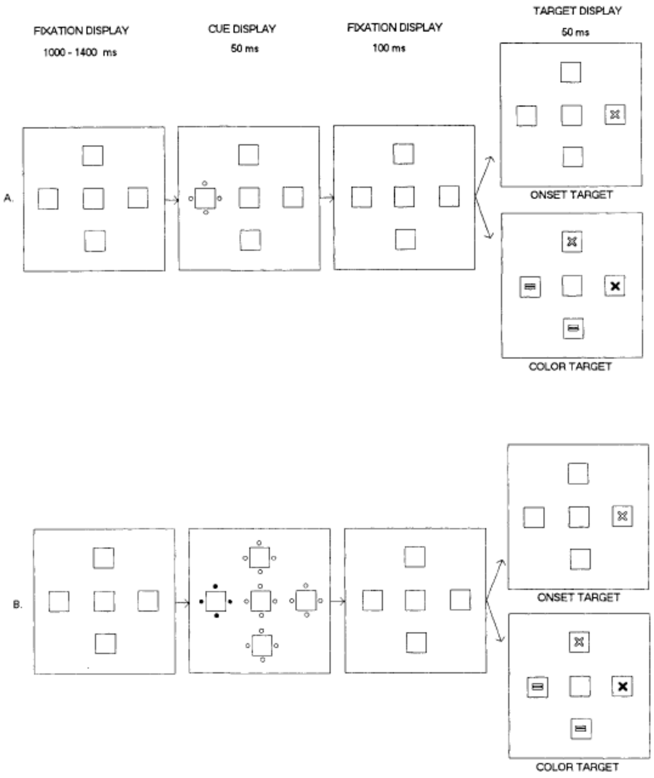


Figure 1.3. Illustration of the study performed by Folk, Remington and Johnston (1992), taken from their manuscript. The cue appeared 150 ms before the search display and could either be an onset (top) or uniquely colored (bottom).

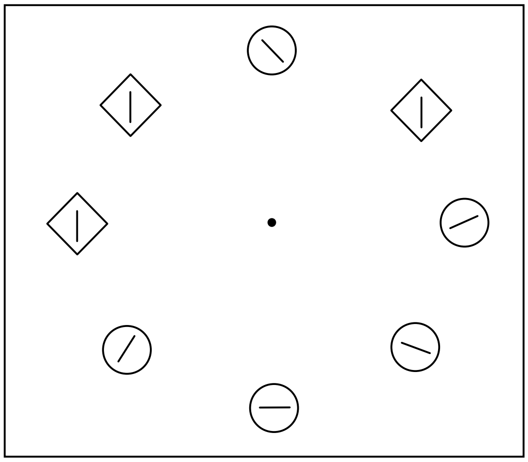


Figure 1.4. Example display of a multi-target display, employed by Bacon and Egeth (1994). In this case participants reported the orientation of the line inside the diamond target.

Rationale behind the present thesis

Summarizing, the three outlined models are not consistent regarding which factors determine attentional allocation. In the following I will review how well these models hold up in conditions involving dynamic display changes within and between trials. The focus is on dynamic displays, because if there has been an absolute attention-puller proposed, it is stimulus dynamics. Dynamic displays will therefore provide the ultimate arena for testing relative versus absolute accounts of attentional capture. First, I will pitch the relative bottom up model against the absolute bottom up model, when the displays are dynamic, and the target is static. Second, I will compare the bottom-up models to the top-down model, in a situation in which the display changes from trial to trial. Such changes create bottom-up effects that may explain phenomena previously attributed to static, top-down settings applied to an entire block of trials.

Attention in dynamic situations

Dynamic among static

Everyday experience suggests that dynamic objects are attention attractors. That is why we wave when we are in a crowded place and we see a friend is looking for us. Similarly, ambulances are equipped with flashing lights, because these are thought to capture attention so strongly that we cannot miss them. According to the absolute bottom up model, this intuition is correct. This model states that dynamic properties are the prime example of attention-attractors. As argued earlier, dynamic objects are thought to attract attention, because they indicate potential danger. A moving or suddenly appearing object can be a predator. Conversely, for a predator, any motion may reveal something about the prey (see Abrams & Christ, 2003; Hillstrom & Yantis, 1994; Tipper & Weaver, 1998, for similar arguments). Previous research has provided confirming evidence for the notion that dynamic items capture attention. Using a visual search task in which observers had to detect a moving target among static distractors, Hillstrom and Yantis (1994) and Yantis and Egeth (1999) found no effect of the number of distractors on search reaction times (RTs; i.e. search slopes were flat), indicating that the moving target could be found efficiently and in parallel across the displays used. Similarly, Mcleod, Driver and Crisp (1988) showed that when there is more than one moving item in the display, search is confined to the moving set and the static set is effectively ignored. Search was also efficient when the type of dynamics was not motion but looming. Hillstrom and Yantis (1994) found that a looming target among static distractors is efficiently found. Interestingly, the same authors found that a third type of dynamics - a “scintillating” noise pattern - was also efficiently found.

Another important type of dynamics is the abrupt onset of an object. We already mentioned the studies of Yantis and Jonides, who found efficient search for an abrupt onset even when it was not the target. Not surprisingly then, Watson and Humphreys (1995) found very efficient search when the target was always defined by an abrupt onset relative to a set of static distractors. Similarly, Watson and Humphreys (1997) later found that search can be restricted to a whole set of new onsets among a set of (at least by then) old static distractors, although it deserves mentioning that Watson and Humphreys explained this effect in terms of inhibition of the non-onsets. Donk and Theeuwes (2003) found that participants attended the new onsets before they started attending the static items, even when there were up to fourteen objects abruptly appearing. These studies provide evidence that attention can be immediately directed towards onsets.

The physiology of dynamics

We might understand the attractiveness of dynamic items better, if we consider how, at a physiological level, the brain treats dynamic objects. Already at a computational level, the processing of dynamic stimuli is different from the processing of static stimuli. When the visual system is confronted with a static object, this initially causes a cascade of neural activity corresponding to the features of that object (e.g. Livingstone & Hubel, 1988). However, after some time the responding neurons fatigue, and neural response to the static object declines. Neural response to a dynamic stimulus is somewhat different. Initially, the dynamic object triggers the same neural response as a static object. But due to its change, it continues to excite different neurons. Hence the neural response to a dynamic stimulus suffers less from fatigue than neural response to static input. Moreover, to detect motion, static feature analysis does not suffice. The mere activation of a retinal cell by itself is not enough to discern whether an object is moving, let alone in which direction. This problem can only be solved if early in the process, the input of several cells is compared. For instance, by comparing changes in luminance at one point in the retina, and correlating this to changes in luminance at neighboring point in the retina after a delay, the visual system could detect a moving stimulus and its direction (this mechanism is in fact carried out by so-called Reichardt cells, see for instance van Santen & Sperling, 1985). The computational differences are reflected physiologically, as there are two major subsystems in the brain preferentially dealing with either dynamic or static stimuli: the processing of dynamic aspects of stimuli takes mainly place in the magnocellular system, whereas static, or more sustained, properties are preferentially analyzed in the parvocellular system (e.g. Breitmeyer & Ganz, 1976; Livingstone & Hubel, 1988; Zeki, Watson, Lueck, Friston, Kennard & Frackowiak, 1991). This diversion starts already at the retina. Light that enters the eye excites the photoreceptors at the retina, and this electric current is subsequently transmitted to ganglion cells located just behind the retina. There are two types of ganglion cells. M (for *magni* or large) cells that detect primarily whether an object is dynamic or not, and P (for *parvi* or small) cells that detect the wavelength (i.e. the color) and the form of an object. The ganglion cells send their signals to the Lateral Geniculate Nucleus (LGN). The LGN is retinotopically organized (i.e. each retinal cell has a corresponding cell in LGN). Moreover, the LGN is divided up in M- and P-layers, which react to either M-cells or P-cells. Thus, in the LGN there is a strict division between the processing of dynamic and static visual information. This separation remains intact in the primary visual cortex (V1), since different layers in the LGN project to different layers in V1. This strict division between the processing of dynamic and static information is referred to as the M and P pathways. After V1 the P-pathway mainly continues in the ventral cortical pathway that extend to the inferior temporal cortex (also called the what-pathway), whereas the M-pathway becomes the dorsal pathway that extends to the posterior parietal cortex (called the how-pathway). Until the primary visual cortex (V1) the most important dynamic stimuli, onsets and moving objects, are treated alike (Andersen, 1997). This common physiological basis is reflected psychophysically. Adaptation to moving stimuli has been shown to impair the perception of blinking stimuli, and vice versa (Chapman, Hoag, & Giaschi, 2004; Green, 1981). Furthermore, at an attentional level, Folk, Remington and Wright (1994) found evidence that dynamic and static stimuli are treated as two distinct categories. They presented participants with a visual search task, preceded by an irrelevant cue. This cue only affected subsequent search if both cue and search target were either static or dynamic. No cross-over between static and dynamic was found, suggesting that attention reflects the brain-physiology, in the sense that it is organized along a broad division between static and dynamic. These findings suggest that for the visual system a dynamic object is easy to discern when it is surrounded by static objects, since dynamic and static items are so different (physiologically speaking). Interestingly, this would also predict the reverse, since dynamic and static objects are so different, a static object should also be easy to discern when it is surrounded by dynamic objects.

However there is also evidence that not all dynamic stimuli get processed in essentially the same manner. Obviously, the final percept of motion versus flicker is different. This suggests that somewhere later in the process the brain has to distinguish between these inputs. Indeed, after V1 the processing of blinking and moving stimuli seems to diverge. The processing of moving stimuli proceeds to V5/MT, whereas the path of onset-processing is less clear. Some studies suggest that onsets are also processed in specialized areas of MT (O'Keefe & Movshon, 1998), whereas other research indicates that the lateral intraparietal sulcus is essential for processing abruptly appearing objects (Gottlieb, Kusunoki, & Goldberg, 1998). Furthermore, patient-studies have shown that some lesions cause impairment to motion-perception, but not flicker-perception and vice versa (see Vaina, Makris, Kennedy & Cowey, 1998; Vaina, Cowey & Kennedy, 1999; Zihl, von Cramon & Mai, 1983). Importantly, in chapter two of the thesis, we report evidence that for detecting a static object in a dynamic environment, the visual system does *not* treat all dynamic objects alike (the data suggests a split between onsets and moving stimuli), suggesting that the visual system may not just employ a broad division between static and dynamic.

Static among dynamic

Altogether, the fate of a dynamic object against a static background is straightforward, but the reverse - a static target among dynamic distractors– is less clear. Can we easily detect a static item because it is so different from dynamic objects? Or are we predisposed in such a way that we cannot avoid attending to dynamic stimuli? The latter suggestion seems more in line with the absolute bottom up model, whereas the relative bottom up model would state that in a fully dynamic environment static items should actually become more attractive (since they are now the unique ones). The study of McLeod et al. (1988) supports the relative bottom up model. They showed that a non-moving item among moving items can be found independent of the number of moving distractors, although search was still somewhat less efficient than for a moving target among stationary distractors. This appears to suggest that a static item may indeed be efficiently found among dynamic items. However, it remains a question as to whether motion represents a special case or whether in general static items can be efficiently discriminated from dynamic items. Pashler’s (2001) research may shed some light on this issue. He presented participants with a visual search task in which they searched through one subset, while another to-be-ignored subset of items was blinking on and off (i.e. participants searched through all the red items, while the green items were blinking). Contrary to Pashler’s expectations, the distracting subset was more easily ignored when it was blinking than when it was static. Thus, his study indicates that blinking distractors might be ignored easily, allowing efficient search of a static target. However, Pashler's study has some caveats. First, the to-be-searched subset had a unique color. Therefore, any effect might be due to the unique color rather than to the blinking distractors. Second, Pashler did not manipulate set size. Therefore, it is not clear whether blinking of the distractors speeded search (and thus attentional deployment) or factors unrelated to search (such as a general alerting due to the dynamics in the display). Third, Pashler only found a reliable improvement in search when all the blinking items blinked on and off simultaneously. When Pashler made the items blink at random rates he no longer found any reliable effects. Perhaps then Pashler's results were due to common-onset grouping (where items that appear together are clustered, see Jiang, Chun, & Marks, 2002) rather than blinking.

The issue as to whether static objects can attract attention was further investigated by Theeuwes (2004), who presented participants with a static target surrounded by distractors that abruptly changed orientation (i.e. a vertical or horizontal bar among tilted bars). Theeuwes (2004) found that the static target was efficiently detected and concluded that static objects can efficiently be found among dynamic distractors in general. However, Davis and Leow (2005) argued that in Theeuwes' displays apparent motion could still play a role, since a bar that changes orientation can also be viewed as a rotating bar. Therefore, Davis and Leow (2005) suggested Theeuwes (2004) essentially found the same result as McLeod et al., namely that a static target can be found among moving distractors. Theeuwes' (2004) results still did not show that a static item can be found among dynamic distractors in general.

Thus, the issue was still unresolved. Can a static target be found in any dynamic environment, because it is unique against this background? Or is it hard to find a static target even under these conditions, because we are genetically inclined to look for dynamic objects? In this thesis, I present three studies that investigate this issue in depth. These studies show that, in accordance with the relative bottom up model, a static target can be efficiently found in various dynamic environments. Furthermore, this efficient detection is not based on an advanced motion-filter, nor on top-down settings. In Chapter two, Pinto, Olivers and Theeuwes (2006) investigate whether a static target can be found when it is surrounded by dynamic, non-moving distractors. Pinto et al. presented participants with a static target surrounded by blinking items. This set-up ensured that no form of motion could play a role. In follow-up experiments Pinto et al. excluded possible confounds from luminance, long-range apparent motion and temporal grouping. With all possible confounds eliminated, the static target was still efficiently detected, implying that a static target can be immediately detected among several types of dynamical distractors. In Chapter three, Pinto, Olivers and Theeuwes (in press-a) investigated whether, for the attentional system, searching for a static target among blinking distractors is essentially the same as searching for a static target among moving distractors. Pinto et al. found evidence that this was not the case. They showed that certain manipulations, such as making the objects equiluminant with the background, affected the search for a static object among moving but not among blinking distractors. Thus, the rejection of blinking and moving distractors cannot be entirely based on the same mechanism (otherwise a manipulation would either affect both or none of these capabilities). The results of Pinto, Olivers and Theeuwes (in press-a) again suggest that the efficient detection of a static target in a dynamic environment stems from a general rule and not a particular exception.

These results put severe constraints on the absolute bottom up model. Apparently, dynamic objects loose their attractiveness (in favour of the static object) given the right surroundings. These findings clearly support the main tenet of the relative bottom up model, namely that the saliency of any object (and thus how much it attracts attention) depends on which objects surround it.

A further question would be if attention goes to the static object only because it is salient, or also because people *want* to attend to it. In Chapter four, Pinto, Olivers and Theeuwes (in press-b) investigate this issue, by employing the irrelevant-feature paradigm. In this set-up all objects except one were dynamic, and the static object was mostly one of the distractors. Therefore, participants no longer had the incentive to look for a static object (this set-up is similar to the one in earlier mentioned studies of Yantis and Jonides). Pinto et al. found that when the target happened to be static, search was more efficient than when it was dynamic. Importantly, this indicates that not only a static object can guide attention, it involuntarily captures attention when surrounded by dynamic objects.

Synchronicity: dynamics in tune among dynamics out of tune

Attention may not only be needed to distinguish objects from each other, but also to distinguish objects from the background. Previous research has revealed that *grouping principles* are essential for separating items from the background. Therefore, if attention plays a crucial role in foreground/background dissociation, it is expected that attention is needed for grouping.

Over centuries, several grouping principles have been discovered. An important non-dynamic grouping principle is grouping on symmetry, where items that are symmetric are seen as belonging together. An example of dynamic grouping is grouping by common fate, items that move together are perceived as one object (Wertheimer, 1923). Another dynamic grouping example is grouping by common onset, where items that appear together are seen as one object or surface (Jiang et al., 2002). Similarly, Sekuler and Bennett (2001) discovered grouping by common luminance change, items that change luminance at the same time and in the same direction are clustered.

A crucial question is whether attention is involved in these grouping mechanisms. The evidence so far is mixed. For instance, in visual search Olivers and van der Helm (1998) showed that focused attention is needed for detecting symmetry. On the other hand, common fate grouping and common onset grouping appear to occur without the need for focused attention, even when the to-be-grouped items are interspersed with irrelevant distractors (McLeod, Driver & Crisp, 1988). Thus, it could be argued that dynamic grouping against static backgrounds does not require attention. This is in line with both the relative and the absolute bottom up account that both state that dynamic items in static backgrounds are good in guiding attention, and therefore should be separated from their backgrounds without the need for attention.

A newly discovered grouping principle, *temporal grouping*, provides a new testing ground for attention and grouping. This is because in temporal grouping displays, both the figure *and* the background are dynamic. Figure and background typically consist of continuously and rapidly changing elements. The striking finding is that, to obtain grouping, the elements do not need to change in the same direction, nor do they need to undergo the same type of change. As long as they change at the same moment, they are grouped together.

Evidence for the existence of temporal grouping started with Fahle (1993). He found that when a group of dots changed luminance out of phase with the surrounding dots, participants saw these dots as one group. He concluded that the common moment of change caused the grouping. However, his results might also be explained by common onset grouping, since the target dots all appeared at the same moment, at a time when all the background dots were switched off.

Lee and Blake (1999) continued to investigate grouping solely based on temporal information, by presenting participants with a field of Gabor patches, each of which contained a randomly oriented grating moving in a direction perpendicular to this orientation. At random moments in time, each Gabor patch could change motion direction (by 180°). In the background these motion flips were uncorrelated, but for a central rectangular region the patches changed motion direction in synchrony. Thus, in the target rectangle the motion *direction* of the gabor patches was uncorrelated, only the *moment* that the motion direction changed was synchronized. Participants had to determine the overall orientation of the target rectangle (horizontal or vertical) and could do so almost without errors. Lee and Blake (1999) concluded that temporal information alone is sufficient to segment spatial regions from their background (see also Aslin, Blake, & Chun, 2002; Guttman, Gilroy, & Blake, 2005).

Thus, temporal grouping appears to be a grouping principle that the visual system employs. However, it is unclear if this principle requires attention. Reasoning along the lines of the absolute bottom up account would suggest that it does. None of the elements by itself has any unique properties, thus when it comes to absolute qualities none of the items could serve as a base for attention. Since groups or objects that are segregated pre-attentively from their surroundings can serve as a base for attention, this would imply that the temporal group cannot be segregated pre-attentively. Conversely, the relative bottom up model predicts the opposite. According to this model attentional distribution is based on temporal and spatial comparison. Temporal comparisons underlie temporal grouping, and thus temporal groups could serve as an attentional base (and thus be construed pre-attentively).

In Chapter 5, Pinto, Olivers and Theeuwes (in press - c) investigated this issue by employing a visual search task. They presented participants with a visual search task that encompassed several temporal groups. If these temporal groups require attention to be perceived, then it is expected that the more temporal groups there are, the longer it takes participants to respond. Pinto et al. found that the number of temporal groups did not affect reaction times. This suggests that temporal grouping occurs without attention. Thus, Pinto et al.'s findings provide another context - figure-ground segregation - in which the relative bottom up model seems to fit the data better than the absolute bottom up model.

The two dynamic situations outlined so far mostly compared the relative bottom up model to the absolute bottom up model. In these dynamical settings, the relative bottom up model fared better. However, in these situations the bottom-up models have hardly been compared to the top-down model. In the next section we will pitch the bottom up models against the top-down model by investigating what the influence of display changes between trials is on attentional distribution.

Dynamic changes between trials

Changing search displays

An item which carries a unique feature on one dimension (e.g. an object with a unique color) is referred to as a singleton (Pashler, 1988). According to the bottom-up view singletons capture attention, irrespective of top-down settings (e.g. Theeuwes, 1991, 1992). If this claim is correct, then there is at least one type of stimulus, namely a singleton, that defies top-down control over attention. This then would, at least partly, falsify the top-down view. Therefore, Yantis and Egeth (1999) have investigated whether there are top-down factors that can modulate attentional capture by singletons. In their study participants performed a difficult search task, for instance the search for a vertical bar among tilted bars. However, sometimes the target carried a unique color, which turned the target into a singleton (the unique color could also be attached to a distractor). Yantis and Egeth manipulated how often the target and singleton coincided, making it more or less beneficial for the subject to attend to singletons. They found that when the target was rarely a singleton (e.g. on 20% of the trials) search was inefficient even on the trials where the target happened to be a singleton. However, when the target was often a singleton (e.g. on 80% of the trials) search was aided when the target carried a unique color. Their findings suggest that participants only used color information when it was beneficial (and therefore supposedly wanted to use this information). This would mean that attentional capture by singletons is under top-down control.

Another possible example of top-down influence on attentional capture by singletons comes from the studies of Theeuwes (1991, 1992). In these studies participants searched for a shape singleton (e.g. a diamond among circles) and sometimes a color singleton would be present as well (e.g. one of the circles would be red, while all the other objects would be green). In Theeuwes' (1991) experiments participants always searched for a shape singleton, but they did not know beforehand which shape singleton. That is, they searched for the unique shape, either a diamond among circles or vice versa. In this case Theeuwes found that participants were, on average, 150 ms slower when a color distractor was present. In contrast, in Theeuwes' (1992) study, participants did know the exact shape they were looking for. That is, within one block of trials, they would either always search for a diamond among circles or vice versa. In this study a distractor cost of only about 20 ms was found. Thus, these two studies combined seem to corroborate Yantis and Egeth's findings. In this case, it seems that knowing the exact shape of the target beforehand reduces attentional capture.

Importantly, an alternative explanation of the Yantis and Egeth, and Theeuwes studies is possible. This explanation would rely on dynamic changes between displays, allowing for *intertrial priming*, rather than static knowledge about the singleton which remains constant across a block. The importance of intertrial priming in search tasks has been demonstrated by Maljkovic and Nakayama (1994). They found that when a target carries a feature that it also carried on a previous trial, it is found faster. Thus, if a target is red on the current trial, and it was also red on the previous trial, reaction times are faster, than when the target was green on the previous trial. Such priming effects are not limited to one trial back. Reaction times were even affected by what the target color was up to 7 trials before the current trial (i.e. participants were faster if the current target color matched the target color seven trials before the current trial). Priming seems not to be under top-down control. First, participants have no recollection of the target color more than one trial back. This makes it unlikely that they actively searched for the color previously associated with the target. Second, when participants are induced to search for a specific color, priming effects are not modulated. For example, if participants know that on most trials the target alternates between colors (e.g. from green to red), they should search for another color than the target just had. However, even in this case, participants are faster when the target color repeats than when it changes. Thus, the priming of the target color seems not to be affected by what participants expect or look for (Maljkovic & Nakayama, 1994). Similar priming effects are found for distractors. Features associated with the distractor are automatically inhibited on subsequent trials. Thus if a distractor was red on a previous trial, then participants will be less inclined to attend to red on the current trial. Note that when a color that was previously associated with the distractor now becomes associated with the target (or vice versa) priming is at its strongest. In that situation participants are maximally slowed down due to target-distractor priming.

Perhaps then, Yantis and Egeth's (1990) results were not due to overall knowledge, but to priming on the trial level as argued by Olivers and Humphreys (2003). Increasing the coincidence, increases the number of times the target has the same color as on the previous trial, thus increasing target-target priming. Furthermore, it reduces the number of times that the target on the current trial has the color of a distractor on the previous trial, reducing target-distractor priming. Thus, by increasing the coincidence between target and singleton, search may be made more efficient due to priming, rather than to knowledge.

Similarly, the difference in distractor costs between Theeuwes (1991) and Theeuwes (1992) studies might also be due to changed intertrial priming relations rather than distractor knowledge. In a pure block (i.e. when the shape of the target would remain the same throughout a block) the shape of the distractor on the current trial would always be the same as the shape of the distractor on the previous trial, maximally suppressing the distractor through distractor-distractor priming. However, in a mixed block (i.e. when the shape of the target and of the distractors could vary from trial to trial) the shape of distractor on the current trial was not always the same as the shape of the distractor on the previous trial. Furthermore, sometimes the shape of the distractor on the current trial was the same as the shape of the target on the previous trial, maximally enhancing the attractiveness of the distractor through target-distractor priming. Thus, perhaps priming, rather than knowledge, caused more suppression of the distractor in a pure block than in a mixed block.

In Chapter six, Pinto, Olivers and Theeuwes (2005) investigated this issue. First they showed that the distractor effect in the mixed block is indeed larger than the distractor effect in the pure block. Second, they compared repetition trials (i.e. when the shape of the target was the same on the current and the previous trial) in a mixed block to trials in a pure block. Note that in a pure block, all trials are repetition trials. Thus, from a priming perspective repetition trials in the mixed block are largely the same as trials in the pure block (since in both cases target and distractor shapes repeat). However, from a knowledge perspective, repetition trials in the mixed block are entirely different from trials in the pure block. Since trials are randomly presented, in the mixed block participants have no way of knowing that the target will have the same shape on the current trial as on the previous trial (when on the previous trial the target was a diamond this does not increase the chance that on the current trial the target will again be a diamond). Conversely, in the pure block, participants know beforehand which shape the target will carry, since in a pure block the target shape is the same on every trial. Thus, if the reduced distractor effect in the pure block is caused by participants knowing the exact shape of the target, then there should be a larger distractor effect on repetition trials in the mixed block than on trials in the pure block. However, if intertrial priming underlies the reduced distractor effect in the pure block, then the distractor effect on repetition trials in the mixed block should be (roughly) equal to the distractor effect in the pure block. Importantly, Pinto et al. found the latter. There was no difference between the distractor effect on repetition trials in the mixed block and the distractor effect in the pure block. Pinto et al.'s findings suggest that priming and not knowledge causes the reduced distractor effect.

Summarizing, although studies have been put forward that seem to show that target or distractor knowledge influences attentional distribution, closer examination reveals that these claims may have been incorrect. Not target knowledge, but dynamic changes between displays caused these effects. This strengthens the bottom-up models. It seems that target knowledge cannot influence attentional capture by singletons, suggesting that this capture is indeed outside of the control of the subject.

General Discussion

In the current thesis we have investigated three theories on attentional allocation. The relative bottom-up model states that attention is allocated based on comparisons between stimuli. The absolute bottom-up model suggests that attention is attracted to certain types of stimuli (especially dynamic ones). The top-down model argues that not stimuli, but search goals determine where attention goes.

We have reviewed two situations. The first situation involved dynamic displays, in which the target had no property by itself that could attract attention. First, we considered a static target in a dynamic environment. Second we investigated a dynamic target that was only different from its dynamic background, by integrating stimulus information over time. In both cases the target could be efficiently found, indicating that attention could be directed to the target immediately. Both findings limit the absolute bottom-up model and show that, at least in some cases, attention is driven by stimulus properties compared (over space or time) to other stimulus properties. In the second situation we reviewed how display changes across trials influences attentional allocation towards a singleton. We found that knowledge does not affect how much a singleton attracts attention, but priming (resulting from dynamic display changes) does. All findings discussed here support the relative bottom-up model.

Bottom-up versus top-down

It should be mentioned that the bottom-up models do not claim that attention is *always* bottom-up driven. First, this would hold the intuitively absurd conclusion that people can never determine themselves what they attend to, but are slaves to whatever stimuli they are confronted with. This would make day to day operating virtually impossible. Furthermore, such a notion would not be able to explain the large body of evidence that many features can guide attention. If a subject performs a search task, and knows that the target has a certain distinguishable feature, this aids his search process (Wolfe, 1994). If attention would *always* be bottom-up driven, then attention would move towards objects, irrespective of whatever knowledge or search goals the subject has. Consequently, in such a scenario knowing what to look for should not help the search process. However, the claim of the bottom-up models is more modest. They claim that *initial* attention is bottom-up driven. Thus, the controversy of top-down versus bottom-up comes down to questions regarding initial attentional deployment. If you are confronted with a new visual scene, can you immediately control where your attention goes? According to the top-down theories you can, whereas bottom-up theories claim that this is not possible. The findings we have discussed so far support the bottom-up view. Further support for the bottom-up view comes from several studies. Van Zoest, Donk and Theeuwes (2004) presented participants with a visual search task in which two singletons were present (and various non-singleton objects), one was a distractor, the other one the target. They found that fast eye movements (i.e. eye movements that started shortly after image presentation) always went to the most salient singleton, irrespective of what the target was. Conversely, slow eye movements always went to the target, irrespective of what the most salient item was. Since eye movements are preceded by attention (Deubel & Schneider, 1996; Irwin, 1992), this suggests that attention first goes to the salient object, and then moves on to the object that matches the search goal.

The hypothesis that initial attention is not under voluntary control could perhaps receive support from the *recurrent processing* theory of awareness (Lamme & Roelfsema, 2000). According to this theory participants become aware of visual information after it has been recurrently processed. Thus, according to this theory during the first feedforward sweep (which lasts about 100ms) participants do not yet consciously see the stimulus (see Figure 1.5). Only after feedback from other cortical areas arises, participants consciously perceive the image. Intuitively it makes sense that as long as you do not see an image, you cannot voluntarily steer your attention around. Thus, it could be that the initial sweep of attention is bottom-up driven, due to limitations in visual awareness.

Since it is only the first sweep that is bottom-up driven, the bottom-up models are more difficult to falsify than just providing evidence that certain stimuli do not always capture attention. The timing becomes crucial. For instance, in the study of Folk, Remington and Johnston (1992), where they showed that a cue that does not match the search goals does not affect attention 150 ms later, the 150 ms difference between cue and target might be crucial. It could be that attention initially did go to the incongruent cue (i.e. the cue that did not match the search goal), but was already disengaged 150 ms later. This explanation is supported by a study of Theeuwes, Atchley and Kramer (2000), who found that when the the time between cue and search display was shortened RT effects of the incongruent cue could be measured.

That is, when time between search display and incongruent cue was less than 100 ms, participants were slowed if the incongruent cue was at a different location then where the target would appear, and they were faster when the cue appeared at the same location as the target, indicating that attention did go to the cue.

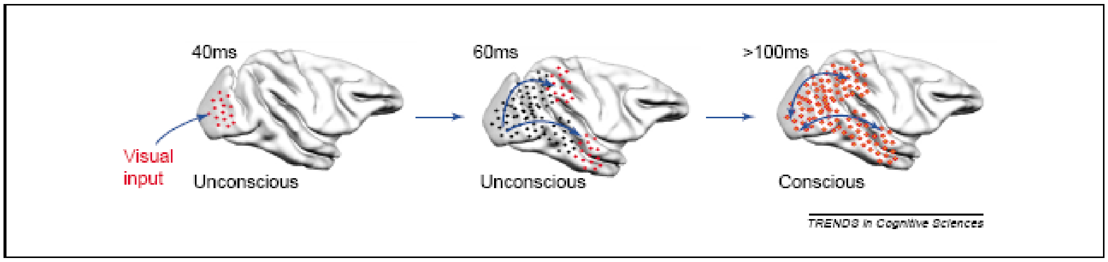


Figure 1.5. Illustration of the time course of feed-forward and feedback neural activation (taken from Lamme, 2003).

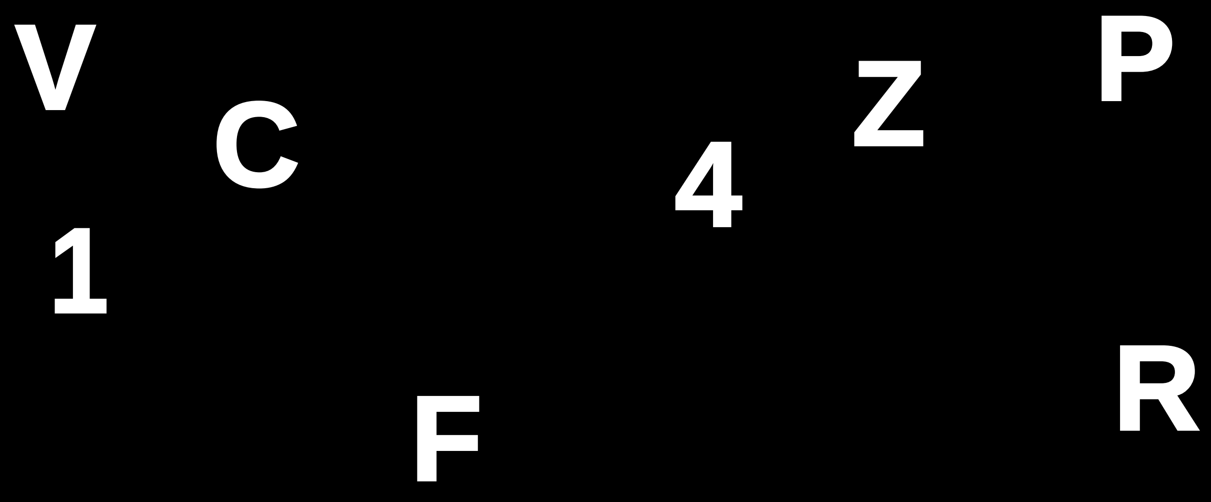
Relative versus absolute bottom-up

Although in the current thesis we present findings supporting the relative bottom-up model over the absolute bottom-up model, it should be pointed out that there is also evidence for the reverse. First, there is a search asymmetry between static and dynamic objects. A dynamic object in a static environment is found effortlessly, with search slopes indistinguishable from 0 ms/item (e.g. Mcleod et al., 1988; Watson & Humphreys, 1995). However, a static target in a dynamic environment produces a small, but significant, search slope (Pinto et al., 2006). Thus, it seems that differences between target and distractors do not entirely determine attentional deployment. After all, a static target in a dynamic environment is as different from its surroundings as a dynamic target in a static environment, but still the latter is found more easily. This search asymmetry could be due to an attentional bias. Müller and von Mühlenen (1999) found that when looking for motion-form conjunctions, participants were initially faster when they searched for a moving target than a static target. They hypothesized this was due to an attentional bias to look for dynamic items, since in everyday life attending to dynamic objects is more useful then attending to static objects (since most objects are static). Their suggestion was supported by the finding that after intensive training participants were no longer faster at detecting the motion target, supposedly since an intensive training cancelled the attentional bias. Note that even if the attentional bias can explain the search asymmetry, then this still implies that initial attention is driven by more than stimuli differences alone, and that for some reason certain stimuli are more easily attended than others.

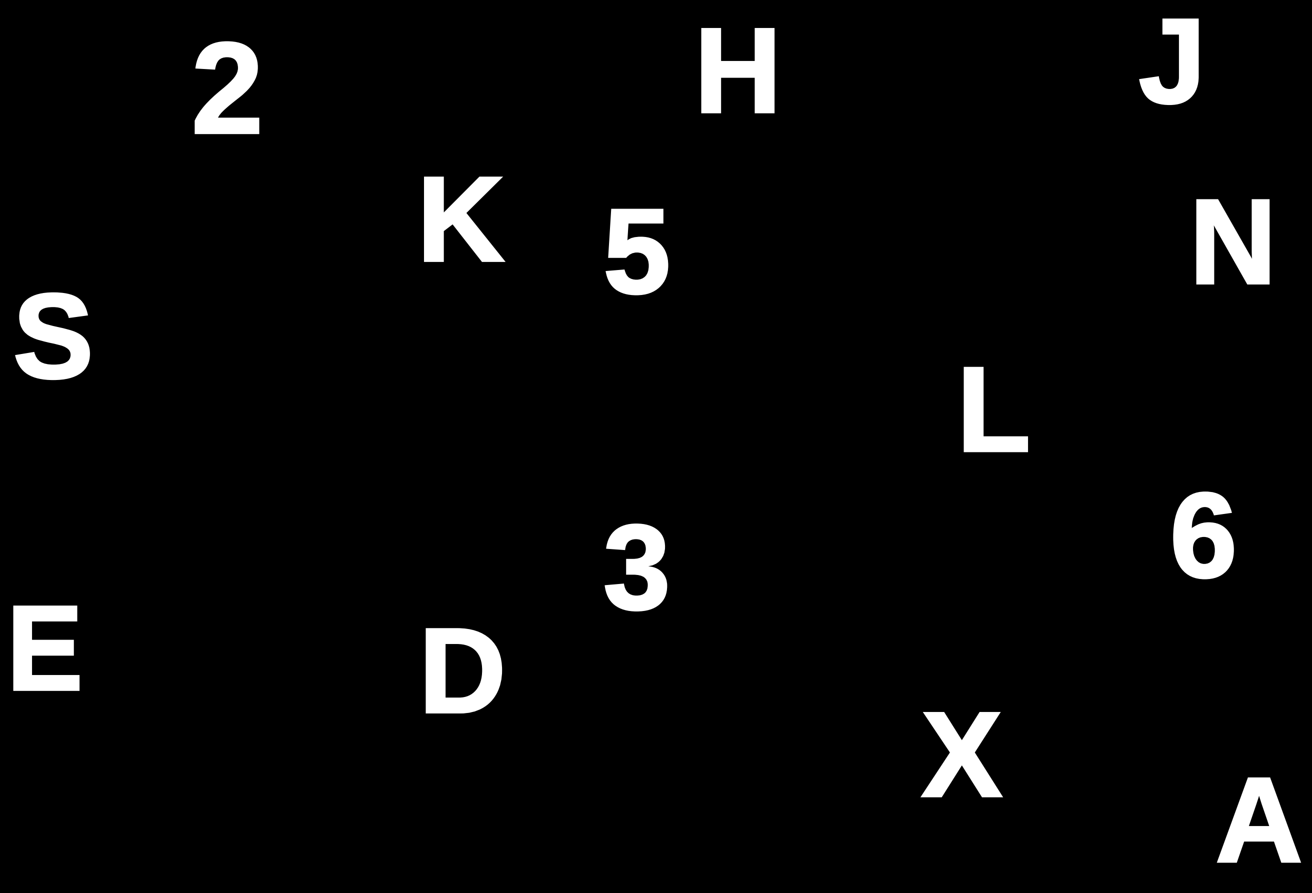
Conclusion

All in all, a single theory on which factors determine attentional allocation seems not to yield a simple answer. Not one of the three models on attention seems to be entirely correct. Rather, it seems that the correct explanation demands a combination of these models. Attention might be allocated as follows. Initially attention is bottom-up driven, but later on top-down factors determine where attention is allocated. During the initial deployment of attention both feature differences and features by themselves are important.

Perhaps this variety of factors explains why different researchers find evidence for different models. If you measure during quick attentional deployment you will find evidence for the bottom-up models, whereas slowing participants down will yield data that supports the top-down model. Furthermore, under some circumstances properties by themselves are more important than property differences and vice versa. This leads to research finding evidence for the absolute or the relative model depending on the search task employed. All in all, this is crucial for the aim of attentional research. Rather than trying to establish which model is correct, it should be determined which model is correct under which circumstances.



When is search for a static target among dynamic distractors efficiënt?



Abstract

Intuitively, dynamic visual stimuli, such as moving objects or flashing lights, attract attention. Visual search tasks have revealed that dynamic targets among static distractors can indeed efficiently guide attention. The present study shows that the reverse case, a static target among dynamic distractors, allows for relatively efficient selection in certain but not all cases. A static target was relatively efficiently found among distractors that featured apparent motion, corroborating earlier findings. The important new finding was that static targets were equally easily found among distractors that blinked on and off continuously, even when each individual item blinked at a random rate. However, search for a static target was less efficient when distractors abruptly varied in luminance, but did not completely disappear. We suggest that the division into the parvocellular pathway dealing with static visual information on the one hand, and the magnocellular pathway common to motion and new object onset detection on the other, allows for efficient filtering of dynamic and static information.

From everyday experience, it is clear that dynamic properties of the visual world can guide us in directing our attention. Dynamic stimuli are characterized by transient changes in the visual pattern, such as those induced by motion and abrupt onsets. For example, when searching for a friend in a crowd, it helps if that friend is waving a hand. Another example is provided by the flashing lights of ambulances, which are explicitly designed to attract attention and notify us of potential danger. It is exactly this detection of potential danger that has been thought to be the underlying reason why the visual system is so sensitive to dynamic information, since movement or abrupt appearances may signal the presence of a competitor or predator. Alternatively, for the predator, dynamic information may reveal something about the prey (see e.g. Abrams & Christ, 2003; Hillstrom & Yantis, 1994; Tipper & Weaver, 1998, for arguments along these lines). In the present paper we focus on the complementary question, namely whether, in a dynamic environment, attention can also be efficiently directed towards static objects.

Previous research has indeed confirmed that participants can efficiently detect a dynamic target among static distractors. Using a visual search task in which observers had to detect a moving target among static distractors, Hillstrom and Yantis (1994) and Yantis and Egeth (1999) found no effect of the number of distractors on search reaction times (RTs; i.e. search slopes were flat), indicating that the moving target could be found efficiently and in parallel across the displays used. Similarly, McLeod, Driver, and Crisp (1988) showed that when there is more than one moving item in the display, search is confined to the moving set and the static set is effectively ignored. With standard moving stimuli, the transients are accompanied by a position change of the object. However, dynamic targets that do not change position also guide attention. For instance, looming targets among static distractors are efficiently found (Hillstrom & Yantis, 1994). This effect is probably related to motion, since the looming is perceived as a 3D movement towards the observer. Interestingly, the same authors also reported efficient search for targets that remained at their locations but that were defined by a “scintillating” noise pattern, a characteristic that might not be so clearly associated with movement.

Another important dynamic property other than motion is the abrupt onset or appearance of an object.Watson and Humphreys (1995) found very efficient search when the target was always defined by an abrupt onset relative to a set of static distractors. Similarly, Watson and Humphreys (1997) later found that search can be restricted to a whole set of new onsets among a set of (at least by then) old static distractors. Both studies provide evidence that, when relevant, onset differences between stimuli can be used to effectively guide attention.

In sum, so far studies have shown that a dynamic stimulus is efficiently selected among static items. However, it is not clear whether the reverse case – a static target among dynamic distractors – allows for efficient detection too. McLeod et al. (1988) showed that a non-moving item among moving items can be found independent of the number of moving distractors, although search was still somewhat less efficient than for a moving target among stationary distractors. This appears to suggest that a static item may indeed be efficiently found among dynamic items. However, it remains a question as to whether motion represents a special case in this or whether static items in general can be efficiently discriminated from dynamic items. In a recent study, Theeuwes (2004) sought to explore this issue by presenting participants with a search task in which the target was always a static item (either a vertical or horizontal bar; the participant's task was to detect its orientation), whereas the distractors were all abruptly changing bars of various orientations. That is, in one condition, all distractor bars changed, in a single frame, from horizontal or vertical to either left or right oblique (by 45°, hence after the change the target was the only horizontal or vertical bar). In another condition, in addition to changing orientation, the distractors also disappeared from their old locations and abruptly reappeared randomly at new locations (hence the target was also the only bar that kept its position and was not characterized by an abrupt new onset). The key finding was that search was much more efficient (as indicated by small or even absent set size effects) than in a control condition in which all items (including the distractors) were static. Theeuwes (2004) argued that the visual system calculates in parallel across the whole visual field whether an item is dynamic or static. Attention then does not prefer a dynamic item per se, but the item that differs the most from its surroundings – in this case the static item.

However, Theeuwes' (2004) explanation did not go by undisputed. Davis and Leow (2005) recently argued that it is actually not the distinction between dynamic and static that allows for efficient search, but that motion is the crucial factor. They argued that Theeuwes' (2004) displays allowed for apparent motion to operate as the items changed from one orientation or position to the other. In line with McLeod et al.'s (1988) earlier results then, a static among moving items may indeed have been efficiently found. In contrast, a static item among items with other dynamic features, like luminance changes or onsets, may not be found efficiently. In support of this Davis and Leow (2005) found that search was highly inefficient for a static target among distractors that abruptly changed both color and luminance (without disappearing). Davis and Leow (2005) concluded that filtering on the basis of motion may have a special status, whereas filtering a single static item from a set of items carrying dynamic properties other than motion (such as abrupt luminance changes) may be very difficult.

There may be a good reason for why a static target allows for more efficient search among moving distractors than among abrupt onset distractors. Although there is substantial evidence that the automatic capture is contingent on stimulus-specific or display-wide attentional settings (e.g. Folk, Remington, & Johnston, 1992; Gibson & Kelsey, 1998), there is also evidence that abrupt onsets automatically capture attention even when they are not relevant to the observer (e.g., Jonides, 1981; Remington, Johnston, & Yantis, 1992; Theeuwes, 1991; Todd & Van Gelder, 1979; Yantis & Jonides, 1984). In a classic example, Yantis and Jonides (1984) presented participants with a varying number of items. After 1000 ms, parts of the items were switched off, revealing the to-be-searched letters. Simultaneously with these offsets, one new item appeared through an abrupt onset. The abrupt onset was not predictive of the target, yet Yantis and Jonides (1984) found search to be very efficient when the target was the new onset (as indicated by flat search slopes), compared to when it was one of the previewed items. Yantis and Jonides (1984) therefore concluded that onsets capture attention, and do so automatically. Important for the present discussion is the finding that when the very same paradigm is applied to motion (i.e. one of the items is moving – occasionally the target), search slopes are not flat when the target is the only moving item in the display, indicating that motion per se does not capture attention automatically (Hillstrom & Yantis, 1994; Yantis & Egeth, 1999; note that Franconeri and Simons, 2003, do report some capture for moving stimuli, but Abrams and Christ, 2003, have argued that it is actually the motion *onset* that captures attention, not motion per se). The difference in the ability or strength with which motion and abrupt onset stimuli can capture attention may explain why one allows for more efficient search of a static target than the other: Moving distractors may be effectively ignored, whereas abruptly onsetting distractors may automatically capture attention, making search for the static target more difficult.

In the present paper we present six experiments following up on Theeuwes' (2004) results. We investigated whether his finding that a single non-changing item can be easily found is indeed best explained by a motion filter, as Davis and Leow (2005) suggested, or whether there is also support for the idea that static items can be efficiently detected in dynamic displays in general. To this end, we introduced dynamic displays in which the distractors would abruptly blink on and off in a continuous cycle without changing orientation or position. We argued that this should minimize the apparent motion in the displays and therefore allow for a more stringent test of the hypothesis that static targets can guide attention among dynamic items. This blinking condition was then compared to an apparent motion condition in which the distractors did change orientation (comparable to Theeuwes', 2004 original displays), and to a control condition in which all items were static. If only motion allows for efficient segmentation of target and distractors, then we should find an improvement relative to the control condition only for the apparent motion condition. However, if we find an equal improvement in the blinking condition, then this lends support to the idea that, more generally, static items can be efficiently detected among dynamic items.

A similar manipulation was recently reported by Pashler (2001). In his visual search task two sets of items were presented, one red, the other green. Participants were instructed to search one set (e.g. the red one), which would remain static throughout the trial. Importantly, when search started, the other set (e.g. green) could also remain static, or it could start blinking, as it continuously disappeared and reappeared throughout the trial. Pashler expected that search in the latter condition might be more difficult, since the continuous blinking was likely to capture attention away from the relevant set. To his surprise, he found that overall RTs in the blinking condition were somewhat faster, indicating that observers could make use of the differences in dynamics to detect the static target. However, there may be a number of caveats in Pashler's (2001) study. First, in the blinking condition of his first two experiments, all dynamic distractors blinked on and off in synchrony. This may have allowed for strong temporal grouping between blinking elements, allowing for them to be efficiently rejected as a single set (Alais, Blake, & Lee, 1998; Blake & Yang, 1997; Lee & Blake, 1999; Leonards, Singer, & Fahle, 1996; Usher & Donnelly, 1998). This grouping may have been further strengthened by the fact that Pashler used different colors for the static and dynamic sets. In a third experiment, Pashler (2001) abandoned the synchrony and made the dynamic items appear and disappear at random (within constraints). Unfortunately the results were unclear. There was some RT benefit in the dynamic condition, but it was relatively small, limited to target absent trials, and moreover accompanied by increased errors on target present trials. Note also that Pashler did not vary set size, thus performance could only be measured in terms of overall RTs and not in terms of search slopes (reflecting search efficiency). This leaves open the possibility that search efficiency may actually have benefited substantially from the differences in dynamics, but that observers needed some time to perform the initial segmentation (leading to increased overall RTs; i.e. a slope effect vs. an intercept effect respectively). In the present experiments, we controlled for these, and several other factors. We consistently find that a static target is efficiently detected among continuously blinking distractors. Contrary to Davis and Leow (2005) we conclude that efficient search for a static among dynamic items is not limited to motion displays. In a final experiment we end up investigating how our results and Davis and Leow's (2005) results can be reconciled.

Experiment 1: Efficient search for a static target among blinking distractors

In Experiment 1 participants searched for a static horizontal or vertical line segment among tilted distractors (see Figure 2.1). In the *control* condition all distractors were static. We presented participants with two dynamic conditions. In the *apparent motion* condition they searched for a static item among items that abruptly flipped back and forth between two orientations, in a continuous cycle. In the *blinking* condition they searched for a static item among items that continuously blinked on and off (at the same frequencies as the flipping in the *apparent motion* condition). We used four different frequencies, and two different phases within each frequency, so that the distractors would not all flip or blink at the same time. If the hypothesis that static items in general can guide attention is correct then we expect efficient search slopes for both the *blinking* as well as the *apparent motion* condition. If, on the other hand, motion represents a special case in allowing for efficient guidance of attention by static items, we should only see efficient search in the *apparent motion* condition.

Method

Participants: Six participants, ranging in age from 21 to 31 years, average 24.5 years, took part as paid volunteers. All participants completed all of the conditions. All had normal or corrected-to-normal vision.

Apparatus and Stimuli: The experiment was conducted on a computer with a Pentium IV processor, a 17 inch monitor and a standard QWERTY keyboard. The software package E-Prime was used for the layout and timing of the experimental trials. The stimulus field consisted of a 7 x 6 imaginary matrix (12.68° x 8.26° visual angle). In its cells white line segments (Commission Internationale de l'Eclairage [CIE] x, y coordinates: .283 , .301) of size 0.76° were randomly placed.

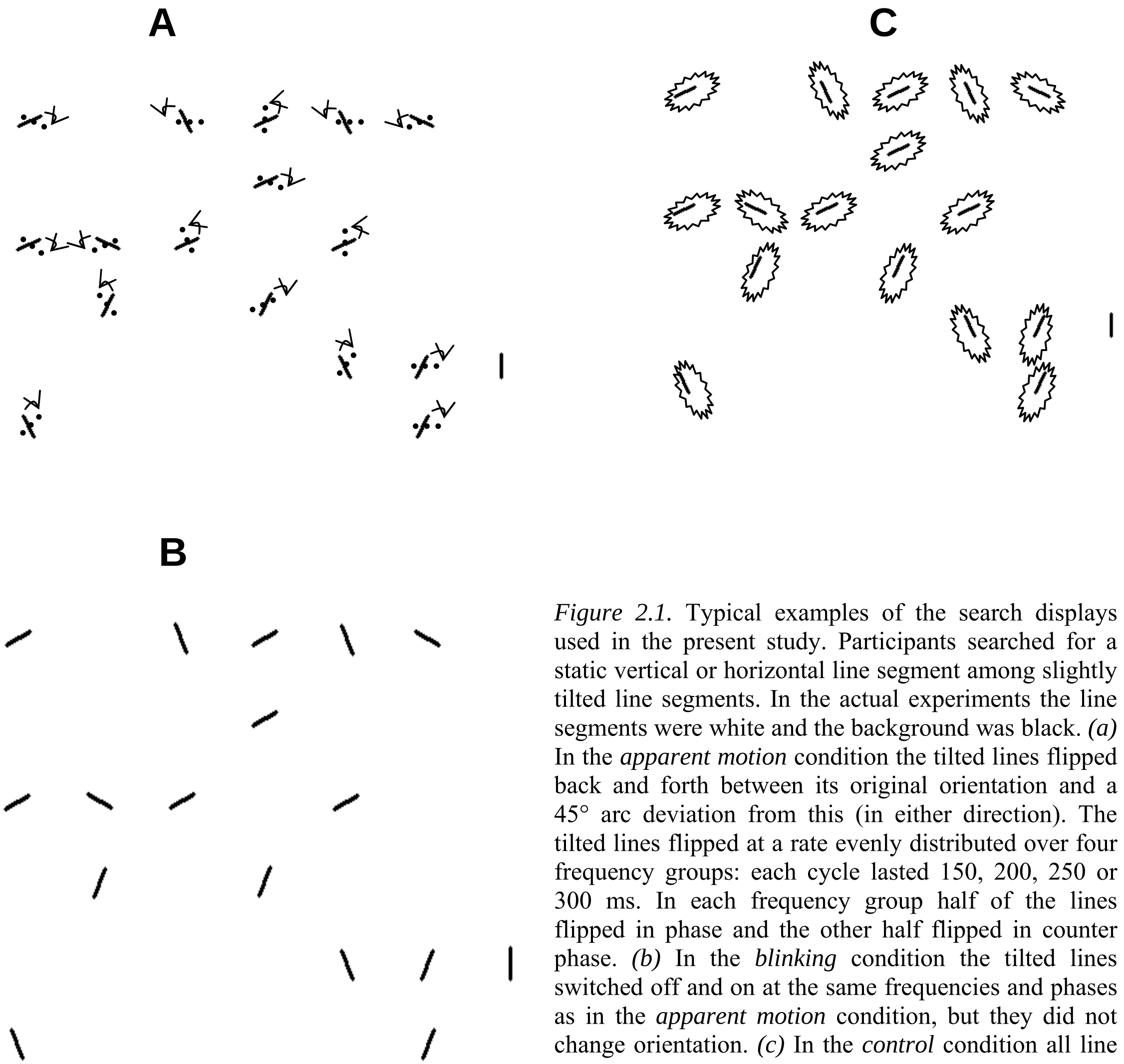


Figure 2.1. Typical examples of the search displays used in the present study. Participants searched for a static vertical or horizontal line segment among slightly tilted line segments. In the actual experiments the line segments were white and the background was black. *(a)* In the *apparent motion* condition the tilted lines flipped back and forth between its original orientation and a 45° arc deviation from this (in either direction). The tilted lines flipped at a rate evenly distributed over four frequency groups: each cycle lasted 150, 200, 250 or 300 ms. In each frequency group half of the lines flipped in phase and the other half flipped in counter phase. *(b)* In the *blinking* condition the tilted lines switched off and on at the same frequencies and phases as in the *apparent motion* condition, but they did not change orientation. *(c)* In the *control* condition all line segments remained static.

The distractors could appear anywhere on the 7 x 6 matrix, the target could appear anywhere except in the middle (row 4 or column 3 or 4). The luminance of the line segments was 65.62 cd/m^2, the background 0 cd/m^{2}as measured with a Tektronix photometer. In each display there was a vertical or horizontal white line target, among white lines that were tilted 22.5° to either side of the horizontal or vertical.

Procedure: Participants sat at approximately 90 cm from the monitor, with their fingers resting on the z- and m-key which were used as the response buttons. The experiment consisted of fifteen blocks, each containing ninety trials. The order of the blocks was repeated every three blocks, and was counter-balanced across the participants. Each sequence of three blocks corresponded to three main conditions: in the *apparent motion* condition participants looked for a static horizontal or vertical white line among tilted white lines that flipped back and forth between its original orientation and a 45° arc deviation from this (in either direction). The tilted lines flipped at a rate evenly distributed over four frequency groups: each cycle lasted 150, 200, 250 or 300 ms. In each frequency group half of the lines flipped in phase and the other half flipped in counter phase. In the *blinking* condition participants looked for a static horizontal or vertical white line among blinking tilted white lines. This means that the tilted lines switched off and on at the same frequencies and phases as in the *apparent motion* condition, but they did not change orientation. In the *control* condition participants looked for a static horizontal or vertical white line among static tilted white lines. In all conditions set sizes varied randomly within a block, between 9, 17 and 33 (i.e. 8, 16 or 32 distractors plus one target). The task was to determine the orientation of the target element. Participants pressed “z” for vertical, and “m” for horizontal lines. The task was assumed to require focal attention to be directed to the target element. Before every block there appeared a text on the screen instructing the participants which condition followed, either “apparent motion”, “blinking” or “control”. Participants were instructed that both speed and accuracy were important. The first three blocks were disregarded as practice. The other twelve blocks were included in the analyses. The experiment took approximately 120 minutes, with breaks between the blocks.

Results

Error percentages were overall low (see Table 2.1), and an ANOVA revealed no significant effects. We will therefore concentrate on the mean RTs of the correct trials. Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 4% of the trials. See Figure 2.2 for a graphical depiction of the findings. A two-way ANOVA on mean RT for each participant with condition (*control*, *apparent motion* or *blinking*) and set size (9, 17 or 33) as factors revealed a main effect for condition, as RTs were elevated in the *control* condition compared to the *apparent motion* and *blinking* conditions [$F(2,10) = 22.02$, $MSE = 101194.86$, $p < 0.001$], and a main effect for set size, as RTs increased with set size [$F(2,10) = 19.03$, $MSE = 58566.74$, $p < 0.001$].

There was also a significant interaction reflecting the steeper search slope in the *control* condition compared to the *apparent motion* and *blinking* conditions [$F(4,20) = 15.74$, $MSE = 12014.35$, $p < 0.001$]. Equivalent overall effects were present throughout all

	set size		
	9	**17**	**33**
Experiment 1			
control	5.58	7.30	10.26
apparent motion	3.20	4.10	4.44
blink	3.55	3.90	5.33
Experiment 2			
control	0.56	0.43	0.74
apparent motion	2.33	1.75	1.44
blink	1.90	2.22	1.73
Experiment 3			
control	3.05	3.39	6.92
random blink	4.10	3.01	4.25
standard blink	4.26	2.15	3.12
Experiment 4			
control	3.73	4.71	3.38
blink	2.68	0.68	3.76
apparent motion	3.00	3.33	2.69
Experiment 5			
control	1.22	1.79	3.06
all blink	2.22	1.98	6.25
standard blink	4.04	2.09	3.23
Experiment 6			
control	3.99	4.32	7.33
twinkle	4.54	5.47	4.66
bright blink	4.52	3.82	4.30
dark blink	5.19	4.92	3.75

Table 2.1. Average error percentages for the different conditions and the different set sizes of Experiments 1-6.

subsequent experiments and will not be reported on further. Instead, we concentrate on the separate comparisons between conditions. These revealed that RTs were faster, and search slopes were shallower in both the *apparent motion* condition and the *blinking* condition than in the *control* condition (effects of condition, $F(1,5) = 26.02$, $MSE = 128794.84$, $p < 0.005$; $F(1,5) = 19.55$, $MSE = 170617.65$, $p < 0.01$ and condition x set size, $F(2,10) = 17.72$, $MSE = 14935.69$, $p = 0.001$; $F(2,10) = 15.34$, $MSE = 19629.03$, $p = 0.001$ respectively). Importantly, there was no difference in RTs, or in search slopes, between the *blinking* condition and the *apparent motion* condition (all $ps > 0.40$).

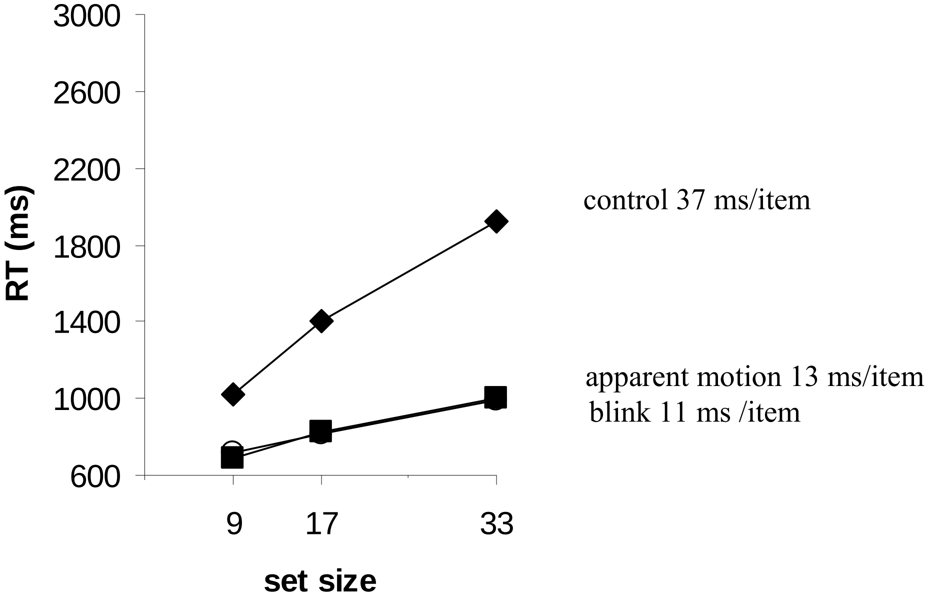


Figure 2.2. Mean reaction time for each condition of Experiment 1 (control, apparent motion and blink) as a function of set size. For each condition, the mean search slopes are provided.

Discussion

Experiment 1 shows that participants are equally efficient in detecting a static target among moving items as in detecting a static target among blinking items. This is not in accordance with Davis and Leow's (2005) explanation that a static target can only be rapidly found among moving items. Instead, it provides evidence for Theeuwes' (2004) original account that in general a static target can be found efficiently among dynamic items. It also corroborates and extends Pashler's (2001) earlier findings of faster overall RTs when half the distractors are blinking synchronously. Relatively efficient search in the *blinking* condition is the more surprising given the evidence reviewed in the introduction that abrupt onsets capture attention automatically. In the *blinking* condition, the static target was present among up to 32 distractors continuously blinking on and off at various rates. This constant multitude of abrupt onsets should have prevented observers from quickly finding the target. We will return to this issue in the General Discussion. Before that, we need to exclude several alternative explanations of our findings. A first alternative explanation may be based on the average luminance level across display frames within a trial and was tested in Experiment 2.

Experiment 2 : Controlling for average luminance level

In Experiment 2 we investigated the possibility that it was the average luminance of the target that causes efficient search in the *blinking* condition in Experiment 1. Note that across the changing frames of the *blinking* condition the static target (which is always on) has a higher average luminance than the surrounding dynamic distractors, because the latter are switched off on half the number of frames. Furthermore, there is evidence that luminance is perceived differently shortly after stimulus onsets and offsets (Eagleman, Jacobson & Sejnowski, 2004). This may have enabled participants to efficiently search for an overall luminance difference instead of for a static item among dynamic items. To control for this, in Experiment 2 we varied the luminance of all elements randomly. The luminance of the target varied between 25% and 62.5% of the maximum, the luminance of the distractors, when on screen, varied between 25% and 100% of the maximum. Therefore the average luminance of the distractors across frames varied between 11.25% and 50% of the maximum, assuring that neither the average luminance of the target, which on most trials was lower than 50% of the maximum, nor the momentary luminance of the target within each frame, which was exactly in between that of the distractors present, could provide a reliable clue for search. If average luminance is the cause of the relatively efficient search for a static among blinking items then the more efficient search in the *blinking* condition compared to the *control* condition should no longer be possible in Experiment 2. In contrast, relatively efficient search in the *apparent motion* condition should still be possible. If it does not play any role in causing the relatively efficient search of a static among on/offsets then the search slopes in the *apparent motion* and *blinking* conditions should remain similar, as was the case in Experiment 1.

Method

Six new participants, ranging in age from 21 to 25 years, average 24.3 years, took part as paid volunteers. Everything was identical to Experiment 1, except that now the luminance of the target-element varied randomly between 16.32 cd/m^2 (.290 , .300) and 41.04 cd/m^2 (.282, .300), the luminance of the distractor elements randomly varied between 16.32 cd/m^2 (.290 , .300) and 65.62 cd/m^2 (.283, .301) (CIE x, y coordinates between brackets). Thus the target had a luminance between 25% and 62.5% and the distractors had a luminance between 25% and 100% of the maximum luminance. This was to assure that neither average luminance across frames nor momentary luminance within each frame was a reliable clue for target search.

Results

Error percentages were overall low, as can be seen in Table 2.1. However a two-way ANOVA with condition (*control*, *apparent motion* or *blinking*) and set size (9, 17 or 33) as factors revealed a main effect for condition [F(2,10) = 6.73, MSE = 1.53, $p < 0.05$] but no effect for set size nor for the interaction [ps > 0.7]. Overall, fewer errors were made in the *control* condition than in the dynamic conditions. However there was no effect on error slopes, and most importantly, there was no difference between the *apparent motion* and *blinking* conditions (all ps > 0.7). We will therefore concentrate on RTs.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 3% of the trials. Figure 2.3 shows a graphical depiction of the results, which were analyzed in the same way as in Experiment 1. Separate comparisons between the conditions revealed that RTs were faster and search slopes were shallower in both the *apparent motion* condition and the *blinking* condition than in the *control* condition (condition, F(1,5) = 18.91, MSE = 312377.36, $p < 0.01$; F(1,5) = 19.16, MSE = 351068.71, $p < 0.01$, and condition x set size, F(2,10) = 21.61, MSE = 25522.36, $p < 0.001$; F(2,10) = 16.75, MSE = 42762.39, p = 0.001 respectively). Importantly, there were no differences in RTs or slopes between the *blinking* condition and the *apparent motion* condition (all ps > 0.10). If anything there was a trend for participants to be faster in the *blinking* condition than in the *apparent motion* condition.

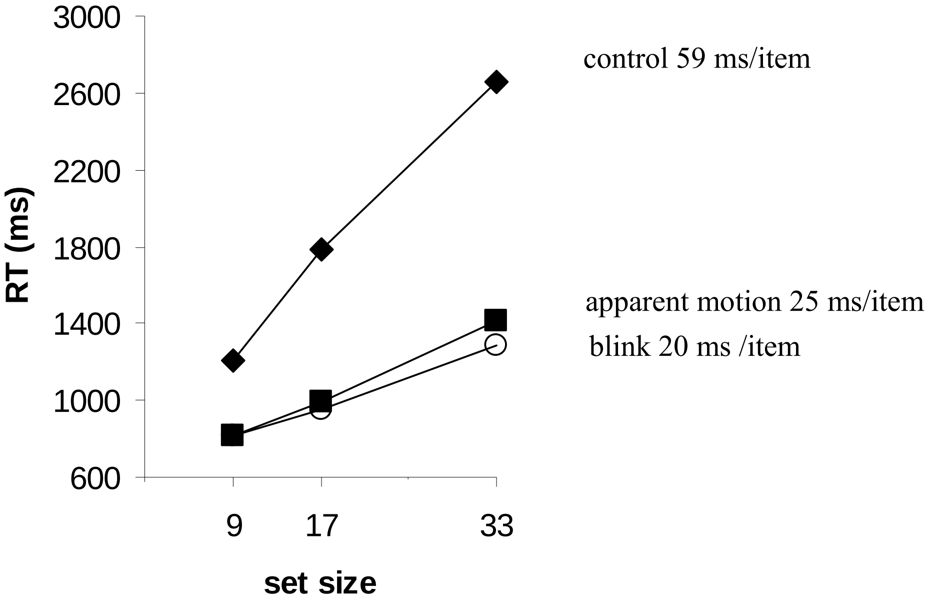


Figure 2.3. Mean reaction time for each condition of Experiment 2 (control, apparent motion and blink) as a function of set size. For each condition, the mean search slopes are provided.

Discussion

The results were essentially the same as in Experiment 1 and unaffected by the luminance differences. We therefore dismiss the notion of average or temporary luminance uniqueness as a cause of the relatively efficient search of a static target among blinking distractors. Note however that overall, search slopes were a bit increased compared to Experiment 1, but this affected all conditions in the same way. Thus, the variable luminance of target and distractor elements made search a little more difficult in general, without affecting the ability to efficiently segment static from dynamic items.

Experiment 3: Controlling for long-range apparent motion and temporal grouping

In Experiment 3 we assessed the possibility that apparent motion might still provide an explanation for the relatively efficient search of the static target surrounded by on- and offsets. In both Experiment 1 and 2 the distractors of the *blinking* condition were evenly distributed over four frequency groups, and within each frequency group half the lines were in phase and the other half in counter phase. This may have permitted for long-range apparent motion to occur (Burt & Sperling, 1981): If two lines were in the same frequency group but in counter phase, it could appear that one line was jumping back and forth between two positions. Although this should have been much weaker than in the actual *apparent motion* condition, it may just have been sufficient for the relatively efficient search found in the *blinking* condition. To determine whether this long-range apparent motion is the explanation of the relatively efficient search in the *blinking* condition, in Experiment 3 we added a *random blinking* condition. Instead of at a fixed frequency, in the *random blinking* condition all blinking elements switched on and off randomly. All blinking lines had an equal chance of switching (turning from on to off or vice versa) after 150 ms, 200 ms, 250 ms or 300 ms. How much time it took before the previous switch occurred did not affect chances for when the current switch would occur. Consequently in the *random blinking* condition the odds are much smaller that at any given moment two elements are in counter phase at the same frequency and long-range apparent motion therefore is unlikely to occur. If long-range apparent motion is part of the explanation of why a static target is relatively efficiently found among blinking distractors, then it is expected that in this experiment search in the *random blinking* condition will not be as efficient as search in the *standard blinking* condition.

In addition to acting as a control for long-range apparent motion, the *random blinking* condition also allowed us to investigate whether temporal grouping contributes to the relatively efficient search of the static target among blinking distractors. In Experiments 1 and 2, the blinking distractors changed at either one of four frequencies. It may have been the case that items that shared a frequency were grouped together. Since there were four frequencies, observers may have always distinguished four distractor groups, regardless of whether the distractor set consisted of 8, 16 or 32 items (resulting in four temporal groups of 2, 4, or 8 items respectively). Relatively efficient rejection of these temporal groups as a whole would then result in relatively efficient search. Evidence that observers are able to use temporal differences to group certain stimuli and segment them from others comes from a study by Lee and Blake (1999; see also Alais, Blake, & Lee, 1998; Blake & Yang, 1997; Leonards, Singer, & Fahle, 1996; Usher & Donnelly, 1998). In their displays, all items moved in random directions and most items changed direction at random moments in time. However, one spatially contiguous patch of items always changed direction at the same moment. Even though the direction in which they changed was still random, the fact that these items changed together was sufficient for them to be perceived as segmented from the background elements. Lee and Blake (1999) concluded that synchrony per se is a strong segmentation cue. Note that in our displays, the synchronously blinking items were usually not spatially contiguous – a factor that has been shown to weaken grouping by synchrony (Fahle & Koch, 1995; Forte, Hogben, & Ross, 1999; Kiper, Gegenfurter, & Movshon, 1996). Nevertheless, it seemed prudent to control for this factor. In the *random blinking* condition of the present experiment there were no frequency groups and temporal grouping of the distractors could no longer contribute to efficient search. Consequently, if temporal grouping of the distractors caused relatively efficient search of the static target in the dynamic displays used in Experiment 1 and 2, relatively efficient search is no longer expected in the *random blinking* condition in Experiment 3.

Method

Twelve participants, ranging in age from 20 to 30 years, average 23.7 years, took part as paid volunteers. This experiment was identical to Experiment 1, except now there was a *random-blinking* condition instead of the *apparent motion* condition. In the *random-blinking* condition the tilted elements all stayed on the screen for a random period between 150 and

300 ms. Every tilted element had a chance of 25% to switch (on or off) after 150 ms, 25% after 200 ms, 25% after 250 ms and 25% after 300 ms. Previous switching time did not affect following switching times. The experiment consisted of 9 blocks of 90 trials. The order of the blocks was repeated every three blocks, and was counter-balanced across participants. The first three blocks were regarded as practice.

Results

Error percentages were overall low (see Table 2.1), and an ANOVA with condition and set size as factors only revealed a significant effect for set size [$F(2,22) = 3.64$, $MSE = 9.04$, $p<0.05$]. We will concentrate on the mean RTs of the correct trials.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of less than 3% of the trials. See Figure 2.4 for a graphical depiction of the findings. The results were analyzed in the same way as in the previous experiments. Separate comparisons between the conditions revealed that RTs were faster and search slopes were shallower in both the *random blinking* condition and the *standard blinking* condition than in the *control* condition (condition, $F(1,11) = 60.10$, $MSE = 158449.59$, $p < 0.001$; $F(1,11) = 75.07$, $MSE = 118051.12$, $p < 0.001$, and condition x set size, $F(2,22) = 28.60$, $MSE = 29929.91$, $p < 0.001$; $F(2,22) = 29.30$, $MSE = 21412.60$, $p < 0.001$ respectively). Furthermore, the search slope in the *random blinking* condition was somewhat shallower than the search slope in the *standard blinking* condition, 11.9 ms per item compared to 16.3 ms per item (condition x set size, $F(2,22) = 4.26$, $MSE = 4206.86$, $p < 0.05$).

Discussion

We found that participants were neither slower nor less efficient in the random blinking than in the *standard blinking* condition. There may have been some long range apparent motion in the *standard blinking* conditions of Experiments 1 to 3, but if there was, it should have been reduced substantially in the present *random blinking* condition. If long-range apparent motion was a major contributor to the relatively efficient search of a static among dynamic items, we should therefore have found increased slopes in the *random blinking* condition. However, if anything, we found slightly (but significantly) decreased slopes. Therefore, the findings from Experiment 3 imply that long-range apparent motion does not contribute to the relatively efficient search for a static element among on and offsets. Another account tested in Experiment 3 was temporal grouping. It could be argued that four temporal groups of distractors were created in Experiment 1 and 2, and that this caused the

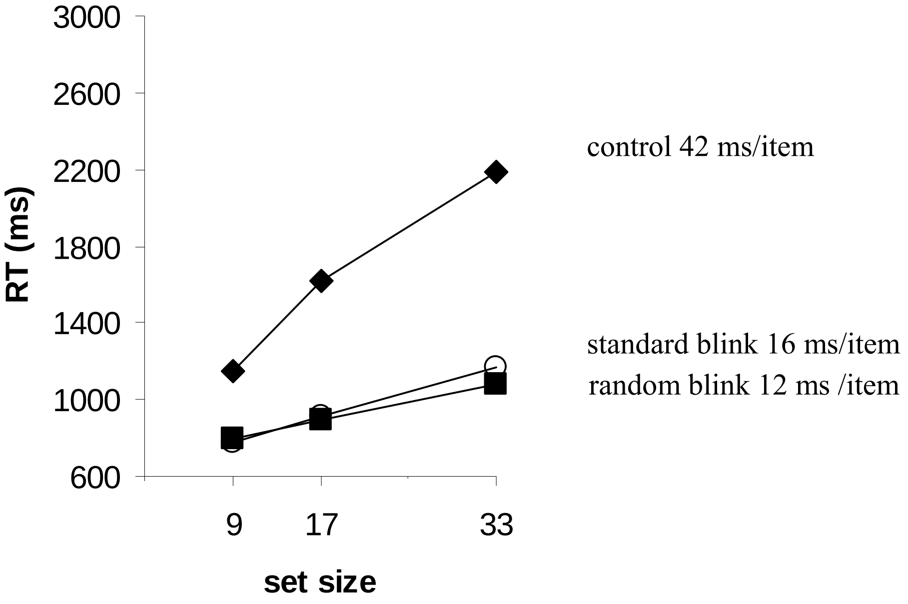


Figure 2.4. Mean reaction time for each condition of Experiment 3 (control, standard blink and random blink) as a function of set size. For each condition, the mean search slopes are provided.

relatively efficient search for the static among dynamic items. In the *random blinking* condition temporal synchrony between any of the distractors was eliminated, yet relatively efficient search for the static target was still observed. We conclude that temporal grouping of the distractors cannot be the cause of the relatively efficient search for a static target among dynamic distractors. Instead we propose that the fact that it is static grants the target a unique status among the dynamic distractors, resulting in relatively efficient search.

Experiment 4: Search for a static target without pre-knowledge

Since in all previous experiments conditions were blocked and participants knew beforehand if the distractors were dynamic or static, it could well be that the top-down expectations of participants influenced the efficiency with which they selected a static target among dynamic items. To assess this possibility, in the present experiment all conditions were randomly mixed. The target was static, whereas the distractors could undergo apparent motion, blink or remain static as well. Because conditions appeared in random order, participants did not know beforehand what kind of distractors they would be presented with.

If pre-knowledge is crucial for the relatively efficient search of a static target among dynamic distractors, it is expected that this search is no longer efficient in this experiment.

Method

Ten participants ranging in age from 18 to 27 years, average 20.7 years, took part as paid volunteers. Apparatus, stimuli and procedure were the same as in Experiment 3 except for the following changes. There were three conditions: the *control* condition, the *blinking* condition and the *apparent motion* condition. The *control* condition and the *blinking* condition were the same as in Experiment 3 the *control* condition and the *random blinking* condition. The *apparent motion* condition was the same as the *apparent motion* condition in Experiment 1, except now the items moved at random rather than at a given frequency. The tilted elements stayed in one orientation for a random period between 150 and 300 ms. Every tilted element had a chance of 25% to flip 45° arc deviation from its current orientation (in either direction) after 150 ms, 25% after 200 ms, 25% after 250 ms and 25% after 300 ms. Previous switching time did not affect following switching times. The experiment consisted of five blocks, one block consisted of 90 trials. Within one block, all conditions were randomly mixed. The first two blocks were disregarded as practice.

Results

Error percentages were overall low, as can be seen in Table 2.1. A two-way ANOVA with condition (*control*, *apparent motion*, or *blinking*) and set size (9, 17 or 33) as factors revealed no significant effects. Therefore we will concentrate on RTs.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of less than 4% of the trials. Figure 2.5 shows a graphical depiction of the results, which were analyzed in the same way as in the previous experiments. Separate comparisons between the conditions revealed that RTs were faster and search slopes were shallower in both the *apparent motion* condition and the *blinking* condition than in the *control* condition (condition, $F(1,9) = 33.37$, $MSE = 163180.86$, $p < 0.001$; $F(1,9) = 38.22$, $MSE = 236706.26$, $p < 0.001$, and condition x set size, $F(2,18) = 33.27$, $MSE = 33206.08$, $p < 0.001$; $F(2,18) = 30.34$, $MSE = 52100.45$, $p < 0.001$ respectively). Moreover participants were faster and had shallower search slopes in the *blinking* condition compared to the *apparent motion* condition (condition, $F(1,9) = 42.31$, $MSE = 10738.61$, $p < 0.001$, and condition x set size, $F(2,18) = 5.84$, $MSE = 9188.81$, $p < 0.05$ respectively).

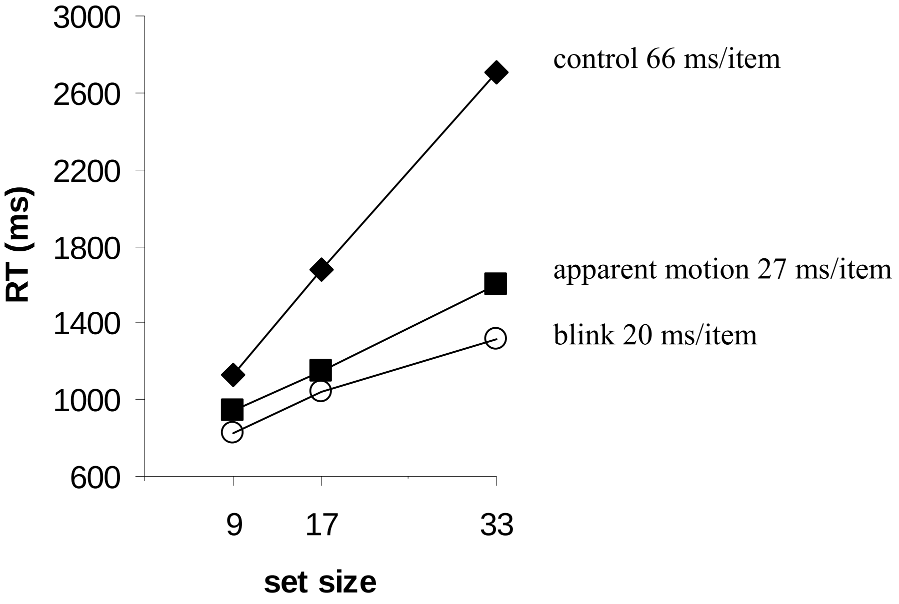


Figure 2.5. Mean reaction time for each condition of Experiment 4 (control, apparent motion and blink) as a function of set size. For each condition, the mean search slopes are provided.

Discussion

The results of Experiment 4 were highly comparable to Experiments 1 and 2. Again participants were slower in the *control* condition than in the *apparent motion* condition and the *blinking* condition. Since in the current experiment conditions were mixed, these results show that participants do not need to know before the start of the trial that the distractors are dynamic to use this as a cue for search for the static target. Note that although the general pattern of results was the same, overall search slopes were increased compared to Experiment 1. Thus, the lack of pre-knowledge regarding the nature of the target made search a little more difficult in general, without affecting the ability to segment static from dynamic items.

In accordance with the trend observed in Experiment 2, we found participants to be slightly faster in the *blinking* condition than in the *apparent motion* condition. This tendency might be due to the fact that on/offsets provide a stronger dynamic cue than movement. We will elaborate on this in the General Discussion.

Experiment 5: Search for a dynamic target among dynamic distractors

There is the possibility that there is nothing special about static items. A static among dynamic items may be unique in the sense that it changes at an infinitely slow frequency, but perhaps observers can efficiently direct their attention at any unique frequency. To test this possibility, we introduced the *all blinking* condition, in which not only the distractors blink on and off, but the target too – at a unique frequency. Furthermore there were three versions of this condition, presented in separate blocks. In the *slow blinking target* condition the target would show the lowest blinking rate of all items in the display. In the *medium blinking target* condition, the target blinked at a frequency in between the frequencies of the distractors. In the *fast blinking target* condition the target blinked at the highest rate of all items. We included these different versions because previous evidence has indicated that the unique target feature may have to be linearly separable from the distractor features for efficient search to occur. (Saumier & Arguin, 2003; Bauer, Jolicoeur & Cowan, 1996; D'Zmura, 1991; Wolfe, Friedman-Hill, Stewart, & O'Connell, 1992). Thus efficient search for a unique frequency may occur for the low and high frequency targets (because they are linearly separable from the distractors) but not for the medium frequency target. For the purpose of comparison we also included a *standard blinking* condition in which only the distractors blinked (at frequencies matched to those in the *all-blinking* conditions) and a *control* condition in which all items were static. If static targets have a special status then we should only see efficient search in the *standard blinking* condition. If any unique frequency allows for the efficient search then we should also find improved performance in the *all-blinking* conditions, compared to the *control* condition.

Method

Seven participants ranging in age from 16 to 29 years, average 20.1 years, took part as paid volunteers. There were seven conditions. Three *all blinking* conditions, three *standard blinking* conditions and a *control* condition. In the *slow blinking target* condition the target element switched on or off every 350 ms, the tilted elements switched on or off every 150, 200, 250 or 300 ms. As in Experiments 1 and 2 the tilted elements were evenly distributed over frequency groups and within one frequency group half switched in phase and half in counter phase. The *medium blinking target* condition was the same as the *slow blinking target* condition except that now the target switched on or off every 250 ms, and the distractors switched on or off every 150, 200, 300 or 350 ms. In the *fast blinking target* condition the target switched on or off every 150 ms and the distractors switched on or off every 200, 250, 300 or 350 ms. For comparison there were also three *standard* conditions. In these conditions the target was always static, but the distractors behaved in the same way as in the *slow*, *medium*, and *fast blinking target* conditions. Finally, the *control* condition was the same as the *control* condition in Experiments 1, 2 and 3, in which all items were static. Before every block there appeared a text on the screen instructing the participants which of the seven conditions followed. The experiment consisted of 5 clusters of 7 blocks, each block consisted of 36 trials. The order of the blocks was the same within each cluster. The order was determined by a 7 x 7 latin square design.

Results

Error percentages were overall low (see Table 2.1), and an ANOVA with condition and set size as factors revealed no significant effects. We will therefore concentrate on the RTs.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of less than 4% of the trials. See Figure 2.6 for a graphical depiction of the findings. First we looked if there were any differences between the different versions of the *all blinking* conditions. A two-way ANOVA with condition (*slow*, *medium* or *fast blinking target*) and set size (9, 17 or 33) as factors revealed a trend for a main effect for condition, [F(2,12) = 3.36, MSE = 179481.76, p = 0.07]. Participants tended to be overall somewhat faster in the *slow blinking target* condition. However, there was no interaction with set size [F(4,24) = 1.25, MSE = 95323.25, p > 0.3], indicating that search efficiency was very similar across these conditions. Therefore, we pooled the three versions of the *all blinking* conditions together. A similar analyses on the three versions of the *standard blinking* conditions (in which only the distractors blinked) revealed no main effect for condition [F(2,12) = 0.73, MSE = 22709.42, p > 0.50], but a marginally significant interaction of condition and set size [F(4,24) = 2.80, MSE = 7069.59, p = 0.049]. Closer analyses revealed that search was somewhat less efficient when the distractors were blinking at the same rate as in the *medium blinking target* condition (28.8 ms/item, vs. 20.9 ms/item and 23.0 ms/item for the equivalent controls for the *slow* and *fast blinking target* conditions). Because of this difference we also compared each of the *slow*, *medium* and *fast standard blinking* conditions to their equivalent counterparts of the *all blinking* conditions. These pairwise comparisons revealed that observers were always faster and always more efficient when the target was static (standard blinking condition) compared to when it was blinking (all blinking condition; all ps < 0.015). Therefore, since all three standard blinking conditions appeared to behave in more or less the same way relative to the all blinking conditions, we decided to pool them together to form one *standard blinking* condition.

A two-way ANOVA with these pooled conditions (*all blinking*, *standard blinking* or *control*) and set size (9, 17 or 33) as factors revealed a main effect for condition, as RTs were shortest in the *standard blinking* condition followed by the control and the *all blinking* conditions [F(2,12) = 18.20, MSE = 239352.54, $p < 0.001$], a main effect for set size, as RTs increased with increasing set size [F(2,12) = 25.37, MSE = 301088.77, $p < 0.001$] and a significant interaction, indicating shallower search slopes in the *standard blinking* condition than in the *all blinking* and *control* conditions [F(4,24) = 9.04, MSE = 58809.39, $p < 0.001$]. Separate comparisons between the conditions revealed that RTs were faster and search slopes were shallower in the *standard blinking* condition compared to the control and to the *all blinking* condition (condition, F(1,6) = 23.58, MSE = 262164.93, $p < 0.005$; F(1,6) = 17.73, MSE = 387533.10, $p < 0.01$ and condition x set size, F(2,12) = 6.90, MSE = 89844.89, $p < 0.05$; F(2,12) = 18.44, MSE = 49712.61, $p < 0.001$ respectively). RTs and search slopes did not differ significantly between the *all blinking* condition and the *control* condition (ps > 0.24).

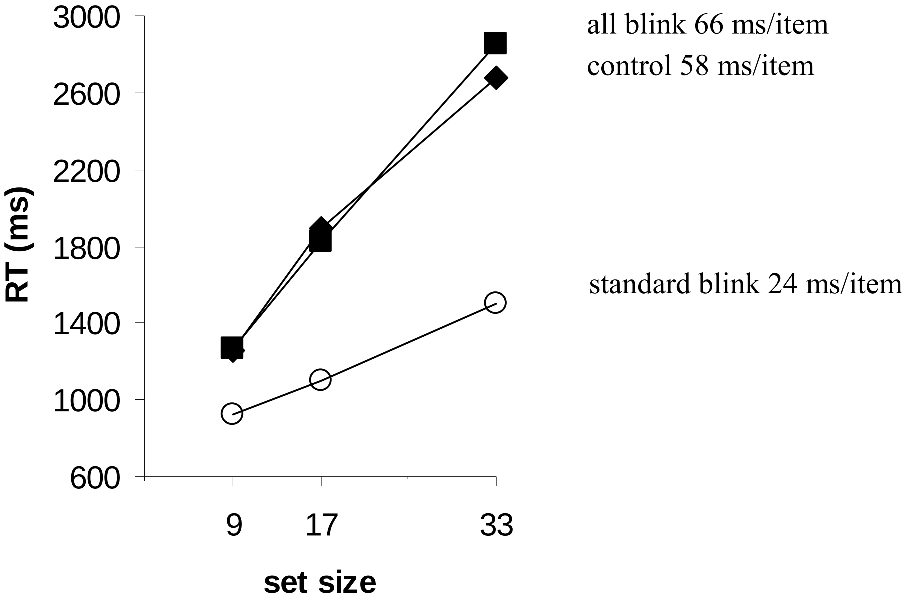


Figure 2.6. Mean reaction time for each condition of Experiment 5 (control, all blink and standard blink) as a function of set size. For each condition, the mean search slopes are provided.

Discussion

The results indicate that participants could not make use of the unique target frequencies when all items blinked, even when these frequencies were linearly separable from the distractor frequencies. This indicates that the unique frequency aided little to nothing. We conclude that it is not just any temporal difference that may guide attention, but that it is specifically the target being static which allows for efficient search.

Of course, our results may heavily depend on the range of frequencies we have used. Perhaps the difference between the target frequency and the distractor frequencies in the *all blinking* conditions was simply not large enough. The fastest rate contained one blink every 150 ms (a frequency of 6.67 Hz) and the slowest rate one blink every 350 ms (a frequency of 2.86 Hz), with the other rates falling in between at steps of 50 ms. The problem is that if we would extend this range much further, the dynamic items become practically undistinguishable from static items. That is, if we made the rate much slower, then in its "on" period an item is on for so long that it might be regarded as a static item. In this respect we were especially careful not to let items be on for longer than one would normally expect observers to start generating a response (i.e. around 400 ms). If we would make the rate much faster, then subsequent frames will be merged into a single percept, again making it virtually static. In this respect we were careful not to choose a frequency at which the blinking object might be perceptually treated as one and the same object across frames (i.e. faster than once every 100 ms; Yantis & Gibson, 1994), a point to which we will return in the General Discussion. Finally, psychophysical studies have shown that observers are quite sensitive to frequency and phase differences below 10Hz (as used in the present study), with relative difference thresholds of around 0.1 (Mowbray & Gebhard, 1955; Mandler, 1984; see also Forte, Hogben, and Ross, 1999). This means that observers should be able to distinguish the 50 ms differences between rates. Thus, it deserves pointing out that our conclusions are limited to the frequency range used here, but that this range is not unreasonable.

Experiment 6: Luminance offsets vs. complete object offsets

In Experiments 1-5 we showed that participants are able to find a static among blinking items and by elimination of other explanations we conclude that it is indeed the static nature of the target that allows for relatively efficient search. This is in line with Theeuwes' (2004) account but contradicts Davis and Leow's (2005) claim that search for a static target among dynamic distractors is not possible unless the distractors exhibit some form of motion. They based this claim on their finding that search was inefficient for a static target among distractors that abruptly changed both color and luminance from frame to frame. Thus, a question remains how our results can be brought into accordance with Davis and Leow's (2005) findings. An important difference between our experiments and Davis and Leow's (2005) experiments is that in our blinking conditions the blinking distractors completely disappeared and reappeared. In Davis and Leow's (2005) experiment the distractors changed in luminance and color but did not disappear. A possible explanation for the discrepancy between our and Davis and Leow's (2005) results then could be that luminance change of the distractors is not enough for relatively efficient search but that complete on- and offsets of the distractors are required. There is substantial evidence that the effectiveness of luminance transients depends not only on the relative increase or decrease in luminance, but also on whether or not a new perceptual object is being created (Cole, Kentridge & Heywood, 2004; Enns, Austen, DiLollo, Rauschenberger & Yantis, 2001; Yantis & Hillstrom, 1994). A second reason why search may have been less efficient in Davis and Leow's (2005) displays, is that the luminance changes were accompanied by a color change. It has been found that simultaneous changes in color on the one hand and dynamic properties such as motion or orientation changes on the other hand are not always perceived as simultaneous (Moutoussis & Zeki, 1997; Clifford, Arnold & Pearson, 2003). The same asynchrony may apply to color and luminance changes, possibly obscuring the dynamic signal. Moreover, the color changes are likely to have activated the color-sensitive parvocellular pathway. There is evidence that the parvocellular pathway inhibits the magnocellular pathway thought to be sensitive for dynamic information such as luminance transients (Breitmeyer & Williams, 1990; Tassinari, Marzi, Lee, DiLollo & Campara, 1999; Yeshurun & Levy, 2003; Yeshurun, 2004). To investigate these possibilities, Experiment 5 presented participants with four conditions. A *twinkle* condition, in which the distractors underwent luminance changes but never disappeared from the display (comparable to Davis and Leow's (2005) displays, but without a color change), two *blinking* conditions and a *control* condition. In the *twinkle* condition distractors abruptly changed luminance between 33% and 100% of the maximum, against a black background of zero luminance. In the *bright blinking* condition the distractors also abruptly switched between 33% and 100% of the maximum luminance, but now against a grey background of 33% luminance. In the *dark blinking* condition the distractors abruptly changed between 0 and 67 % of the maximum luminance , against a zero luminance background. This way both the absolute luminance change and the luminance change relative to the background were controlled for.

If complete object dis- and reappearances are important then we would expect efficient search only in the *blinking* conditions, and not in the *twinkle* condition, where luminance changes were equivalent but the distractors did not disappear. Furthermore, unlike in Davis and Leow's (2005) study, the distractors in our *twinkle* condition did not undergo a color change. If color changes were the main reason for inefficient search in their study, then we might expect efficient search in our *twinkle* condition.

Method

Sixteen participants, ranging in age from 18 to 33 years, average 12.0 years, took part as paid volunteers. Apparatus, stimuli and procedure were the same as in Experiment 1 except for the following changes. There were four conditions: the *control* condition in which all elements stayed on the screen, with luminance 59.99 cd/m^2, (.286, .305) and the background had a luminance of zero; the *bright blinking* condition in which the target remained on the screen with a luminance of 59.99 cd/m^2, (.286, .305), the background had a luminance of 20.13 cd/m^2, (.291, .305) and the tilted elements alternated between these two luminances; the *dark blinking* condition in which the target remained on the screen with a luminance of 40.13 cd/m^2, (.285, .305), the background had zero luminance and the tilted elements alternated between these two luminances, and the *twinkle* condition in which the target remained on the screen with a luminance of 59.99 cd/m^2, (.286, .305), the background had zero luminance and the tilted elements alternated between a luminance of 59.99 cd/m^2, (.286, .305) and a luminance of 20.13 cd/m^2, (.291, .305)([CIE] x, y coordinates between brackets). The experiment consisted of five clusters of four blocks, each block consisted of 36 trials. The first cluster of four blocks was disregarded as practice. Within each cluster the blocks had a fixed order. This order was counterbalanced between participants.

Results

Error percentages were overall low (see Table 2.1). An ANOVA with condition and set size as factors revealed no significant main effects, but a significant effect for the interaction [F(6,90) = 2.35; MSE = 9.35; $p < 0.05$]. Further analyses revealed that errors increased more with set size in the *control* condition, especially in comparison to the *dark blink* condition. Since this pattern did not go against the pattern of RTs, we exclude the possibility of a speed/accuracy trade-off, and we will concentrate on RTs.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of less than 3% of the trials. See Figure 2.7 for a graphical depiction of the findings. The results were analyzed in the same way as in the previous experiments. Separate comparisons between the conditions revealed that RTs were faster and search slopes were shallower in the *dark blinking* condition, the *bright blinking* condition and the *twinkle* condition compared to the *control* condition (condition, F(1,15) = 93.94, MSE = 179734.26, $p < 0.001$; F(1,15) = 101.56, MSE = 203462.42, $p < 0.001$; F(1,15) = 93.82, MSE = 60607.43, $p < 0.001$, and condition x set size, F(2,30) = 68.53, MSE = 31922.70, $p < 0.001$; F(2,30) = 71.62, MSE = 37418.55, $p < 0.001$; F(2,30) = 17.59, MSE = 26071.62, $p < 0.001$). Also RTs were faster and search slopes were shallower in both the *dark blinking* condition and the *bright blinking* condition compared to the *twinkle* condition (condition, F(1,15) = 53.12, MSE = 55985.96, $p < 0.001$; F(1,15) = 65.39, MSE = 71416.13, $p < 0.001$, and condition x set size, F(2,30) = 26.89, MSE = 23970.92, $p < 0.001$; F(2,30) = 34.03, MSE = 27118.90, $p < 0.001$). Overall, participants were somewhat faster in the *bright blinking* than in the *dark blinking* condition [F(1,15) = 32.53, MSE = 5680.51, $p < 0.001$] and participants had shallower search slopes (by 4 ms/item) in the *bright blinking* than in the *dark blinking* condition [F(2,30) = 10.32, MSE = 2420.00, $p < 0.001$].

Discussion

The results from Experiment 6 again show that search for a static target among on- and offsets is relatively efficient. The main finding is that search for a static target among distractors changing only in luminance without offsets was considerably less efficient, even when the extent of the luminance change was the same as in the on/offset conditions in either relative or absolute terms. This implies that the change of luminance of distractors is not enough for efficient search. Instead, the distractors need to completely dis- and reappear to allow the visual system to fully separate the distractors from the static target.

Our results are in accordance with the hypothesis that the crucial difference between our experiments and Davis and Leow's (2005) search task is the complete on- and offsets of the distractors. When items change in luminance but produce no on or offsets, participants are less able to efficiently detect a static target. In contrast to Davis and Leow's (2005) experiment, in our task there were no color changes, yet the results were very much comparable. This suggests that the color change probably plays little to no role in causing the inefficient search in David and Leow's displays. This result furthermore implies that Theeuwes' (2004) original account is not entirely correct. Participants are not always able to rapidly find a static target among dynamic distractors. They can do so when the distractors are moving or blinking, but not when the distractors are only changing in luminance. Note though that there were nevertheless some benefits in the *twinkle* condition relative to the *control* condition, suggesting that the observers could make some (but limited) use of the luminance changes. The implications of these findings are elaborated on in the General Discussion.

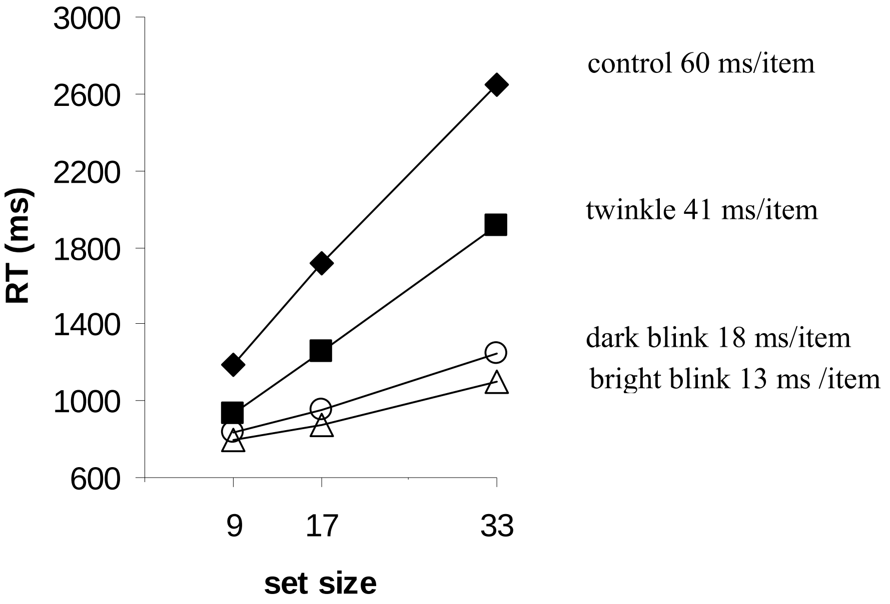


Figure 2.7. Mean reaction time for each condition of Experiment 6 (control, twinkle, bright blink and dark blink) as a function of set size. For each condition, the mean search slopes are provided.

General Discussion

This work started with the question whether observers are able to efficiently detect a static target among dynamic distractors. Others have claimed that such efficiency may only be confined to the case of moving distractors (Davis & Leow, 2005). However, here we have shown that relatively efficient search may also be achieved when the distractors are characterized by multiple asynchronous abrupt onsets, and that this search is equally efficient or even slightly more efficient than when the distractors are moving, lending support to Theeuwes' (2004) claim that in general, static information may be detected relatively rapidly from among dynamic information. In Experiment 1 we showed that search for a static target among blinking distractors is performed efficiently, and that this search is as efficient as for a static target among moving distractors. In Experiment 2, average or momentary luminance differences between the target and the distractors were ruled out as an explanation. In Experiment 3, long-range apparent motion was also dismissed as a possible cause, as was temporal grouping on the basis of common onset frequencies. Experiment 4 showed that pre-knowledge of the dynamic nature of the distractors is not needed for efficient search of the static target. The results of Experiment 5 showed that it is not just any unique frequency that results in efficient search. Experiment 6 made clear that a luminance change alone is not enough for efficient search. It does improve search efficiency, but the largest improvement in search efficiency arises when the blinking objects fully dis- and reappear. The results of this last experiment suggest that neither Theeuwes (2004) nor Davis and Leow (2005) were entirely correct. Participants cannot efficiently find a static target among dynamic distractors, regardless of the dynamic nature of the distractors. They can do so when the distractors move or blink on and off completely, but not when the distractors only change in luminance (though luminance changes per se appear to contribute too).

Note that so far we have discussed improvements in performance in the dynamic conditions in terms of relative efficiency. It deserves mentioning that, even though search became substantially more efficient when distractors were dynamic in nature, search slopes were not completely flat, indicating that the target was usually not found entirely in parallel across the display. This contrasts with the flat search slopes usually found when participants search for a dynamic target among static distractors (Hillstrom & Yantis, 1994; Watson & Humphreys, 1995; Yantis & Egeth 1999). However, Müller and Found (1996) showed that participants after intensive practice were as efficient in finding a static target among moving distractors as vice versa. It could be that in our experiments, with more extensive practice participants would have shown parallel search.

In any case, contrary to Davis and Leow's (2005) claim, the present results show that motion is not unique in allowing for relatively efficient search. Instead we agree with Pashler (2001) that dynamic differences between stimuli, such as abrupt onsets, are just another aspect on which these stimuli can be discriminated, and prioritized for attentional selection. The question remains as to how the visual system performs this discrimination.

Memory

One way the visual system might discriminate static from dynamic stimuli is by building up a memory representation of the successive frames of the changing displays. By taking a series of complete "snapshots" and comparing them, the visual system may then filter out the only item that is present in every single snapshot. Such snapshots may be taken from iconic memory, a large-capacity initial storage of visual information (Sperling, 1960). However, various studies have now shown that not much visual information survives from one snapshot to the next, at least not across brief interruptions or eye movements (Irwin, 1991; O'Regan, Rensink & Clark, 1999; Pashler, 1988; Phillips, 1974; Simons, 1996). Illustrative in this respect are the change blindness studies showing that observers often fail to detect large changes between two separate displays when the transients accompanying these changes are eliminated (see Rensink, 2002, for a review). Closer to the present study, Theeuwes (2004) presented two successive displays in which all elements changed, except the target, which remained identical. When the second display followed the first without interruption, the target was easily found. However, when a blank display was inserted between the two frames, search for the one non-changed element became very effortful. Taken together, the evidence indicates that a high-level memory representation of the displays offers an implausible explanation of the efficient detection of static among dynamic elements. Instead, just as efficient detection of a changing target appears to rely on the presence of transients at its location, efficient detection of a static target appears to rely on the presence of transients at the distractor locations. This appears to point to an important role of relatively earlier visual transient detection mechanisms.

Transient vs. sustained channels

The dynamic properties of the stimulus are already distinguished at the level of retinal ganglion cells. One group of cells, the so-called X-cells (or β/B-cells), have relatively slow conduction velocity and they show sustained firing to predominantly stationary stimuli. The Y-cells (or α/A-cells) have faster conduction velocities and they show transient bursts of firing in response to abrupt changes in the stimulus such as onset and motion (Enroth-Cugell & Robson, 1966; Cleland, Dubin & Levick, 1971, Leventhal, Rodieck, Dreher, 1981; Stone & Fukuda, 1974). This division is thought to lie at the basis of what have been referred to as the magno- and parvocellular pathways at the physiological level, or transient and sustained channels of visual processing at a more functional level, and it extends into (and probably beyond) the primary visual cortex (e.g. Breitmeyer & Ganz, 1976; Livingstone & Hubel, 1988; Todd & Van Gelder, 1979).

The relatively independent transient and sustained subsystems may provide a direct explanation for the efficient discrimination of static and dynamic information. When searching for a dynamic target, the visual system only has to look for activity in the transient (magno) channel. When looking for a static target, as in the present experiments, the registration of activity in the sustained (parvo) channel is sufficient. The fact that dynamic targets are usually somewhat faster and more efficiently detected than static targets may then be explained by a slight preference of the visual system for the transient channel or by the fact that the transient neurons have faster conduction velocities. Note however that the transient-sustained dichotomy at a pure retinal level cannot account for the data. In the *twinkle* condition of Experiment 6, the distractors featured abrupt luminance changes equivalent to those in the blinking conditions, but without completely disappearing from the displays. Retinal cells should have responded equally in these conditions, yet search was much more effortful when the distractor offsets were not complete. Thus, the crucial distinction between changing and non-changing elements appears to be whether a new object has been created relative to its background rather than a simple luminance change. Such new object comparisons relative to its surroundings are more likely to be made at higher levels, for instance in V1, where centre-surround cells provide important information about the background. Moreover, V1 cells respond to both moving and blinking stimuli, but do not distinguish between them (Andersen, 1997). This would explain why performance in our motion and blinking conditions was so similar. In contrast, the “higher-up” motion-sensitive area MT responds only weakly or not at all to blinking stimuli (Andersen, 1997). Thus, V1 may provide the necessary initial mechanisms for both motion processing and temporal segmentation of static and dynamic stimuli (Fahle, 1993; Forte, Hogben, and Ross, 1999).

Attentional capture

A somewhat surprising aspect of our findings is that search for a static item among blinking items is efficient, despite the fact that the distractors are characterized by repeated abrupt onsets. As mentioned in the introduction, there is substantial evidence that, under the right circumstances, abrupt onsets automatically capture attention (Yantis & Jonides, 1984). As also mentioned earlier, moving stimuli appear to be less strong attentional captors (Hillstrom & Yantis, 1994; Yantis & Egeth, 1999). So in our blinking conditions, why were observers not continuously distracted by the abrupt onsets of the blinking distractors?

One possible explanation is that after the first abrupt onset, subsequent onsets become much less salient. As has been suggested before, what appears to make an abrupt onset so salient is the appearance of a new object (Yantis & Hillstrom, 1994). Relevant to this is a study by Kahneman, Treisman and Gibbs (1992) who found that features were recognized faster when they had been part of one and the same object across time relative to when they had switched objects. Kahneman et al. (1992) suggested that whenever a new object appears, an object file is created storing the object properties as long as the spatio-temporal continuity is preserved. The creation of this object file requires attention. In our experiments continuously appearing items failed to attract attention. Perhaps then, the blinking line segments were not seen as new objects but as one and the same object simply dis- and reappearing. However, a study by Yantis and Gibson (1994) argues against this account. In one of their experiments, they used a visual search task in which one of the items briefly disappeared. When it reappeared, it could be the target, although it was more likely to be a distractor. The amount of attentional capture was determined as the relative efficiency of search when the blinking item was indeed the target. Yantis and Gibson (1994) found that the blinking item automatically captured attention as long as the temporal interval between the offset and onset was more than about 100 ms. In the same study, the same interval was also found crucial in determining the percept of bistable apparent motion displays (so called Ternus displays, in which part of the array may be seen as stationary or moving depending on the interval between frames). Yantis and Gibson (1994) concluded that a spatiotemporal discontinuity of around 100 ms is sufficient for an object to be regarded as new. In the present study, the distractor items were always switched off for at least 150 ms (and up to 350 ms). Thus, according to Yantis and Gibson’s (1994) measure, these items should be regarded as new, and in principle capable of capturing attention.

Another possibility is that abrupt onsets only capture attention when they are the only onset in the display. In the same vein, the creation of new object files may only be limited to a small number of items (perhaps due to the limited attentional resources available for such creation). In other words, single onsets may capture attention, but multiple onsets, when distributed evenly across the visual field, may not. Like other features such as color or orientation, abrupt onsets may become more salient the more unique they are. Some support for this idea comes from a study by Chastain and Cheal (1999) who found that a single onset precue shows all the characteristics of involuntary attentional capture (rapid attentional build-up followed by rapid attentional decay across longer precue to target delays), but that an onset of multiple precues show the characteristics of voluntary attentional control (slow attentional build-up, and no attentional decay with longer time between precue and target). However, other studies suggest that multiple onsets can still capture attention. For instance, Yantis and Johnson (1990; see also Yantis & Jones, 1991) found just as strong attentional capture in displays of up to 16 items, half of which were defined by abrupt onsets. Similarly, Donk and Theeuwes (2003) found that in a visual search task participants prioritized up to 14 new elements (as defined by an abrupt onset) over up to 14 interspersed old elements, even when the target was twice as likely to be old. Thus, the presence of multiple onsets in itself does not appear to necessarily prevent attentional capture. Note further that, in our displays, the blinking items appeared and disappeared at different rates, making them at least locally relatively unique.

It appears then that observers can at least exert some control over the attentional capture by abrupt onsets (see also Yantis & Jonides, 1990; Pashler, 2001). Attention may be initially captured by one of the blinking items (or sometimes even the target, since it too is initially defined by an onset), but soon observers are able to ignore them and actually use the difference between transient and sustained signals to direct their attention to the target. This account may be regarded as in between the automatic capture account (Theeuwes, 1992; Yantis & Jonides, 1984) which states that some stimuli capture attention regardless of the tasks and goals of the observer, and the contingent capture account (Folk, Remington & Johnston, 1992; Folk, Remington & Wright, 1994) which states that capture is dependent on the attentional set of the observer. In case of multiple onsets, attention may initially be captured automatically, but it is then quickly overridden by top-down goal settings to prevent further interference.

A final finding worth returning to, now in relation to attentional capture, is the fact that search for a static target was relatively inefficient when the dynamic distractors only changed luminance, without disappearing (Experiment 5). Recently, Enns et al. (2001) reported a related finding: An item featuring a maximum luminance change (i.e. a polarity reversal: changing from black to white on a grey background) did not get as much priority in search as an item that newly appeared in an empty location (i.e. whose luminance changed from the background grey to either black or white). Enns et al. concluded, as we do here, that the visual system is biased towards new object appearances rather than luminance changes. In our experiment, in terms of attentional capture, one might actually have expected search to be easier when the distractors only changed luminance, since they would draw less attention. The fact that search was actually more difficult means that the effect of new object appearances cuts both ways: They draw more attention when they are unique in the display, but they can also be more easily discriminated and rejected when they constitute the distractors.

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Selecting from dynamic environments: Attention distinguishes between blinking and moving

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Abstract

Pinto, Olivers and Theeuwes (2006) showed that a static target can be efficiently found among different types of dynamically changing distractors. They hypothesized that attention employs a broad division between static and dynamic information, in line with earlier research. The current study investigated whether attention can only make use of this crude division, or that more subtle discriminations within the dynamic domain can be exploited. In Experiment 1 participants were able to efficiently find a blinking target among moving distractors and vice versa, even though all items changed at the same rate and produced the same change in local luminance. In Experiment 2, search for a dynamic target among dynamic distractors was aided by giving the distractors additional dynamic cues. Experiment 3 showed that making the displays equiluminant affected search efficiency for a static target among moving distractors but not among blinking distractors. The findings refute the broad division hypothesis and suggest that object continuity plays an important role in selection.

From everyday experience it is clear that dynamic stimuli stand out. Examples of this are the flashing lights on an ambulance and your friend waving when you are looking for him in a crowd. Both are examples of stimuli intended to attract attention. Research has confirmed the intuitive notion that dynamic stimuli can guide or capture attention (McLeod, Driver & Crisp, 1988; Yantis & Jonides, 1984; Watson & Humphreys, 1995).

The reverse case is harder to appreciate intuitively. What is the fate of a static item in a constantly changing environment? Would the dynamic elements in the environment continuously compete for your attention, making it very difficult to find the static object? Or would dynamic surroundings allow for a relatively efficient segmentation of the static object form its background? And, important in the present study, would this be different for different types of dynamics, such as blinking and motion?

Efficient search in dynamic scenes

To investigate whether static objects can indeed guide attention, Theeuwes (2004) asked participants to determine the orientation of a static bar among distractor bars that were all abruptly changing. In one condition, all distractor bars changed, in a single frame, from horizontal or vertical to either left or right oblique (by 45°, hence after the change the target was the only horizontal or vertical bar). In another condition, in addition to changing orientation, the distractors also disappeared from their old locations and abruptly reappeared randomly at new locations. The key finding was that search was much more efficient (as indicated by small or even absent set size effects) than in a control condition in which all items (including the distractors) were static. Theeuwes (2004) argued that attention does not prefer a dynamic item per se, but the item that differs the most from its surroundings – in a dynamic environment this is the unique static item.

However, Davis and Leow (2005) have argued that it is actually not the general distinction between dynamic and static that allows for efficient search, but that, more specifically, motion is the crucial factor. They reasoned that Theeuwes' (2004) displays allowed for apparent motion to emerge as the items changed from one orientation or position to the other. They suggested that a static item among items with other dynamic features, like luminance changes or onsets, may not be found efficiently. In support of this, Davis and Leow (2005) found that search was highly inefficient for a static target among distractors that did not move, but abruptly changed both color and luminance (without disappearing). Davis and Leow (2005) concluded that filtering on the basis of motion may have a special status, whereas filtering a single static item from a set of items carrying dynamic properties other than motion (such as abrupt luminance changes) may be very difficult.

Pinto, Olivers and Theeuwes (2006) sought to investigate this issue further by conducting a series of experiments in which participants searched for a vertical or horizontal line segment among tilted line segments. In the control condition all line segments were static. In the crucial conditions the target was static, but the distractors behaved dynamically – they either all moved, or all continuously produced abrupt on- and offsets (i.e. they were blinking). Relative to the control condition, in which all distractors were static, search was efficient regardless of whether the distractors were blinking or moving. In fact, performance with blinking and moving distractors turned out to be remarkably the same. Control experiments showed that the efficient search of the static target among blinking distractors was not due to either average or momentary luminance differences, or due to long-range apparent motion. In other words, and contra Davis and Leow (2005), the results provided evidence that a static item is efficiently found in a dynamic environment, without these dynamics necessarily involving motion.

The question then remained why Pinto et al. (2006) found efficient search with blinking distractors, whereas Davis and Leow (2005) failed to do so. To resolve this issue, Pinto et al. (2006) adapted Davis and Leow's (2005) procedure and presented dynamic distractors that were abruptly changing in luminance but without disappearing. The result was that search for the static target became inefficient. Apparently, attention can only effectively distinguish between static and blinking stimuli when the blinking objects completely disappear, suggesting that the static/dynamic segmentation is at least partly object-based rather than purely luminance based.

A broad static/dynamic division?

On the basis of their results, Pinto et al. (2006) argued that attention makes use of a broad division of the visual scene into static information on the one hand, and dynamic information on the other. The dynamic channel is broadly defined, involving motion and blinking, but possibly also other changes related to these two (such as looming). Search for a static target among dynamic distractors or vice versa then becomes efficient, because attention can turn to one type of representation and largely ignore the other. Note here that Pinto et al. (2006) did not find completely parallel search for the static target (i.e. completely flat search slopes). This might be due to a default attentional set, which makes it easier for participants to attend to dynamic than stationary items. This view is supported by a study of Müller and von

Mühlenen (1999), who found search for a static target among moving distractors to become very efficient only after intensive training, while the reverse yielded efficient search without training. Support for such a broad division of visual information into a dynamic and static channel also comes from physiological data. It has been shown that there are two subsystems in the brain, the magnocellular and the parvocellular system. The processing of dynamic aspects of stimuli takes place mainly in the magnocellular system, whereas static properties are preferentially analyzed in the parvocellular system (e.g. Breitmeyer & Ganz, 1976; Livingstone & Hubel, 1988; Zeki, Watson, Lueck, Friston, Kennard & Frackowiak, 1991).

An important question then is whether the attentional system can only make efficient use of this broad division between static and dynamic stimuli, or whether it can differentiate between different types of dynamic stimuli. In other words, are all dynamic stimuli treated alike by attention, or can their representations be separated and guide attention in different ways? Even though Davis and Leow (2005) may not have been right in stating that static stimuli can be segmented only from motion stimuli, and not from luminance onsets, they may still be right in that the attention system differentiates between motion and onsets.

At the very lowest level in the processing stream, cells should treat blinking and moving objects equally because both types of stimuli involve the same luminance changes within the cells' receptive fields (at least in the luminance-based apparent motion displays used by Pinto et al., 2006). Also higher up, there appear to be cells in V1 responding in the same manner to both moving and blinking items (Andersen, 1997). Furthermore, it has been shown that adaptation to blinking stimuli leads to impaired motion perception, and vice versa (Green, 1981; Chapman, Hoag & Giaschi, 2004). This too suggests that, at least at the lower perceptual levels, the two types of dynamic stimuli are processed within a common pathway (presumably the magno pathway).

But also at an attentional level, it has been proposed that there is a general dynamic dimension driving attention (Folk, Remington & Wright, 1994). Folk et al. (1994) presented participants with an irrelevant precue followed by a target display. They found interference of the precue with target processing only when precue and target were either both statically or both dynamically defined. That is, when the target was a moving item or an onset, both moving and onset precues interfered. However, when the target was a color singleton, a moving precue did not interfere and vice versa. As Folk et al. (1994, p. 327) put it : "With respect to the architecture of attentional control, the present results provide support for the hypothesis that attentional control settings may be established for only very broad stimulus categories associated with the distinction between static and dynamic discontinuities." Thus, Folk et al.'s (1994) results support the notion that pre-attentively the visual scene is separated into dynamic and static stimuli and participants can prioritize either of these categories. Furthermore, their results suggest that the attention system is not able to differentiate between the different types of dynamic transients.

Separate motion and onset systems

There are also studies that cast doubt on the hypothesis that motion and onsets are treated alike. On a trivial note, the visual system must eventually treat motion and onset stimuli differently, because, after all, they *look* different. The important question is at what level the representations start to diverge, and whether attention can make use of this divergence.

Physiologically the picture is not entirely clear. It seems that until V1 both motion and onsets may be treated alike. After that, processing diverges with moving stimuli being processed in areas such as V5/MT (e.g. Zeki, 1974; Albright, 1984). The fate of onsets is less clear. There are some studies that suggest that motion derivatives such as flicker are also processed in MT (O'Keefe & Movshon, 1998), but there is also evidence for onset sensitivity in the lateral intraparietal sulcus (Gottlieb, Kusunoki & Goldberg, 1998). Zihl, Von Cramon, and Mai (1983) reported a patient with bilateral lesions in motion-sensitive areas, who had difficulty distinguishing movement, but who had little trouble with detecting flicker.

Also on a functional level there is evidence that suggests that attention is able to distinguish between motion and onsets. Yantis and Jonides (1984) asked participants to search for a target letter among distractor letters. When the target letter appeared with an abrupt onset, search slopes were independent of set size indicating that the abrupt onset captured attention. In a similar design, Hillstrom and Yantis (1994) presented participants with target letters that were in motion. Several versions of moving stimuli were tested, including oscillation, looming and nearby moving contours. None of these moving stimuli captured attention. This suggests that motion and onsets are treated differently by the attention system. However, Hillstrom and Yantis' (1994) findings are not undisputed. Franconeri and Simons (2003) argued that moving items do capture attention, but that this can be masked by simultaneous offsets. Franconeri and Simons (2003) found that several forms of motion captured attention when masking was controlled for. The debate has not ended, as findings by Von Mühlenen, Rempel and Enns (2005) suggest that whereas onsets appear to capture attention regardless of the simultaneous presence of other dynamics, other types of changes require a static environment in order to capture attention.

The present study

The results so far indicate that when a static item is searched, dynamic transients are relatively easily ignored by the visual system. There seems to be a fundamental distinction between the processing of static stimuli and dynamic transients in the brain which suggests that these results can be generalized. However, some studies suggest that, within the dynamic channel, attention can select distinct subcategories, such as onsets.

If, in the case of search for a static object in a dynamic background, attention can indeed only operate on a broad division between static and dynamic items then this yields several general predictions. The first prediction is that it should be hard to find a dynamic object in a dynamic environment even if the exact type of dynamics differ. Second, when participants are searching for a static item, dynamic distractors should be equally easy to ignore regardless of whether they are moving or blinking. The first prediction was tested in the first two experiments, in which we looked at search for blinking targets among moving distractors and vice versa, and search for moving targets among distractors that were both blinking and moving. Both experiments suggested a distinction between motion and onsets. Furthermore, some research suggests that luminance plays a crucial role in motion detection, but not in onset detection. For example, Cavanagh, Tyler and Favreau (1984) found perceived velocity to be a weighted average of luminance and chrominance velocity information. Gegenfurtner and Hawken (1995) showed that determining motion direction, for drifting sinusoidal gratings, was impaired, at low temporal frequencies, when luminance cues were removed. As a comparison, Yantis and Hillstrom' (1994) findings suggest that the onset of a new object captures attention regardless of whether this onset is accompanied by a change in luminance. The third experiment therefore sought to further dissociate the motion and onset transient systems by investigating search efficiency among moving and blinking distractors under equiluminant conditions.

Experiment 1: Blinking item among moving distractors

If attention employs only a broad division between static and dynamic stimuli, then it should be difficult to find a dynamic target among dynamic distractors, just like it is difficult to find a static target among static distractors. This should be the case regardless of whether the dynamics are of the same or of a different type (other things, such as frequency and local saliency of change, being equal). If, however, motion and flicker are differently encoded at an early enough level for attention to distinguish between different types of dynamic stimuli, then it should be easier to find a target that differs in the type of dynamics from the background.

To test these predictions we set up an experiment with four conditions (see Figure 3.1 for example displays). Participants searched for a moving or a blinking target among either moving or blinking distractors. Motion was defined by an intersected vertical line jumping back and forth between two positions. Blinking was established by having an identical stimulus turn on and off. The rate and abruptness of the change was equal for the blinking and moving conditions. The only difference between the two types of dynamics was that in the case of motion, the line abruptly disappeared and reappeared somewhere else for a certain period, whereas in the blinking condition it disappeared and then reappeared after the same period. Therefore, the local luminance change at an item's location was identical in both cases. Because, by definition, blinking items switch off for a brief period, one could argue that observers at any moment in time only need to search half the number of items in the display, as compared to the motion displays. To control for this, the blinking conditions included set sizes that doubled those for the motion conditions. Thus, given the controls for the frequency of change, the saliency of the local luminance change, and the overall set size, the only difference between the conditions was the quality of the dynamics (i.e. blinking vs. motion). If attention can distinguish blinking from moving, then search should be more efficient in the blinking among moving condition, or vice versa, than in the conditions were both target and distractors were moving or blinking.

Method

Participants: Twelve participants, ranging in age from 17 to 35 years, average 23.0 years, took part as paid volunteers. All participants completed all of the conditions. All had normal or corrected-to-normal vision.

Apparatus and Stimuli: The experiment was conducted on a computer with a Pentium IV processor, a 17 inch monitor and a standard QWERTY keyboard. The software package E-Prime was used for the presentation and timing of the experimental trials. The stimulus field consisted of a 9 x 8 imaginary matrix (17.26° x 12.59° visual angle).

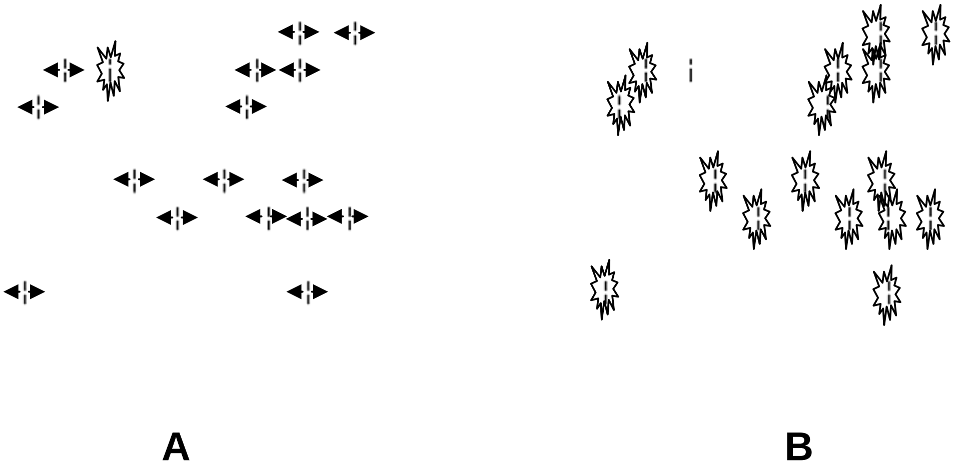

Figure 3.1. Typical examples of the search displays used in Experiment 1 and 3. Participants searched for a line segment with a gap above or below the middle among line segments with a gap in the middle. In Experiment 1 the line segments were white and the background was black. Experiment 3 also featured green lines on an equiluminant grey background. The "flash" surrounding an item indicates that it was blinking, the arrows indicate that it was moving. Panel A depicts an example of a trial in which the target was moving and the distractors were blinking (set size 16). Panel B depicts an example of a trial in which the target was blinking and the distractors were moving (set size 16).

In its cells white (Commission Internationale de l'Eclairage [CIE] x, y coordinates: .283 , .302, luminance 71.86 cd/m^2, background 0 cd/m^2 as measured with a Tektronix photometer) line segments of size 0.87° with a gap in the middle (size 0.12°) and one white line segment with a gap above or below the middle (distance from the middle 0.17°) were placed in the centre of the cells with a horizontal jitter of +/– 0.58° . The distractors could appear anywhere on the 9 x 8 matrix, the target could appear anywhere except in the middle (row 5, column 4 or 5).

Design and Procedure: Participants sat at approximately 90 cm from the monitor, with their fingers resting on the k- and m-keys which were used as the response buttons. The experiment consisted of twenty blocks, each containing thirty-six trials. The order of the blocks was repeated every four blocks, and followed a latin square design. Each sequence of four blocks corresponded to four main conditions. In all conditions, participants searched for a target with a gap either above or below the middle of the line among distractors (with a gap in the middle of the line). In the *blinking among moving* condition participants searched for a blinking target among distractors that moved back and forth between its original location and a location 0.32° to the right of this location. This gave a strong impression of apparent motion. The target changed after a random period between 150 and 300 ms, as it had a chance of 25% to switch on or off after 150 ms, 25% after 200 ms, 25% after 250 ms and 25% after 300 ms. The same held for the distractor elements, which moved after a period between 150 ms and 300 ms (with a chance of 25% to flip after 150 ms, 25% after 200 ms, 25% after 250 ms and 25% after 300 ms). All blinking items started with being "on" (visible). Furthermore, the chances of turning on and off were uncorrelated between the items and were uncorrelated to the previous on/offset time. The same held for the moving items, as the time before an item changed position was uncorrelated between items, and uncorrelated to previous times it took before it moved. In the *blinking among blinking* condition participants looked for a blinking target among blinking distractors (i.e. blinking in the same way as in the *blinking among moving* condition). In the *moving among blinking* condition participants looked for a moving target, that moved in the same way as the moving distractors in the previous conditions, among distractors that blinked on and off, in the same way as the blinking distractors in the previous two conditions. In the *moving among moving* condition participants looked for a moving target among moving distractors (moving in the same way as in the other conditions). In the conditions with moving distractors set sizes varied randomly within a block, between 9, 17 and 33 (i.e. 8, 16 or 32 distractors plus one target), in the conditions with blinking distractors set sizes varied randomly within a block, between 9, 17, 33 and 65 (i.e. 8, 16, 32 or 64 distractors plus one target), to control for the fact that blinking items disappear for half the time (on average). The task was to determine the location of the gap within the target element. Participants pressed "k" and "m" for gaps above and below the middle of the line respecitvely. Before each block there appeared a text on the screen telling participants which condition followed. Participants were instructed that both speed and accuracy were important. The first four blocks were disregarded as practice. The other sixteen blocks were included in the analyses. The experiment took approximately 60 minutes, with breaks between the blocks.

Results and discussion

Error percentages were overall low (see Table 3.1). A two-way ANOVA with condition (*blinking among moving*, *blinking among blinking*, *moving among moving* and *moving among blinking*) and set size (9, 17 and 33) revealed a main effect of condition [F(3,33) = 8.62, MSE = 0.003, $p < 0.001$], a main effect of set size [F(2,22) = 11.69, MSE = 0.005, $p < 0.001$] , and a significant interaction [F(6,66) = 10.41, MSE = 0.002, $p < 0.001$]. More errors were made when all items were of the same type of dynamics than when target and distractors were defined by different types of dynamics. Errors also increased with set size, but again more so when when all items were of the same type of dynamics. The error pattern resembled the RT pattern and there were no speed/accuracy trade-offs. We will therefore concentrate on the mean RTs of the correct trials.

		set size	
	9	**17**	**33**
Experiment 1			
moving - blinking	2.39	2.39	4.82
moving - moving	1.25	2.33	7.66
blinking - moving	3.71	1.80	3.42
blinking - blinking	2.13	6.21	18.44
Experiment 2			
control	2.73	5.07	6.72
flip	3.50	2.70	3.54
blink	2.40	2.38	2.72
Experiment 3			
standard motion	2.48	3.36	3.94
equiluminant motion	3.57	4.28	6.07
standard blinking	2.86	4.12	2.15
equiluminant	4.29	5.01	6.13

Table 3.1. Average error percentages for the different conditions and the different set sizes of Experiments 1-3.

Trials on which RTs were two and a half standard deviations away from the mean of the respective cell were excluded from analysis, resulting in a loss of approximately 5% of the trials. Figure 3.2 shows RTs as a function of set size for each condition, as well as the accompanying search slope. A two-way ANOVA on mean RT for each participant with condition (*blinking among moving*, *blinking among blinking*, *moving among moving* and *moving among blinking*) and set size (9, 17 and 33) as factors revealed a main effects for condition [$F(3,33) = 54.33$, $MSE = 381141.92$, $p < 0.001$] and set size [$F(2,22) = 54.22$, $MSE = 367253.85$, $p < 0.001$], as well as an interaction, [$F(6,66) = 13.48$, $MSE = 200445.95$, $p < 0.001$]. RTs were increased when all items were of one type of dynamics compared to when target and distractors were of different types of dynamics. Furthermore, RTs increased with set size, in all conditions, but search slopes were steeper in the conditions in which all elements had the same type of dynamics compared to those conditions in which target and distractor were of a different types of dynamics. Table 3.2 contains the statistics for all pairwise comparisons between the conditions (except for the set size main effects, which were significant for all comparisons, all ps < 0.001). These comparisons show that the search slope in the blinking among moving condition differed from both the moving among moving and as the blinking among blinking conditions. The same goes for the moving among blinking condition. Of further interest, the *moving among blinking* condition was reliably shallower than the search slope in the *blinking among moving* condition, whereas the *blinking among blinking* condition did not differ from the *moving among moving* condition. At the same time, intercepts in the *moving among blinking* condition were somewhat higher than in the *blinking among moving* condition (1198 ms vs 905 ms, t(11) = 3.74, p<0.005), an effect that may be explained by assuming that abrupt onsets allowed for quicker processing in the response stage, relative to moving targets (see Di Lollo, Enns, Yantis, & Dechief, 2000, that this might be the case). .

Finally, we assessed whether search in the blinking condition was artificially improved by the fact that blinking distractors are invisible half of the time. For this purpose we did the same analyses again, but used set sizes 17, 33, and 65 in the conditions containing blinking distractors. These analyses are shown in Table 3.3, and reveal no major differences in the pattern of findings. Furthermore, a direct comparison of the blinking conditions with the standard set sizes (9, 17, and 33) to those with double set sizes (17, 33, and 65) revealed only a significant increase in overall RTs [F(1,11) = 26.1, MSE = 410147.3, p < 0.001], but no difference in search slopes (ps > 0.1). Note that with this double set size analysis, in the *blinking among blinking* condition search slopes were not lineair, as the search slope for set sizes 9 and 17 was higher than for set sizes 17 and 33 (189 ms/item vs 26 ms/item, t(11) = 3.20, p < 0.01). However, the flattening search slope was accompanied by higher error rates for set size 33 than for the other set sizes (22% vs. 12%, t(11) = 5.20, p < 0.001), suggesting that with the very dense displays, observers decided to cut short search at the expense of accuracy.

The main result of Experiment 1 is that search for a blinking target among moving distractors or for a moving target among blinking distractors is relatively efficient (26 ms/item and 14 ms/item respectively), whereas search for a moving target among moving distractors or a blinking target among blinking distractors is highly inefficient (77 ms/item and 94 ms/item respectively). This was the case even though the blinking and moving occurred at exactly the same frequencies and produced the exactly the same luminance on- and offsets. This finding refutes the broad division hypothesis, according to which attention can distinguish efficiently between static and dynamic channels, but not within these channels[1].

The presence of a search asymmetry further corroborates this (cf. Treisman & Gormican, 1988). Search for a moving target among blinking distractors was more efficient than vice versa, suggesting that attention may find it easier to reject blinking distractors than moving distractors.

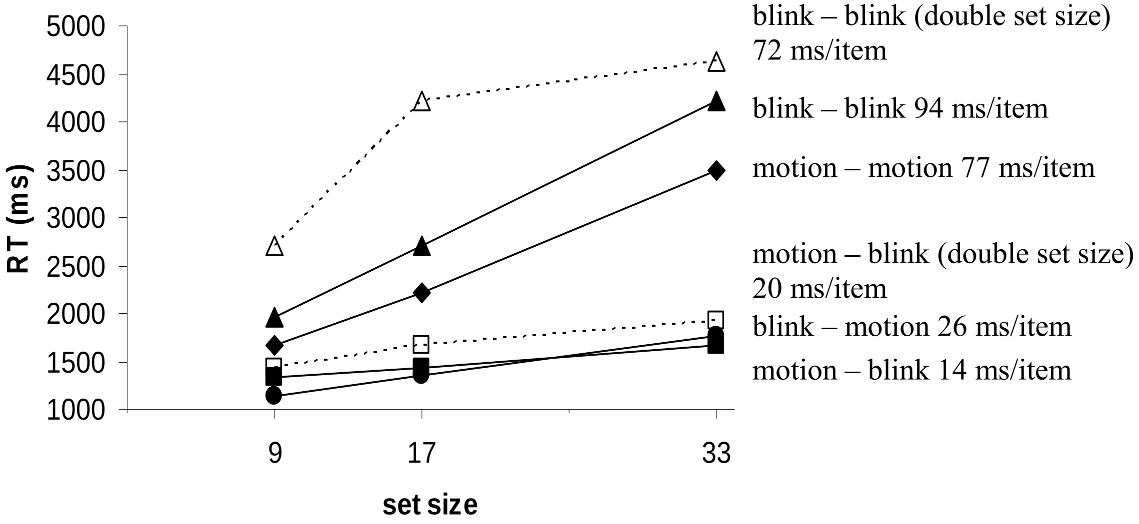

Figure 3.2. Mean RTs for each condition of Experiment 1 (*moving among blinking*, *moving among moving*, *blinking among moving* and *blinking among blinking*) as a function of set size. In addition to these, in dotted lines the results are displayed when each blinking distractor is counted as half a distractor. For each condition, the mean search slopes are provided.

Footnote 1 : Both Experiment 1 and Experiment 3 have been replicated using rotational instead of lateral motion. In the replication of Experiment 3 for each participant different equiluminance values were used. These values were determined for each participant through a flicker fusion test (Ives, 1912). These experiments yielded essentially the same results as the experiments reported in the current paper.

	blink-moving			**blink-blink**			**moving-blink**			**moving-moving**		
	F	MSE	p ≤	F	MSE	p ≤	F	MSE	p ≤	F	MSE	p ≤
blink-moving												
condition				69.9	611936.3	0.001	0.55	92492.6	>0.45	49.3	396020.0	0.001
con x set size				12.2	344293.7	0.001	3.5	36199.93	0.05	14.8	155763.8	0.001
blink-blink												
condition	69.9	611936.3	0.001				65.5	608375.6	0.001	17.8	251697.6	0.001
con x setsize	12.2	344293.7	0.001				17.3	334769.1	0.001	1.13	252386.2	>0.3
moving-blink												
condition	0.55	92492.6	>0.45	65.5	608375.6	0.001				53.9	326329.4	0.001
con x setsize	3.5	36199.93	0.05	17.3	334769.1	0.001				44.3	79262.9	0.001
moving-moving												
condition	49.3	396020.0	0.001	17.8	251697.6	0.001	53.9	326329.4	0.001			
con x setsize	14.8	155763.8	0.001	1.13	252386.2	>0.3	44.3	79262.9	0.001			

Table 3.2: Statistical results of all pairwise comparisons of Experiment 1.

	blink-moving			**blink-blink**			**moving-blink**			**moving-moving**		
	F	MSE	p ≤	F	MSE	p ≤	F	MSE	p ≤	F	MSE	p ≤
blink-moving												
condition				51.1	2083204.2	0.001	5.23	219464.8	0.05	49.3	396020.0	0.001
con x set size				5.85	576033.8	0.01	0.73	51845.5	>0.45	14.8	155763.8	0.001
blink-blink												
condition	51.1	2083204.2	0.001				42.8	1997456.7	0.001	24.3	1422510.7	0.001
con x setsize	5.85	576033.8	0.01				8.12	453599.6	0.002	4.12	296231.3	0.05
moving-blink												
condition	5.23	219464.8	0.05	42.8	1997456.7	0.001				23.9	468288.9	0.001
con x setsize	0.73	51845.5	>0.45	8.12	453599.6	0.002				40.1	72028.7	0.001
moving-moving												
condition	49.3	396020.0	0.001	24.3	1422510.7	0.001	23.9	468288.9	0.001			
con x setsize	14.8	155763.8	0.001	4.12	296231.3	0.05	40.1	72028.7	0.001			

Table 3.3: Statistical results of all pairwise comparisons of Experiment 1, whereby each blinking distractor is counted as half a distractor.

Experiment 2: Search for a moving target among moving and blinking distractors

In Experiment 2 we wanted to assess if we can further falsify the hypothesis that attention can only operate on a broad division between static and dynamic items. Participants searched for a target (a vertical or horizontal line) that moved in a random direction. All distractors (tilted lines) were also moving in random directions. In the control condition the distractors contained no other dynamic cues. In the two experimental conditions the distractors possessed an additional dynamic cue. In one experimental condition the distractors flipped back and forth between oblique orientations while moving, in the other they blinked (see Figure 3.3 for an example display). We employed different stimuli in Experiment 2 than in Experiment 1, since in Experiment 2 all items were moving translationally, and therefore adding another translational motion cue might not be very helpful. The stimuli used in this experiment allowed for the addition of rotational motion cues (the flipping) on top of the translational motion.

If attention can only operate on a distinction between static and dynamic stimuli, then adding extra dynamic cues in an already fully dynamic environment should not improve search efficiency. Thus, according to the broad division hypothesis, search for the dynamic target should be equally inefficient among all types of dynamic distractors. If anything the continuous flipping and blinking might only distract attention away from the moving target.

Of further importance is the question as to what exactly it is that makes dynamic changes so useful to the attentional system. Pinto et al. (2006) found that a static item among distractors that abruptly changed luminance but did not disappear was much less efficient than when the distractors disappeared (even when the absolute and relative transients, in terms of luminance changes, were controlled for). This finding suggests that not only luminance transients, but also object continuity can function as an important cue in visual search (see also Kahneman, Treisman & Gibbs, 1992; Abrams & Christ, 2003). If this is indeed the case, we expect search to be more efficient when the extra dynamical cue is blinking compared to flipping, since in the blinking condition the relative discontinuity of the distractors may provide an additional cue for segregating the background from the target. The search asymmetry found in Experiment 1 also suggests this.

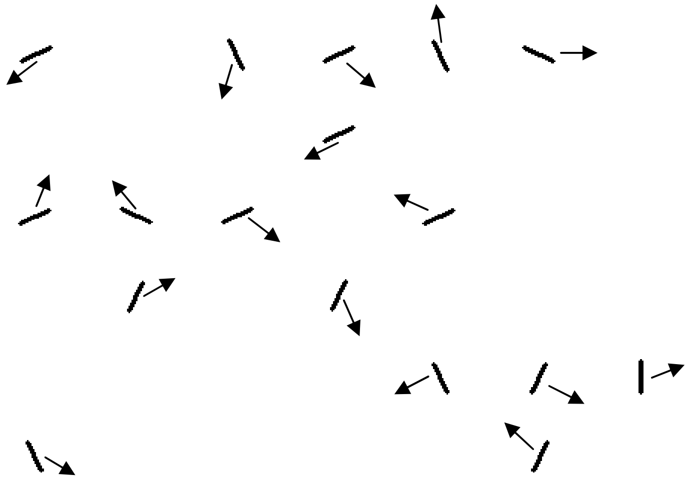

Figure 3.3. Typical example of the search display used in the control condition of Experiment 2. Participants searched for a vertical or horizontal line segment among slightly tilted line segments. In the actual experiments the lines were white and the background was black. In this example all items were moving in a random direction. Motion direction was uncorrelated between the items. In the *motion and flip* condition, in addition to moving, all distractors flipped back and forth between their original orientation and a 45° arc deviation from this (in either direction), whereas the target only moved. In the *motion and blink* condition, the distractors switched on and off in addition to moving, whereas the target only moved.

Method

Participants: Nine participants, ranging in age from 19 to 33 years, average 23.4 years, took part as paid volunteers. All participants completed all of the conditions. All had normal or corrected-to-normal vision.

Apparatus, Stimuli and Procedure: Everything was the same as in Experiment 1 except for the following changes. Participants searched for a non-tilted line segment without a gap of size 0.70°, which could be either horizontal or vertical. The task of the participant was to indicate the orientation of the target. The distractors were the same as the target, but they were tilted (22.5° tilted to either side of the horizontal or vertical plane). The distractors could appear anywhere on an imaginary 7 x 6 matrix (12.68° x 8.26°). The target (horizontal or vertical) could appear anywhere except in the middle (row 4, column 3 or 4). Every element moved at a speed of 1.75° visual angle / sec in a random direction. An item meeting the boundary of the display area would then continue its trajectory at the other end of the screen. The directions of the elements were uncorrelated. There were three conditions: *motion and blink*, *motion and flip* and *motion only*. In all conditions the target moved in a random direction but underwent no other changes. In the *motion only* condition the distractors also moved in random directions and underwent no other changes. In the *motion and flip* condition the distractors moved in random directions and flipped back and forth between their original orientation and a 45° arc deviation from this (in either direction). The items flipped after a random period between 150 and 300 ms, as it had a chance of 25% to flip after 150 ms, 25% after 200 ms, 25% after 250 ms and 25% after 300 ms. The chances of flipping were uncorrelated between the items and were uncorrelated to the previous time in between flips. In the *motion and blink* condition the distractors moved in a random direction and switched on and off, in the same way and at the same rate as in the *motion and flip* condition. In all conditions set sizes varied randomly within a block, between 9, 17 and 33 (i.e. 8, 16 or 32 distractors plus one target). We no longer included set size 65 since Experiment 1 suggested that it added little to the results. The task was to determine the orientation of the target element. Participants pressed “z” for vertical, and “m” for horizontal lines. The experiment consisted of fifteen blocks, each block containing 54 trials. The order of the blocks was determined according to a latin square design. The first three blocks were disregarded as practice. The experiment took approximately 60 minutes, with breaks between the blocks.

Results and Discussion

Error percentages were overall low (see Table 3.1). A two-way ANOVA with condition (*motion only*, *motion and flip* or *motion and blink*) and set size (9, 17 or 33) as factors revealed a main effect for condition [F(2,16) = 4.76, MSE = 8.12, $p < 0.05$]. Participants made most errors in the *motion only* condition. This pattern resembled the RT pattern and a speed-accuracy trade off could be excluded. We will therefore concentrate on RTs.

Trials on which RTs were two and a half standard deviations away from the mean of the respective cell were excluded from analysis, resulting in a loss of approximately 3.5 % of the trials. Figure 3.4 shows a graphical depiction of the results. A two-way ANOVA on mean RT for each participant with condition (*motion only*, *motion and flip*,or *motion and blink*) and set size (9, 17 or 33) as factors revealed a main effect for condition, as RTs were elevated in the *motion only* condition compared to the *motion and flip* and *motion and blink* conditions [F(2,16) = 21.87, MSE = 490817.67, $p < 0.001$]. Furthermore, RTs increased with set size [F(2,16) = 28.09, MSE = 835406.67, $p < 0.001$]. There was also a significant interaction, reflecting the steeper search slope in the *motion only* condition [F(4,32) = 16.04, MSE = 165237.32, $p < 0.001$] compared to the *motion and flip* and *motion and blink* conditions. Pairwise comparisons revealed that all conditions differed significantly from eachother in RTs as well as search slopes. RTs were fastest and slopes shallowest in the *motion and blink* condition and were slowest and steepest in the *motion only* condition (Motion only vs. motion and flip: condition, $F(1,8) = 19.23$, $MSE = 649873.55$, $p < 0.005$; condition x set size, $F(2,16) = 15.18$, $MSE = 195855.73$, $p < 0.001$. Motion only vs. motion and blink: condition, $F(1,8) = 24.76$, $MSE = 768191.63$, $p = 0.001$; condition x set size, $F(2,16) = 18.38$, $MSE = 258901.35$, $p < 0.001$. Motion and flip vs. motion and blink: condition, $F(1,8) = 12.55$, $MSE = 54387.84$, $p < 0.01$; condition x set size, $F(2,16) = 5.36$, $MSE = 40954.87$, $p < 0.05$).

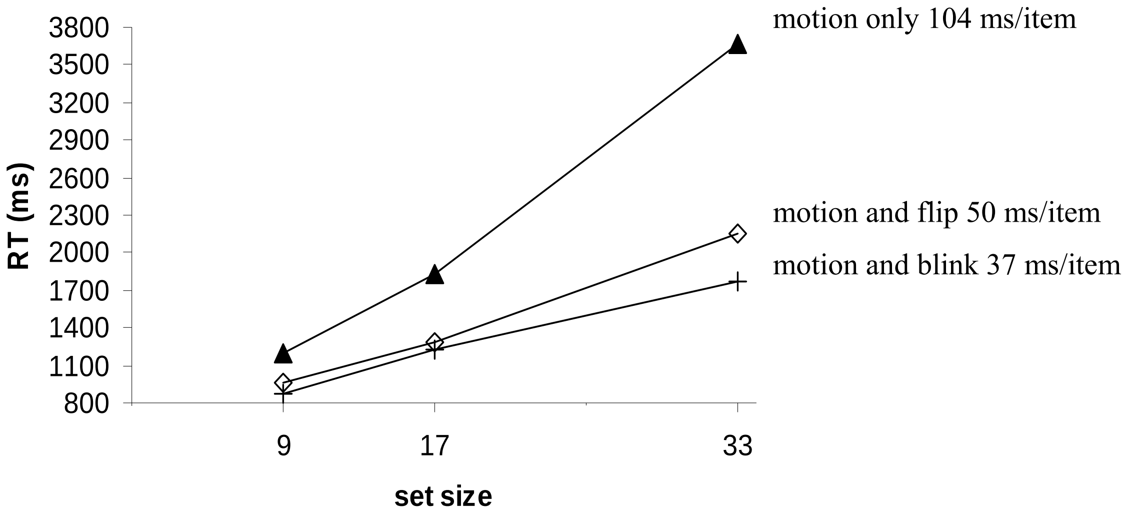

Figure 3.4. Mean RTs for each condition of Experiment 2 (*motion and blink*, *motion and flip* and *motion only*) as a function of set size. For each condition, the mean search slopes are provided.

Experiment 2 shows that participants benefit from the additional dynamic information carried by the distractors when searching for an already dynamic target. This provides further evidence against the broad division hypothesis. Rather than just dividing between static and dynamic stimuli, attention can make use of specific types of dynamic information.

Note that although the target was dynamic (i.e. it moved in a randomly chosen direction), it was also relatively stable, in that it retained its integrity as an object. The distractors on the other hand, apart from moving in random directions, abruptly changed at random moments, and may thus be regarded as less stable. The attentional system may make use of this relative object stability. Consistent with this, search was more efficient when the distractors switched on and off, than when they remained present but flipped (i.e. showed apparent motion).

Experiment 3: Searching for a static target with and without luminance differences

A further way of trying to dissociate different types of dynamic properties with respect to their attention-guiding power is by using equiluminant stimuli. Previous research suggests that luminance plays an important role in motion detection (Cavanagh, Tyler & Favreau, 1984; Gegenfurtner & Hawken, 1994). However, with regard to onset detection, luminance may be less important. Yantis and Hillstrom (1994) provided evidence that abrupt equiluminant onsets captured attention, whereas large luminance changes that did not signal the appearance of a new object did not (though see Theeuwes, 1995). They suggested that the appearance of a new object is crucial, and that luminance change is not mandatory for onset detection. If motion detection is somehow dependent on luminance factors, but onset detection is not, we speculate that, under equiluminant conditions, the rejection of moving distractors may be impaired while the rejection of onset distractors will not be.

Method

Participants: Twelve participants, ranging in age from 18 to 25 years, average 20.8 years, took part as paid volunteers. All participants completed all of the conditions. All had normal or corrected-to-normal vision

Apparatus, Stimuli, Design, and Procedure: Everything was the same as in Experiment 1 except for the following changes. The target was always static, and the distractors were either moving or blinking (in the same way as in Experiment 1). Furthermore, participants were presented with two luminance conditions. In the *standard* conditions, the line segments were white and the background was black. In the *equiluminant* conditions the line segments were green and the background was gray. Items and background were equiluminant. Fixed values for the colors were used, since a flicker fusion test (Ives, 1912) on several participants in pilot studies yielded very similar results. The CIE values were $x = 0.298$, $y = 0.607$; luminance, 8.84 cd / m^2 for the green items; $x = 0.281$, $y = 0.283$; luminance, 8.24 cd / m^2 for the gray background. In the *standard blinking* and *standard moving* conditions, the targets were static whereas the distractors were respectively blinking or moving. The same was the case for the *equiluminant blinking* and *equiluminant moving* conditions were the same as the *standard blinking* and *standard moving* conditions, except now the items were presented green on gray instead of white on black. The experiment consisted of 20 blocks of 36 trials each. The order of the blocks was determined according to a latin square design. The first four blocks were disregarded as practice. The experiment took approximately 60 minutes, with breaks between the blocks.

Results and Discussion

Error percentages were overall low (see Table 3.1). A three-way ANOVA with type of dynamics (*motion* and *blinking*), luminance condition (standard, equiluminant) and set size (9, 17, or 33) as factors only revealed a main effect for condition [$F(3,33) = 2.94$, $MSE = .001$, $p < 0.05$]. Overall, partcipinats made more errors in the equiluminant conditions than in the standard conditions, a pattern that is in line with the RTs. For the remainder of the analyses we will therefore concentrate on the RTs.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 4 % of the trials. Figure 3.5 shows a graphical depiction of the results. A three-way ANOVA on mean RT for each participant with type of dynamics (*motion* and *blinking*), luminance condition (standard, equiluminant) and set size (9, 17, or 33) as factors revealed a main effect for type of dynamics [$F(1,11) = 29.67$, $MSE = 229713.41$, $p < 0.001$]. RTs were higher in the *motion* than in the *blinking* condition. RTs also increased with set size [$F(2,22) = 103.74$, $MSE = 261949.32$, $p < 0.001$] , and were slower for equiluminant stimuli [$F(1,11) = 22.13$, $MSE = 1148496.31$, $p = 0.001$]. There was a significant interaction between type of dynamics and set size [$F(2,22) = 23.26$, $MSE = 95640.92$, $p < 0.001$], reflecting the overall steeper search slope in the *motion* condition than in the *blinking* condition. There was also a significant interaction between luminance condition and type of dynamics [$F(1,11) = 5.17$, $MSE = 210391.34$, $p < 0.05$], as the luminance manipulation had a larger effect in the *motion* condition than in the *blinking* condition. Furthermore there was a significant interaction between luminance condition and set size [$F(2,22) = 6.11$, $MSE = 152783.34$, $p < 0.01$], reflecting the overall steeper search slope in the equiluminance condition than in the standard condition. Most importantly, there was a three way interaction between type of dynamics, set size and luminance condition [$F(2,22) = 9.48$, $MSE = 74169.62$, $p = 0.001$] reflecting the fact that search efficiency in the *motion* condition was more affected by the equiluminance manipulation than search efficiency in the *blinking* condition. Two separate ANOVA's with luminance and set size as factors revealed that the equiluminance manipulation had no effect on search slopes in the *blinking* condition (F < 1. p > 0.4), but did have a significant effect in the *motion* condition [F(2,22) = 8.97, MSE = 177643.78, p = 0.001].

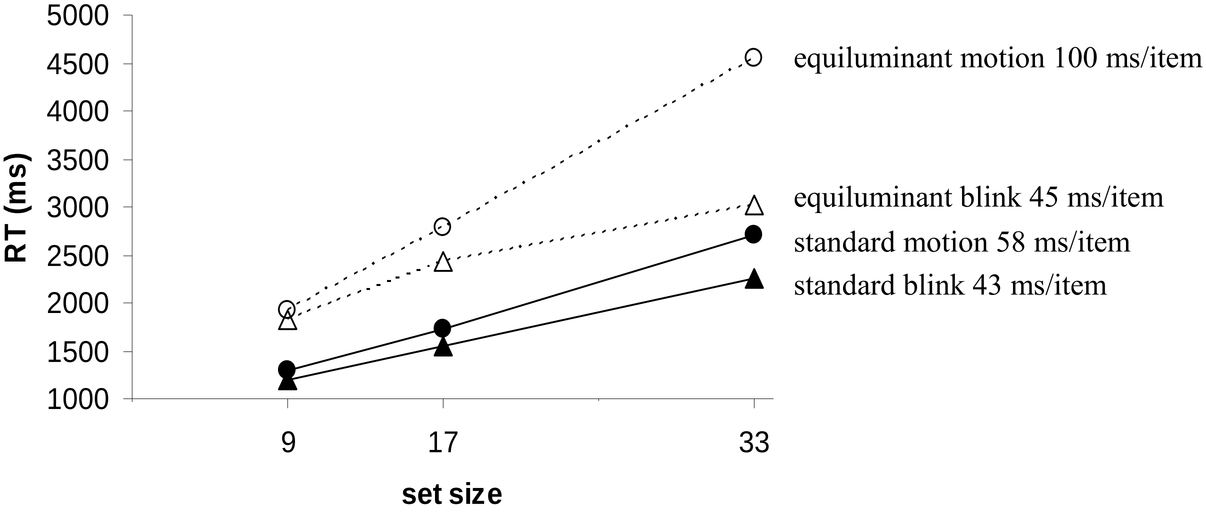

Figure 3.5. Mean RTs for each condition of Experiment 3 (*standard blinking*, *equiluminant blinking*, *standard moving* and *equiluminant moving*) as a function of set size. For each condition, the mean search slopes are provided.

Experiment 3 shows that the rejection of moving distractors is impaired under equiluminant conditions. Importantly, the same did not hold for the rejection of blinking distractors. Blinking distractors were as efficiently rejected under equiluminant as under non-equiluminant circumstances. The results provide further evidence for a dissociation between the effects of different types of dynamic stimuli. The removal of (most) luminance cues differentially affects the rejection of moving and blinking distractors . This again implies that selection is not just based on a broad division between dynamic and static stimuli, but that selection depends on the exact type of dynamic stimulus (in this case blinking versus moving). Thus, the findings of Experiment 3 corroborate the results of the first two experiments and again suggest that onsets and moving stimuli are not treated alike by the attentional system. Furthermore, the results of Experiment 3 are congruent with the suggestion of Yantis and Hillstrom (1994) that onset detection is largely independent of luminance factors, although they are not conclusive support for their account, since

Experiment 3 looked at how efficiently equiluminant onsets can be *rejected* rather than selected.

General Discussion

Recently, we reported evidence that observers can relatively efficiently disregard dynamic distractors and find a static target, regardless of whether these distractors were moving or blinking (Pinto et al., 2006). Apparently, observers can make use of a broad division between static and dynamic channels, and selectively attend to one of them. Here we asked the question whether attention makes use only of this broad division, or whether it makes specific distinctions between different types of dynamic changes.

In Experiment 1 we found that a difference in type of change between the target and the distractors could guide search, even though the abruptness, frequency, and local luminance increase of the changes was the same for both types. This goes against the broad division hypothesis. Search was efficient for blinking targets among moving distractors, as well as for moving targets among blinking distractors, but with a slight advantage for the latter condition. This search asymmetry between the two conditions provides further evidence for a distinction between the two types of dynamics.

In Experiment 2, all display items continuously moved around in random directions. Hence, the entire display was dynamic. Nevertheless it was shown that additional dynamic cues (i.e. the distractors were blinking or flipping) improved search, again suggesting that attention can make use of more information than provided by a broad static/dynamic division. Here too, blinking distractors were more easily ignored than flipping distractors.

Finally, Experiment 3 revealed that under equiluminant conditions, blinking distractors could be as efficiently ignored as under high contrast conditions, whereas the rejection of distractors featuring apparent motion suffered from the equiluminance. This provides further evidence for dissociations in attentional processing of different types of dynamic stimuli.

Object continuity

The findings point towards object continuity as an important factor. In Experiment 1, a moving, but continuously present target was more efficiently found between abruptly on- and offsetting distractors, than the other way around. The same was true in the standard conditions of Experiment 3 for static targets among blinking distractors, compared to moving distractors. This may be because moving distractors are regarded as more continuous than the disappearing distractors. Such continuous distractors may then be regarded as stronger competitors in search for a continuous target. In Experiment 2, the target itself was dynamic (i.e. it was moving), but it was also relatively continuous, in that, unlike the distractors, it did not abruptly change. Again search was aided by changing distractors, and again search was aided a little more when the distractors were blinking rather than flipping (the latter presumably providing more continuity). Finally, under the equiluminant conditions of Experiment 3, the presumably more continuous moving distractors were relatively even more difficult to ignore, whereas the appearing and disappearing blinking distractors allowed for search to be as efficient as in the standard baseline (with luminance differences).

Further support for object continuity playing an important role in visual search of dynamic displays comes from Experiment 5 of Pinto et al. (2006). In that experiment, participants searched for a static target among distractors that changed luminance. The distractors could disappear as a result of the luminance change, or remain on the screen. In both cases the luminance change was equally large. However, search was efficient only when offset was complete. Pinto et al.'s results neatly fitted those of Davis and Leow (2005), who found inefficient search for a static target among distractors that changed luminance and color, but that did not disappear. Both findings suggest that when both target and distractors are relatively continuous (i.e. changing but not disappearing), search is less efficient than when one of the two loses its continuity (i.e. disappearing).

Further evidence that object continuity plays a role in visual search comes from several other studies. Yantis and Hillstrom (1994) employed a visual search task, in which in one condition the target underwent an abrupt luminance change, and in another condition the target appeared as an equiluminant onset. They found that luminance changes did not capture attention, whereas equiluminant onsets did. Again, it seems that a sudden discrepancy in integrity of an object is more important to the attentional system than a physically equally large change to a continuously displayed object. Enns, Austen, di Lollo, Rauschenberger, and Yantis (2001) reported a similar finding. They found that new objects were more effective in guiding search than luminance changes to old objects, even if the luminance change defining the onset was smaller than the luminance change to the old object. Furthermore, Cole, Kentridge and Heywood (2005) found that the appearance of a new object captures attention in visual search, whereas a change of color to an existing object does not. All these findings support the notion that violations of object continuity are important to the attentional system.

Finally, object continuity has also been shown to affect non-search tasks, such as multiple object tracking (Scholl & Pylyshyn, 1999) and object matching tasks (Mitroff, Scholl, & Wynn, 2004). This is not to say that luminance changes per se are not important. Franconeri, Hollingworth and Simons (2005) used dynamic occlusion to show that, under these circumstances, new objects only capture attention when they are accompanied by large luminance changes. This shows that object continuity and luminance information interact: new object onsets make luminance changes more effective, and vice versa.

Attention based on object files

An explanation for why object continuity plays such an important role for the attentional system might come from the object file hypothesis. Kahneman, Treisman and Gibbs (1992) suggested that the visual system is organized on the basis of objects. According to this theory a separate file is created for each object. Whenever something changes within an existing object, the file is updated. The appearance of a new object leads to the creation of a new object file. Thus, it is the appearance of a new object that is most relevant to the attentional system. Within this hypothesis object continuity becomes crucial. Continuously existing objects only lead to updating of existing object files, whereas severe discontinuities in an objects spatiotemporal landscape cause the creation or deletion of object files (see also Mitroff et al. 2004; Yantis & Gibson, 1994).

According to the object file hypothesis new object files require attention to be formed (Kahneman et al., 1992). Perhaps then, large discontinuities, like abrupt onsets, capture attention to make the creation of such a file possible (cf. Yantis, 1998). If the object concerned is the target, then performance will benefit from the attentional capture caused by the discontinuity.

However, there are several difficulties with the object file explanation of the current findings. First, according to Kahneman et al. (1992) only 3 to 4 object files can be maintained at any one time. In the current experiments, there were 8 to 32 distractors, implying that most of the distractors were necessarily unaffected by the existence (or disappearance) of object files. Second, note that in our experiments, the discontinuous objects were the distractors. If such discontinuities indeed automatically demand the creation of a new object file for each of these distractors, then we should expect rather inefficient search, as the new distractors continuously draw attention away.

With respect to the second objection the work of Von Mühlenen et al. (2005) might be important. Their findings suggest that temporal uniqueness of change determines whether or not a changing item captures attention. They found that when a change to an item occurred when no other items were changing, the item was more effective in capturing attention. In our displays, with up to 32 randomly blinking distractors, a single distractor rarely produced a temporally unique onset, making them less effective attentional captors.

Another possibility is that new object files indeed need attention to be created, but that this is not an automatic process. Perhaps, at the start of the display, object files are created for all the items in the display (distractors and target alike). When a distractor then briefly disappears, its object file is destroyed. It is not re-created when the distractor reappears. After a few rounds of disappearances the target remains as the only one with an intact object file, allowing for relatively efficient search.

A similar suggestion could also account for the first objection. Search for the only static object is efficient not *despite* the limited number of object files, but *because* of the limited number of object files. Perhaps, due to the limited amount of possible object files, unstable objects do not get object files assigned to them. This then would leave the static object as the only item with an object file attached to it, which would allow for efficient search.

Temporal synchrony

Another possibility is that it is not so much the individual qualities of the distractors that allowed for efficient search, but their global properties. According to the temporal synchrony account (Engel & Singer, 2001; Jiang, Chun, & Marks, 2002) elements that carry the same temporal properties are grouped together. Perhaps the distractors in these displays are not treated as individual objects, but group into a single dynamic surface, with a single object file attached. This grouping may occur despite the randomness with which each item changes (i.e. they do not change in synchrony). Merely the fact that they are all dynamic may cause them to group (actually, phenomenologically, the displays resemble a water surface glistering in the sun). The target then represents the “discontinuity” to this surface. As the single static item, it breaks the dynamics (like a pole standing out of the glistering water surface).

Fine tuning of attentional control

Davis and Leow (2005) suggested that a static target can be efficiently found among moving, but not among blinking distractors. Pinto et al. (2006) showed that this is not the case and that among both types of distractors static targets can be found efficiently. The present research disproves Davis and Leow's (2005) suggestion even more strongly. In all the current experiments the static target was more efficiently found among blinking than among moving distractors.

The current work also seems at odds with the conclusions of Folk et al. (1994). In their study it appeared that participants could only set their attentional control to either static or dynamic, whereas our findings indicate that within the dynamic domain subtler settings can be adopted. An explanation of this discrepancy might be along the lines of the attentional weighting account of Müller, Heller and Ziegler (1995). According to this account attentional weights are either distributed over different dimensions, such as color, motion, and form. Similar weighting might occur within a certain dimension, to particular values (for instance within the color dimension they might be differentially distributed between blue and red). Such a weighting account would suggest that how fine attentional control is tuned depends on the task at hand. In the first three experiments of Folk et al. (1994), the target could be either static or dynamic. Within this multidimensional task setting, attention may only be set to either the static or the dynamic dimension. A static precue may then not interfere with dynamic targets, or vice versa, whereas different types of dynamic stimuli may interfere with each other. Going against this though are the last two experiments of, Folk et al. (1994), in which only dynamic targets were employed, but attention was still not set to particular values within the dynamic dimension (i.e. motion or onsets). However, note that in Folk et al.'s experiments there may have been no real need to adopt an attentional set for a more specific dynamic property. In all their target displays, the target was a dynamic item among static distractors, regardless of which specific type of dynamics was used. Hence, it would be sufficient for observers to merely adopt a more general attentional set for dynamic targets. In our experiments more specific control settings were sometimes needed, and possible (e.g. search for a blinking target among moving distractors in Experiment 1: The task set allows for specific settings and efficient search makes these specific settings necessary), and therefore in the current study we did find a more fine-tuned attention setting within the dynamic domain.

Finally, a related question here is whether moving and blinking should be regarded as separate dimensions, or whether one is a subdimension of the other. Several researchers have described the detection of blinking items as a form of higher order motion detection (e.g. Nishida & Sato, 1994; O'Keefe & Movshon, 1998). This might suggest that blinking is a subcategory of motion, i.e. that blink detection is a specialized form of motion detection. Experiment 3 of the present study casts doubt on this notion. In Experiment 3 rejection of moving stimuli was impaired under equiluminant condition, while rejection of blinking stimuli was not affected. This suggest that flicker detection is not a subcategory of motion detection.

Conclusion

The present research shows that in search for a static object in a dynamic environment, attentional control is not restricted to a broad division between dynamic and static stimuli. Within the dynamic domain, attention can be specifically set to certain types of change. Furthermore, object continuity and task demands probably play an important role in explaining the current results. Finally, the current work suggests that onset detection is not a specialized form of motion detection.

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Static items are automatically prioritized in a dynamic environment

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Abstract

Everyday experience provides us with the intuition that dynamic events guide or capture attention – something which has been confirmed in experimental studies. Recently, we showed that there are limitations to the extent to which dynamic items attract attention. In a visual search task where all items, except one, were dynamic, the dynamic items could be ignored and the static item could be efficiently detected. In the present study we investigated whether attention is automatically drawn to the static item. Three visual search experiments, in which the target and the static object were uncorrelated, revealed that the static item was nevertheless prioritized. This result is at odds with some of the current theories on attentional capture, including the 'new object' hypothesis. The current study suggests that differences in dynamics, rather than dynamic features per se determine where attention is allocated.

When you are looking for a friend in a crowd it helps when he or she waves. This example suggests that dynamic items attract attention. Research using visual search tasks has indeed confirmed that, within static environments, dynamic items can guide or capture attention (McLeod, Driver & Crisp, 1988; Yantis & Jonides, 1984; Watson & Humphreys, 1995; Theeuwes, Kramer, Hahn & Irwin, 1998; Franconeri & Simons, 2003; von Mühlenen, Rempel and Enns, 2005).

Recently, Pinto, Olivers, and Theeuwes (2006) investigated the complementary question, namely whether in a dynamic environment, a static object is able to efficiently guide attention. Imagine everyone is frantically waving to people they know – would it be easier to find your friend if he or she is the only one who does not wave? Given that dynamic items attract attention, one might expect this to be quite difficult. However, Pinto et al. (2006) have found that when all items are blinking or moving except one, the dynamic items can be largely ignored and attention can be efficiently directed to the static target.

In Pinto et al.'s (2006) study the static item was always the target and participants were aware of this. In other words, the fact that it was static was a task-relevant feature of the target. Therefore, it is not clear if attention went to the static item because it matched the top-down settings of the participants, or whether attention was captured in an involuntary way. The present study intended to resolve this issue by using conditions in which the fact that an item was static was irrelevant to the task. For this purpose, we employed the irrelevant-feature search task developed by Yantis and Jonides (1984). As in a typical search task, participants search for a target item among a variable number of distractors. However, instead of the target always carrying the feature of interest, this feature is assigned to a randomly chosen item in the search display. Consequently, the object with the unique feature is the target in only 1/nth of the trials, with n indicating the number of items in the display. As the feature is uncorrelated with being the target, participants presumably have no top-down incentive to search for it since it is irrelevant to the task. Nevertheless, if the feature of interest draws attention automatically, one should still find improvements in search efficiency when the feature happens to coincide with the target. In other words, reaction times (RTs) as a function of search set size should be reduced. In our case, the unique feature of interest was being static.

Existing psychophysical theories offer two opposite predictions regarding the question whether or not a static object should automatically guide attention in a dynamic environment. Yantis and colleagues (e.g. Jonides & Yantis, 1988; Yantis & Egeth, 1999; Yantis & Hillstrom, 1994) suggest that the creation of a new perceptual object or group automatically draws attention. The abrupt onset of an object is a prime example of such a new object appearance, and has been found to capture attention, whereas a sudden increase in luminance of an existing object may be less effective (Yantis & Hillstrom, 1994). Franconeri and Simons' (2003) findings suggest that specific types of motion (such as looming) may also involuntarily draw attention, as long as these events are ecologically relevant to the organism. Finally, Von Mühlenen et al. (2005) argue that in principle any dynamic change could capture attention, as long as there are no temporally neighbouring changes. Important for the current study is that all these views, which we will refer to as the *dynamic capture hypothesis*, predict that a static object does not automatically guide attention in a dynamic environment, since it does not indicate the appearance of a new object, it is not dynamic, and it does not undergo a change when the environment is stable (rather the reverse).

A different prediction can be derived from the views of for example Theeuwes (1992; 2004), Itti and Koch (2000) and Nothdurft (1993). In their view, attention is not driven by the specific quality of a feature (such as being dynamic), but by the difference between a feature and its (local) environment. The more salient a feature difference, the more likely that it draws attention. According to this saliency account a static item surrounded by dynamic items will automatically draw attention, since it carries a unique feature relative to its surroundings.

In the current study we investigated if a static object automatically guides attention in a dynamic background. We conducted three experiments in which the irrelevant-feature search task was employed.

Experiment 1: Does a static object automatically guide attention?

In Experiment 1, participants searched for a non-tilted line segment among tilted line segments and indicated if the target was vertical or horizontal. Example displays are shown in Figure 4.1. We presented participants with two types of blocks. In the 'irrelevant' block all line segments except one were continuously blinking on and off. The static element coincided with the target in 1/n-th of the trials, with n indicating set size, and therefore was not predictive of the target. In the 'relevant' block all elements except one were blinking, and now the static element was always the target. If the dynamic capture hypothesis is correct, then the static item should not capture attention at all, and performance in the irrelevant block should be similar regardless of the target being static or dynamic. However, if the saliency account is correct then the static singleton should involuntarily draw attention and the target should be more efficiently found when it is static than when it is dynamic. Furthermore, if top-down factors play no role in directing attention to the static object, then performance for a static target should be similar regardless of whether being static is relevant or not.

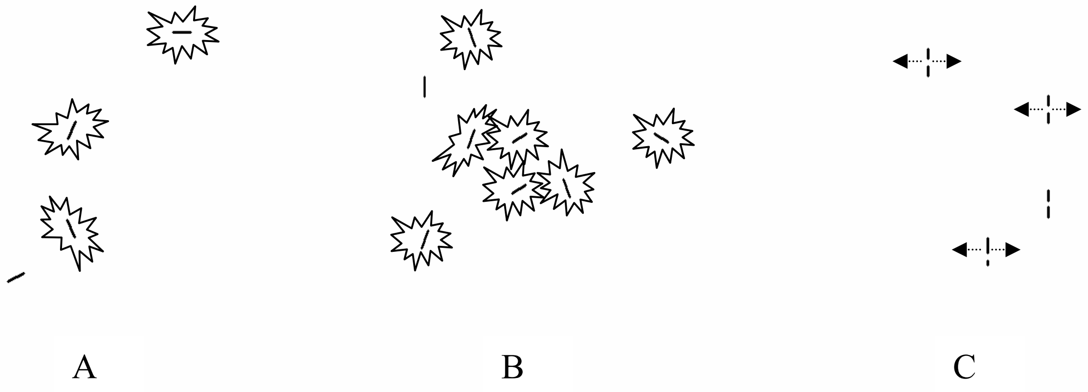

Figure 4.1. Typical examples of the search displays used in Experiment 1, 2 and 3. Panel A and B show examples of Experiments 1 and 2, in which participants searched for a vertical or horizontal line among slightly tilted lines. The flash surrounding an item indicates that it was blinking. Panel A depicts an example of a trial with set size 4, in which the target was one of the blinking items. The blinking objects randomly switched on and off after 150, 200, 250 or 300 ms. Chances of switching were equal for each lag and were not influenced by previous switching latencies. Panel B depicts an example of a trial with set size 8, in which the target was static. Panel C depicts an example of the search display used in the motion conditions of Experiment 3. Participants searched for a line with a gap above or below the middle. In this example all items except one were moving, the target was one of the moving items. In the actual experiments the lines were white and the background was black.

Method

Participants: Eight participants, ranging in age from 18 to 22 years, average 19.6 years, took part as paid volunteers. All participants completed all of the conditions. All had normal or corrected-to-normal vision.

Apparatus and Stimuli: The experiment was conducted on a computer with a Pentium IV processor, a 17 inch monitor and a standard keyboard. The software package E-Prime was used for the layout and timing of the experimental trials. The stimulus field consisted of a 7 x 6 imaginary matrix (12.68° x 8.26° visual angle). In its cells white line segments (Commission Internationale de l'Eclairage [CIE] x, y coordinates: .283, .301) of size 0.76° were randomly placed. The distractors could appear anywhere on the matrix, the target could appear anywhere except in the middle (row 4, column 3 or 4). The luminance of the line segments was 65.62 cd/m^2, the luminance of the background was 0 cd/m^2 , as measured with a Tektronix photometer. In each display there was a vertical or horizontal white line target, among white lines that were tilted 22.5° to either side of the horizontal or vertical plane.

Procedure: Participants sat at approximately 90 cm from the monitor, with their fingers resting on the z- and m-key which were used as the response buttons. The experiment consisted of twelve blocks, each containing 48 trials. In the *relevant* condition participants looked for a static horizontal or vertical white line among tilted white lines that blinked on and off. The tilted lines randomly switched on or off with an equal chance of switching after 150, 200, 250 or 300 ms. The chances of an item switching on or off were independent of the other items, and independent of the item's previous switch times. The *irrelevant* condition was the same as the *relevant* condition, except that now the static object was the target in 1/nth of the trials and a distractor on all other trials, with n indicating set size (i.e. if there were four items in the display the static object was the target in 25% of the cases and a distractor in 75% of the cases). Thus, there were two kinds of blocks: In the relevant blocks, the static item was always the target and all distractors were blinking, in the irrelevant blocks the target was mostly a blinking item (with one of the distractors being static), but in 1/n-th of the trials the target happened to be the item (and all the distractors were blinking). Therefore, there were two types of trials in the *irrelevant* block. *Irrelevant, static target* refers to these trials in the irrelevant block, where the target happened to be static. *Irrelevant, blinking target* refers to these trials in the irrelevant block, where the target was a blinking item among other blinking items. In all conditions set sizes varied randomly within a block, between 4 and 8 (i.e. 3 or 7 distractors plus one target). Within each block, on two thirds of the trials set size was 8 and on one third of the trials set size was 4. This was done in order to have equal numbers of static target trials for both set sizes in the *irrelevant, static target* condition. The order of the blocks was repeated every four blocks. In each sequence of four blocks there was one *relevant* block, and three *irrelevant* blocks. For half of the participants the *relevant* block was the first of the four blocks, for the other half the *relevant* block was the last of the four blocks. The task was to determine the orientation of the target element. Participants pressed "z" for vertical, and "m" for horizontal lines. The task was assumed to require focal attention to be directed to the target element. Before every block started, there appeared a text on the screen instructing the participants either to attend to the static object (since it was always the target), or that attending the static object was not benificial (since the static item and the target only coincided at chance level). Participants were instructed that both speed and accuracy were important. The first four blocks were disregarded as practice. The other eight blocks were included in the analyses. The experiment took approximately 45 minutes, with breaks between the blocks.

Results

Error percentages were overall low (see Table 4.1), and an ANOVA revealed no significant effects. There were no signs of a speed accuracy trade-off. We will therefore concentrate on the mean RTs of the correct trials.

	set size **4**	 **8**
Experiment 1		
relevant	13.68	6.78
irrelevant,static	9.17	13.03
irrelevant,blinking	8.52	9.28
Experiment 2		
static target	3.08	4.18
blinking target	2.71	3.15
Experiment 3		
moving		
relevant	6.44	6.07
irrelevant,static	3.96	2.34
irrelevant,dynamic	5.76	5.29
blinking		
relevant	3.92	4.53
irrelevant,static	4.74	4.84
irrelevant,dynamic	6.78	6.52

Table 4.1. Average error percentages for the different conditions and the different set sizes of Experiments 1-3.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 3% of the trials. See Figure 4.2 for a graphical depiction of the findings. A two-way ANOVA on mean RT for each participant with condition (*relevant*, *irrelevant, static target* or *irrelevant, blinking target*) and set size (4 or 8) as factors revealed a main effect of condition [$F(2,14) = 29.95$, $MSE = 6139.13$, $p < 0.001$], a main effect of set size [$F(1,7) = 37.36$, $MSE = 12881.27$, $p < 0.001$], and a significant interaction [$F(2,14) = 9.06$, $MSE = 2945.35$, $p < 0.005$]. RTs increased with set size in all conditions and this will not be reported on further. Separate comparisons between conditions revealed that RTs were faster, and search slopes were shallower in both the *relevant* condition and the *irrelevant, static target* condition than in the *irrelevant, blinking target* condition (effects of condition, $F(1,7) = 63.30$, $MSE = 5760.43$, $p < 0.001$; $F(1,7) = 14.47$, $MSE = 8482.34$, $p < 0.01$ and condition x set size, $F(1,7) = 15.46$, $MSE = 3168.50$, $p < 0.01$; $F(1,7) = 8.26$, $MSE = 3412.91$, $p < 0.05$ respectively). RTs were overall faster in the *relevant* condition than in the *irrelevant, static target* condition [$F(1,7) = 15.39$, $MSE = 4174.63$, $p < 0.01$]. Importantly, there was no significant difference in search slopes, between the *relevant* condition and the *irrelevant, static target* condition [$F(1,7) = 1.26$, $MSE = 2254.63$ $p = 0.3$].

It is also important to look at intertrial priming. Maljkovic and Nakayama (1994) showed that features associated with the target on the previous trial attract attention on the current trial. Changing the proportions of different trial types (as we did here) not only changes presumed top-down settings, but also changes intertrial contingencies (see Olivers & Humphreys, 2003, for a more extensive argument). Although such effects are still automatic, they are not the type of attentional guidance we are interested in here. To investigate this possibility, we repeated the analyses with the exclusion of static target repititions in the *irrelevant* block. Although, numerically, effects were somewhat weakened, an analysis of the data with *inclusion* as a factor (2 levels: target repetitions included versus target repetitions excluded), revealed no significant interactions of search slopes with this factor in this or subsequent experiments (all $Fs < 1.6$, all $ps > 0.24$). Thus, with respect to search slopes, the overall pattern of results remained the same whether static target repetitions were included or excluded.

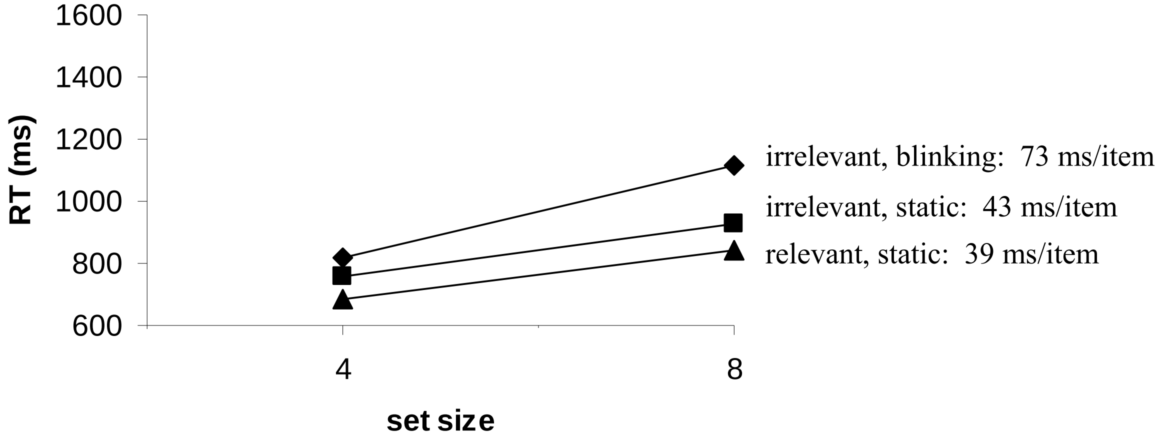

Figure 4.2. Mean RTs for each condition of Experiment 1 (*relevant*, *irrelevant, static target* and *irrelevant, dynamic target*) as a function of set size. For each condition, the mean search slopes are provided.

Discussion

Experiment 1 shows that participants benefit from the target being static in the *irrelevant* blocks, even though in this condition they presumably have no top-down incentive to prioritize static items. Furthermore, the search slopes for the static target are similar in the *relevant* and the *irrelevant* blocks. These findings not only indicate that the static object automatically guides attention, but also that adding a top-down incentive to actively go and look for it does not add anything to the efficiency of search. Nevertheless, participants are overall slower to react when they are automatically guided by the static target, compared to when they voluntarily attend to it. This suggests that top-down settings may affect non-selection processes, such as response factors (e.g. after several trials with a dynamic target, the ‘surprise’ that the target is static might slow down the response).

Note however that search slopes were overall quite high and far from efficient even in the relevant conditions (i.e. around 40 ms/item), especially when compared to the equivalent conditions in Pinto et al. (2006; typically between 10 and 20 ms/item). In this sense it is difficult to argue for strong bottom-up attentional capture by static objects. Instead, we argue for prioritization or guidance. We will return to this point in the General Discussion.

Another important objection to the conclusion that the static object automatically guides attention may be that the inclusion of a relevant block may have given participants the incentive to pay attention to static items, even in the irrelevant blocks. To investigate if the attentional guidance observed in Experiment 1 was due to such top-down factors, Experiment 2 was conducted.

Experiment 2: The attentional guidance is not due to carry-over effects

Experiment 2 investigated whether the attentional guidance observed in Experiment 1 could be the result of residual top-down effects. Although in the irrelevant blocks of Experiment 1 participants were explicitly told that attending to the static item was not beneficial, it may be that because participants were set to search for the static object in the *relevant* block they were inclined to do so also in the *irrelevant* blocks. To control for such possible carry-over effects of top-down settings from the *relevant* blocks to the *irrelevant* blocks, we replicated Experiment 1, but without the *relevant* blocks. If the observed attentional guidance in Experiment 1 was due to carry-over effects, then in Experiment 2 we expect to see no difference in performance whether the target is static or dynamic. However, if the attentional guidance in Experiment 1 was the result of automatic processes, then we expect search slopes again to be shallower when the target happens to be static than when it is dynamic.

Method

Eleven new participants, ranging in age from 18 to 35 years, average 22.7 years, took part as paid volunteers. Everything was identical to Experiment 1, except that now there was no *relevant* condition. The experiment consisted of nine blocks of 48 trials. The first three blocks were disregarded as practice. The other six blocks were included in the analyses. The experiment took approximately 35 minutes, with breaks between the blocks.

Results and Discussion

Error percentages were overall low (see Table 4.1), and an ANOVA revealed no significant effects nor any signs of a speed accuracy trade-off. We will therefore concentrate on the mean RTs of the correct trials.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 3% of the trials. See Figure 4.3 for a graphical depiction of the findings. A two-way ANOVA on mean RT for each participant with condition (*static target* or *blinking target*) and set size (4 or 8) as factors revealed that RTs were elevated in the *blinking target* condition compared to the *static target* condition [$F(1,10) = 28.26$, $MSE = 8085.51$, $p < 0.001$], and that RTs increased with set size [$F(1,10) = 24.63$, $MSE = 22913.65$, $p = 0.001$]. There was also a significant interaction reflecting the steeper search slope in the *blinking target* condition compared to the *static target* condition [F(1,10) = 12.26, MSE = 2421.12, p < 0.01].

The results of Experiment 2 allow for a straightforward interpretation. The exclusion of the *relevant* block left the results virtually unchanged relative to Experiment 1. The prioritization of the static object found in Experiment 1 is again found in Experiment 2, and since there were no *relevant* blocks this cannot be explained by the carry-over of top-down effects.

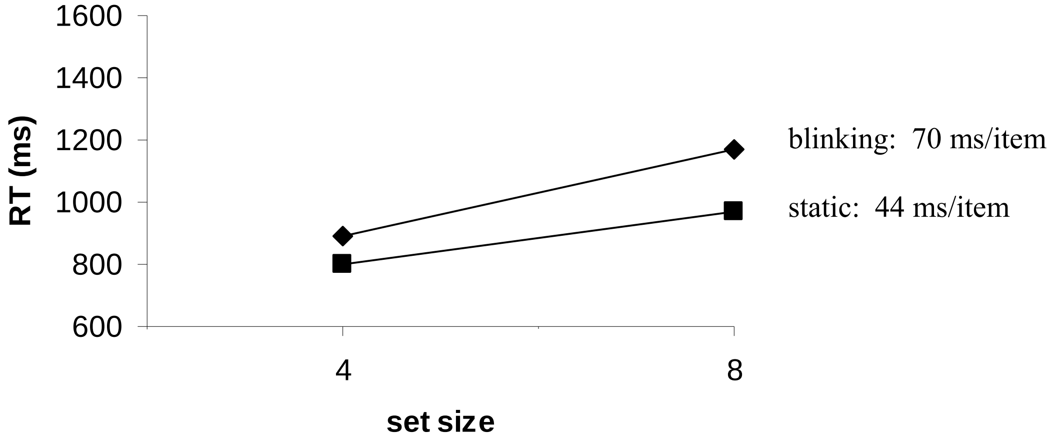

Figure 4.3. Mean RTs for each condition of Experiment 2 (*static target* and *blinking target*) as a function of set size. For each condition, the mean search slopes are provided.

Experiment 3: Automatic attentional guidance of a static object in other dynamic environments?

Experiments 1 and 2 have shown that a static object involuntarily guides attention when it is surrounded by blinking items. However, it is unclear if these results generalize to other dynamic stimuli. Pinto et al.'s (2006) results hint at this generalization, since in their study a static target was efficiently found among both blinking and moving distractors (with search slopes around 15 ms/item in both cases). However, it could be that the efficient search for a static object among blinking distractors is automatic, but the efficient search for a static item surrounded by moving items is the result of other, top-down, mechanisms. To investigate whether search for a static item among blinking objects represents a special case, Experiment 3 investigated if a static object also guides attention when it is surrounded by items featuring apparent motion. If the same mechanisms underlie search for a static object in a blinking or a moving environment, then we expect attentional guidance to be similar in both conditions. However, if top-down processes play a larger role when searching for a static among moving than for a static among blinking, then we expect attentional guidance to be reduced, or even absent in the motion conditions (when all items except one are moving).

Method

Eight participants ranging in age from 18 to 22 years, average 19.9 years, took part as paid volunteers. One participant was replaced, due to exceptionally large error rates of approximately 35%. Everything was identical to Experiment 1, except for the following changes. The experiment consisted of 18 blocks of 48 trials. Figure 4.1C shows an example display. Using the exact Pinto et al. (2006) displays was no option, because in their study, moving items flipped back and forth between two 90 degrees rotated positions. Applied to the current case, this would imply that the target on most trials would be flipping back and forth, making it impossible to determine whether it is vertical or horizontal. Therefore, in the current experiment we used stimuli that allowed for discrimination of the target even if it was moving. The stimulus field consisted of white line segments (size 0.87°) with a gap in the middle (size 0.26°) and one white line segment with a gap above or below the middle (distance from the middle 0.17°). The task was to find the only object with a gap not located in the middle, and to indicate if the gap was above or below the middle by pressing the ‘k’ and ‘m’ keys respectively. There were two types of dynamics and three relevance conditions (*relevant*, *irrelevant, static target* and *irrelevant, dynamic target* as in Experiment 1). When the dynamics were set to *blinking* all items except one were blinking. When the dynamics were set to *moving*, all items were moving horizontally back and forth (over a distance of 0.46° per movement, rate of motion was the same as the blinking rate) except one. Neither direction (left or right) nor moment of change were correlated between the items. The order of the blocks was repeated every six blocks. In every sequence of six blocks there were four possible orders (which remained the same throughout the experiment, but differed per participant). First, blocks alternated between *blinking* and *moving*, with either starting first. Second, within these two types of sequences, either the first or the last two blocks were the *relevant* blocks, the other four the *irrelevant* blocks. The same number of participants was assigned to each of the four orders. The first six blocks were disregarded as practice. The other 12 blocks were included in the analyses. The experiment took approximately 60 minutes, with breaks between the blocks.

Results and Discussion

Error percentages were overall low (see Table 4.1), and an ANOVA revealed no significant effects nor were there signs of a speed accuracy trade-off. We will therefore concentrate on the mean RTs of the correct trials.

Trials on which RTs were two and a half standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 2% of the trials. See Figures 4.4 and 4.5 for a graphical depiction of the findings. A three-way ANOVA on mean RT for each participant with type of dynamics (*blinking* or *moving*), relevance condition (*relevant*, *irrelevant, static target*, or *irrelevant, dynamic target*) and set size (4 or 8) as factors revealed that RTs were overall elevated in the *blinking* conditions compared to the *moving* conditions [$F(1,7) = 81.62$, $MSE = 4439.57$, $p < 0.001$], RTs were overall higher in the *irrelevant* than in the *relevant* blocks [$F(2,14) = 26.47$, $MSE = 42318.20$, $p < 0.001$], and RTs increased with set size [$F(1,7) = 271.17$, $MSE = 5996.42$, $p < 0.001$]. There was a significant interaction between relevance condition and set size reflecting the steeper search slopes when the target was dynamic compared to when the target was static [$F(2,14) = 9.46$, $MSE = 9663.44$, $p < 0.005$]. There were no significant interactions between type of dynamics and relevance condition or type of dynamics and set size ($Fs < 1.6$, $ps > 0.24$). There was a significant three-way interaction between type of dynamics, relevance condition and set size [$F(2,14) = 4.91$, $MSE = 1382.32$, $p < 0.05$]. Further analysis revealed that this three-way interaction was mainly the result of a higher search slope in the irrelevant block when the target was blinking compared to when it was moving [$F(1,7) = 5.53$, $MSE = 3103.00$, $p = 0.051$]. Separate comparisons between relevance conditions for each type of dynamics revealed the following. With *dynamics* set to *blinking*, in the *irrelevant, static target* condition RTs were faster, and search slopes were shallower than in the *irrelevant, dynamic target* condition (effects of condition, $F(1,7) = 7.26$, $MSE = 47165.20$, $p < 0.05$; condition x set size, $F(1,7) = 9.95$, $MSE = 10150.05$, $p < 0.05$). Furthermore, in the *relevant* condition RTs were faster than in the *irrelevant, static target* condition [$F(1,7) = 12.73$, $MSE = 15934.0$, $p < 0.01$]. Importantly there was no significant interaction between relevance condition and set size, indicating that search slopes in these conditions did not differ significantly from each other ($F<0.25$, $p>0.6$). The same pattern was found with *dynamics* set to *moving*. RTs were faster and search slopes were shallower in the *irrelevant, static target* condition than in the *irrelevant, dynamic target* condition (effects of condition, $F(1,7) = 33.92$, $MSE = 18009.28$, $p = 0.001$; condition x set size, $F(1,7) = 6.20$, $MSE = 5715.60$, $p < 0.05$). In the *relevant* condition RTs were faster than in the *irrelevant, static target* condition [$F(1,7) = 12.91$, $MSE = 5481.0$, $p < 0.01$], but again there was no significant interaction between relevance condition and set size, indicating that search slopes in both conditions were not significantly different from each other (F = 0.01, p > 0.9).

As in the previous experiments, static targets received priority even when static items were not relevant to the task. Experiment 3 shows that this result generalizes to motion stimuli. For both blinking and moving environments, search for a static target was more efficient than for a dynamic target regardless of whether static was a relevant feature or not. The only difference between the relevant and irrelevant static target search was an overall RT effect, again suggesting that top-down factors affect post-selection processes, rather than the saliency of the static item per se.

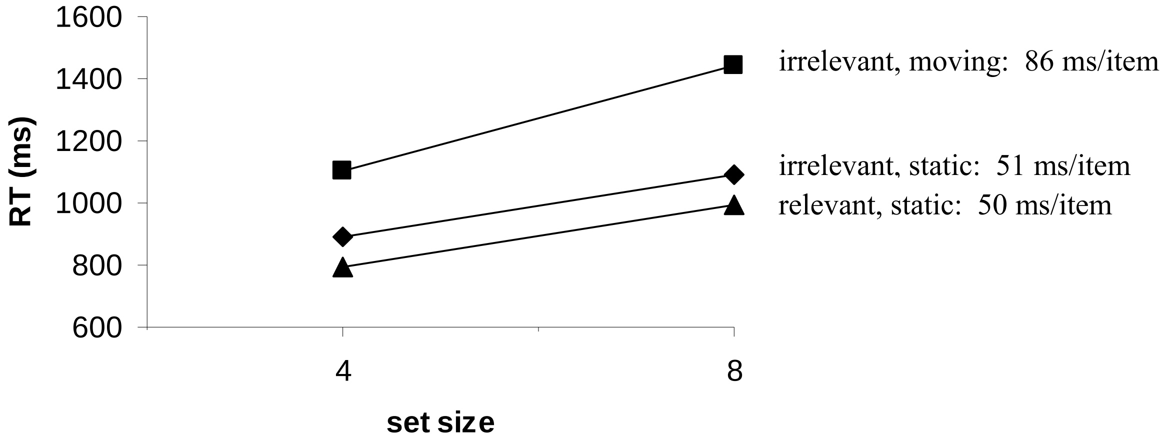

Figure 4.4. Mean RTs for each condition of Experiment 3 (*relevant*, *irrelevant, static target* and *irrelevant, dynamic target*) as a function of set size when the dynamics were set to *moving*. For each condition, the mean search slopes are provided.

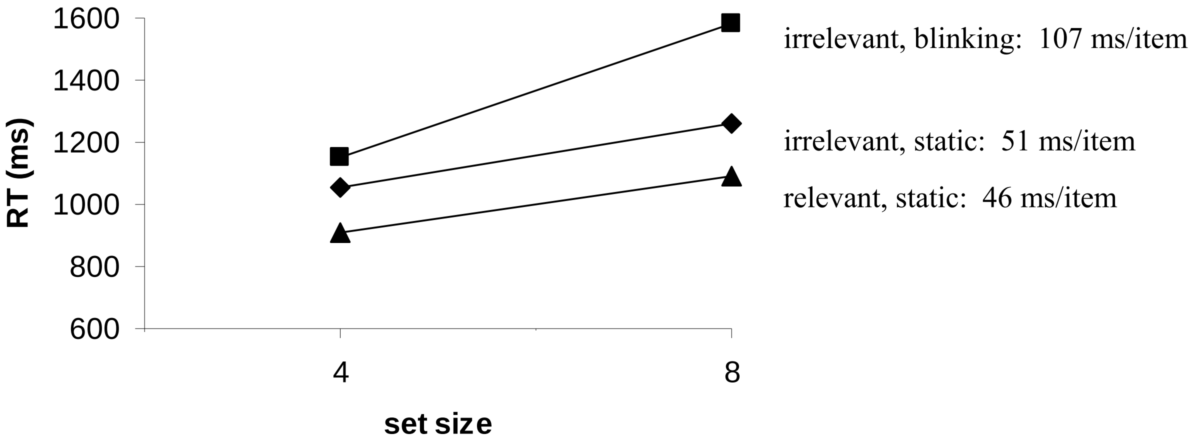

Figure 4.5. Mean RTs for each condition of Experiment 3 (*relevant*, *irrelevant, static target* and *irrelevant, dynamic target*) as a function of set size when the dynamics were set to *blinking*. For each condition, the mean search slopes are provided.

General Discussion

In the present study we employed the irrelevant-feature search task to investigate if static items automatically guide attention in a dynamic environment. All three experiments suggested that, to some degree, static objects involuntarily guide attention. Experiments 1 and 3 showed that making the static object task-relevant did not make search more efficient than when the static object was task-irrelevant. Experiment 2 demonstrated that this was not due to inadvertent carry-over effects between task-relevant and task-irrelevant conditions. Furthermore, Experiment 3 showed that a static object is equally effective in guiding attention among moving as among blinking objects.

In all experiments search slopes were considerably shallower when the target was static than when it was dynamic, but at a rate of 40 ms/item, search was still far from parallel. Obviously then, the automatic guidance by static items here was not an all-or-none phenomenon. It may have been the case that the static item drew attention on some, but not all, trials, or that that the attentional weight assigned to the static item was insufficiently strong to immediately receive priority over all other items in the display (see Todd and Kramer, 1994, for a similar argument). Note that relatively high slopes have not precluded the conclusion of automatic attentional guidance in the past (e.g. Yantis & Hillstrom, 1994).

Higher slopes mean that the static item is not always optimally salient, but when it is, it is prioritized automatically.

The question then is why the static item may occasionally evade capture. The answer may lie in the fact that, in the current study, the target is most often a dynamic object in a dynamic environment, and therefore hard to find. This may have caused participants to adopt a conservative, serial, search mode, using a relatively small attentional window (e.g. Belopolsky, Zwaan, Theeuwes & Kramer, 2007). Alternatively, participants may have adopted a specific feature search mode (looking for specific orientation) instead of a more global singleton search mode (Bacon & Egeth, 1994). In turn, such a narrowed spatial window or search mode may then have hindered search when the target was static. This suggestion is also supported by the results of Pinto et al. (2006), who found search for a static target in a dynamic surrounding to become less efficient when in some other blocks within the same experiment the target was actually dynamic and therefore hard to find.

To see if such context indeed plays a role, we ran another experiment in which participants searched for a static target amongst dynamic distractors (using the same displays as in Experiments 1 and 2), but now without the irrelevant blocks (i.e. the static item was always the target). On average across 6 participants, for the set sizes employed here (i.e. 4 to 8), search slopes dropped below 10ms/item again [8.5 ms/item; not significantly different from zero ($p=0.2$), but significantly different from the search slopes of the relevant condition in Experiment 1 ($p < 0.05$)], confirming the idea that the inclusion of an irrelevant block may induce a different type of search mode. Note that this suggestion implies that given the right circumstances, i.e. when the static object is the target in *all* blocks, participants can adopt a search strategy that allows them to increase search efficiency. This means that there still is some top-down contribution to the efficient detection of a static object, albeit a relatively crude version: The top-down control is in the overall spatial distribution of attention, not in the selective prioritization of a static/dynamics feature.

A special role for dynamic capture?

Several researchers have used the irrelevant-feature search task to investigate which features involuntarily capture attention. This has yielded a couple of influential accounts, such as the new object hypothesis (Jonides & Yantis, 1988; Yantis & Hillstrom, 1994) and the unique event hypothesis (von Mühlenen et al., 2005). Although the accounts differ, they all claim that dynamics are essential for capturing attention. The current result, that a static object involuntarily draws attention in a dynamic setting, provides a clear example of a non-dynamic property automatically guiding attention in the irrelevant-feature search task. Thus, the present findings seem to pose a problem for any account that suggests that features essentially need to be dynamic in order to draw attention.

According to the saliency account (e.g. Theeuwes, 1991, 1992), whether or not an object attracts attention depends on the relative feature difference between the object and its background. The current results seem to fit neatly into the saliency account, since the static object was unique relative to its surrounding, and therefore more salient than the other items. According to this account, the static/dynamic distinction is no more special than a very distinctive color, shape or any other feature. An interesting corroboration of this conclusion comes from Pashler and Harris (2001). They found that when participants were to describe or aesthetically judge a display, a unique item was most likely to be reported. This was true when the unique item was a flashing item in a static environment, but importantly the reverse also held. When the unique object was a static object surrounded by flashing objects, it was still the most reported item.

However, note that both Theeuwes (1991, 1992) and Pashler and Harris (2001) used a somewhat different paradigm than the irrelevant-feature task employed here and elsewhere. In fact, whenever the irrelevant-feature paradigm has been applied to features other than dynamic properties, no evidence of attentional capture has been found (Jonides & Yantis, 1988; Yantis & Hillstrom, 1994; Yantis & Egeth, 1999). This discrepancy may be (and has been) explained in terms of different search modes (Bacon & Egeth, 1994) or differently sized attentional windows (Theeuwes, 2004). But, in any case, on the basis of the task used here, we cannot exclude the possibility of a special status for the static/dynamic distinction.

Perhaps then, both the saliency account and the dynamic capture hypotheses are both partly true. The saliency account correctly suggests that not features per se, but feature differences determine which items capture attention. The dynamic capture hypotheses might be correct in stating that the dynamics dimension is intrinsically more important than other dimensions, and that feature differences within the dynamics dimension are even more effective than other feature differences in capturing attention. Thus, new objects capture attention, but static items in a dynamic environment do as well, since they are both unique with regard to their dynamic properties (cf. Von Mühlenen et al, 2005).

This hybrid view above also accounts for what appears to be a search asymmetry (Treisman & Gormican, 1988). Search for a static object surrounded by blinking items yields search slopes significantly higher than 0 ms/item, whereas the reverse case, the search for a blinking item in a static background, probably yields search slopes that are close to 0 (this, to our knowledge, has never been explicitly tested, see Watson and Humphreys (1995) for a manipulation that comes close).

Thus, although any salient difference may attract attention, there appears to be an attentional bias on top of that towards dynamic items. This may be due to life-long experience, in which dynamic objects are usually the ones to look out for. Interestingly, a similar asymmetry disappears with extensive training. Untrained participants are more efficient at detecting a motion-form conjuntion among static distractors than a static-form conjunction among dynamic distractors. However after approximately 1000 practice trials, search for these latter conjunction targets becomes equally efficient (Müller & von Mühlenen, 1999).

Another influences on search efficiency was the earlier mentioned finding that search for a static target in a dynamic environment becomes less efficient, when the task is interleveled with blocks containing a very difficult search task (such as a blinking target among blinking distractors). It seems unlikely that adding a difficult block would affect entirely efficient pop-out search (such as a green target among red distractors) in the same way it affects search for a static target in a dynamic background here. However, since search for a static target among dynamic distractors is not completely efficient to begin with, this may make the task more sensitive to difficulty (or search mode) manipulations, than a task that allows for obvious pop out from start.

Conclusion

We found that a static object involuntarily draws attention when it is surrounded by dynamic items, regardless of the type of dynamics (i.e. moving or blinking). This finding is a clear example of a static feature being prioritized within the irrelevant-feature search task and therefore necessitates a modest revision of current theories on automatic attentional guidance. We conclude that feature differences in general, but especially dynamic feature differences, are essential for the involuntary guidance of attention.

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The detection of temporally defined objects does not require focused attention

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Abstract

Perceptual grouping is crucial to distinguish objects from their background. Recent studies have shown that observers can detect an object that does not have any unique qualities other than unique temporal properties. A crucial question is whether focused attention is needed for this type of grouping. In two visual search experiments, we show that searching for an object defined by temporal grouping can occur in parallel. These findings suggest that focused attention is not needed for temporal grouping to occur. It is proposed that temporal grouping may occur because the neurons representing the changing object elements adopt firing frequencies that cause the visual system to bind these elements together without the need for focused attention.

Distinguishing objects from the background is one of the basic capabilities of the visual system and has been a focus of research since the start of psychophysical science. Dynamic properties allow for particularly strong grouping. An example of a dynamic grouping principle is the Gestalt principle of common fate, which states that items that move together are seen as one object (Wertheimer, 1923). Other, later proposed, examples are grouping by common onset, in which items that appear together are treated as a single object, set or surface (Jiang, Chun & Marks, 2002), and grouping by common luminance change, in which items that change luminance together in the same direction, are clustered (Sekuler & Bennett, 2001).

Interestingly, it has been suggested that elements do not need to change in the same direction in order to be grouped. They may not even have to undergo the same type of change. They may group as long as they change *together*, at the same moment in time. This has been called *temporal grouping*. It occurs not on the basis of a common change (as in common fate, common onset, or common luminance change), but on the basis of a common *moment* of change.

For example, Fahle (1993) found that a group of dots changing luminance out of phase with the surrounding dots could be detected with phase shifts as short as 10ms (depending on the frequency of the luminance change) between target dots and background. He concluded that participants can segregate an object from the background purely based on temporal cues. However, his results might also be explained by common onset grouping, since the target dots all appeared at the same moment, at a time when all the background dots were switched off. Lee and Blake (1999) continued to investigate grouping solely based on temporal information, by presenting participants with a field of Gabor patches, each of which contained a randomly oriented grating moving in a direction perpendicular to this orientation. At random moments in time, each Gabor patch could change motion direction (by 180°). In the background these motion flips were uncorrelated, but for a central rectangular region the patches changed motion direction in synchrony. Thus, in the target rectangle the motion *direction* of the gabor patches was uncorrelated, only the *moment* that the motion direction changed was synchronized. Participants had to determine the overall orientation of the target rectangle (horizontal or vertical) and could do so almost without errors. Lee and Blake (1999) concluded that temporal information alone is sufficient to segment spatial regions from their background (see also Aslin, Blake & Chun, 2002; Guttman, Gilroy & Blake 2005).

An important question is whether focused attention is needed for temporal grouping to occur. In other words, does attention need to focus on the changing items or regions in order for them to be grouped, or does grouping occur in parallel across the visual scene?

Intuitively, it seems that most grouping takes place without focused attention. It appeals to common sense to assume that the visual scene is pre-attentively parsed according to basic grouping principles, after which focused attention is directed to items or regions of interest to extract further information. However at presence, the picture regarding the need for focused attention in grouping mechanisms is mixed. For instance, it has been shown that focused attention is needed to detect bilateral symmetry in visual search, despite symmetry being a prime example of strong Gestalt grouping (Olivers and van der Helm, 1998). On the other hand, Moore and Egeth (1997) found a line judgment task to be affected by irrelevant dots in the background, which, when grouped by proximity, formed displays similar to the Ponzo illusion or the Müller-Lyer illusion - despite the fact that participants could not accurately report what the background patterns were. This implies that this type of grouping may occur without focused attention. Furthermore, both common motion and common onset grouping appear to occur in parallel, without the need for focused attention, even when the to-be-grouped items are interspersed with irrelevant distractors (McLeod, Driver and Crisp, 1988). Therefore, it seems that neither form of dynamic grouping requires focused attention.

In the present research we will conduct two experiments to investigate whether focused attention is needed to detect objects solely defined by temporal cues.

Experiment

We presented participants with displays comparable to those of Lee and Blake (1999). However, instead of presenting one temporally defined target bar on each trial, the number of temporally defined bars was varied from trial to trial (between 2 and 8, see Figure 1 for an example). We ran two versions of the task. In the Detection version, on half the trials all bars were vertically oriented, on the other half one of the vertical bars was replaced by a bar tilted to the left. Participants performed a detection task in which they indicated whether the tilted bar was present or absent. In the Discrimination version, a tilted bar was always present, and observers indicated whether it was tilted left or right.

If focused attention is needed for the temporal grouping of elements into an object that can be distinguished from the background, then search RTs are expected to increase with the number of such temporally defined objects (the *set size*). Furthermore, the slope of the search function on target absent trials should be twice the slope on target present trials, since for a correct target absent decision all the bars need to be attended whereas on target present trials, on average, only half of the bars need to be checked. If focused attention is not required for the detection of a temporally defined object, then RTs should be roughly the same for target present and target absent trials, and should not increase with set size. Note that although set size effects are often interpreted as reflecting attentional effects (be it either serial or limited-capacity parallel), alternative interpretations are possible (e.g. Carrasco, Evert, Chang & Katz, 1995; Eckstein, Thomas, Palmer & Shimozaki, 2000). However, to foreshadow the results, here we will report the *absence* of set size effects, and hence argue for the absence of the need for focused attention, as it is difficult to argue that the need for highly selective, focused attention results in parallel search.

Method and procedure

Participants: Eleven paid volunteers, ranging in age from 18 to 27 years, average 22.6 years, participated in the Detection version of the task. Ten paid volunteers ranging in age from 19 to 35 years, average 26.8 years, participated in the Discrimination version. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. Five volunteers were a priori excluded from the study because they failed to see any object at all during the practice session. Three participants were excluded a posteriori. Two of them had overall error rates exceeding 25%, and the third showed a considerable speed accuracy trade-off (a 360 ms drop in RTs combined with a 12% drop in accuracy between set sizes 2 and 8).

Apparatus and Stimuli: The experiment was conducted on a computer with a Pentium IV processor, a 17 inch monitor and a standard QWERTY keyboard. The software package E-Prime was used for the layout and timing of the experimental trials. See Figure 5.1 for an example display. The stimulus field consisted of a 80 x 60 matrix (17.7° x 13.3° visual angle). Each cell contained a circular patch (0.22° diameter) consisting of a greyscale sinusoid grating comprising 1½ period. Contrast and luminance were randomly modulated during each trial on a frame by frame basis with a mean contrast of 0.85 and an amplitude of 0.15. The maximum luminance varied between 56 cd/m^2 and 64 cd/m^2 (as measured with a Tektronix photometer). Each element's sinusoidal grating was phase shifted by $2\pi/6$ radians per frame, a spatial displacement sufficient to produce smooth apparent motion of the grating within the circular aperture, with the direction of motion being in either of the two directions orthogonal to the grating's orientation (both directions were equally likely, there were eight possible orientations). The direction of the phase shift in each frame was constrained so that no four consecutive frames contained either alternations between positive and negative phase shifts, or continuous phase shifts in a single direction. This constraint, as well as the randomization of contrast and luminance among elements, was implemented to minimize potential luminance, contrast, or motion artefacts which may contribute to the object perception in temporal grouping displays (Adelson & Farid, 1999; Lee & Blake, 1999b; Morgan & Castet, 2002), even though it is arguable whether these potential cues are actually realized by the visual system (Lee & Blake, 1999b). In any case, the method we used here was similar to the method employed by Aslin, Blake and Chun (2002). The matrix was divided in eight 20 x 30 rectangular areas. Each area could contain a temporally defined vertical bar, comprising 7 x 17 cells (1.56° x 3.79° visual angle). In the Detection version of the task, on half of the trials one temporally defined bar was tilted to the left, diagonally spanning 5 x 12 (1.57° x 3.78° visual angle) cells. The bar could appear anywhere within the rectangular area, as long as it was at least two cells away from the borders. In the Discrimination version, the same bar could also be tilted to the right. The orientation of each grating was randomly determined from a set of 8 (between 0° and 157.5° with 22.5° intervals), with the restriction that two horizontally, vertically or diagonally neighboring gratings could not have the same orientation. Every 8 ms a new frame was presented, hence the average frequency of motion change was 62.5 Hz. Within each bar, but also within the background, the change of motion direction was synchronized (between the gratings). However, the moment of motion direction change between objects and background, and between objects themselves, was uncorrelated. Trials started with the presentation of the dynamic background. After 360 ms a black fixation cross appeared in the middle of the screen (0.341º x 0.341º), and after 1160 ms all temporally defined objects appeared. The display disappeared after response or after 25.5 seconds (whichever came first).

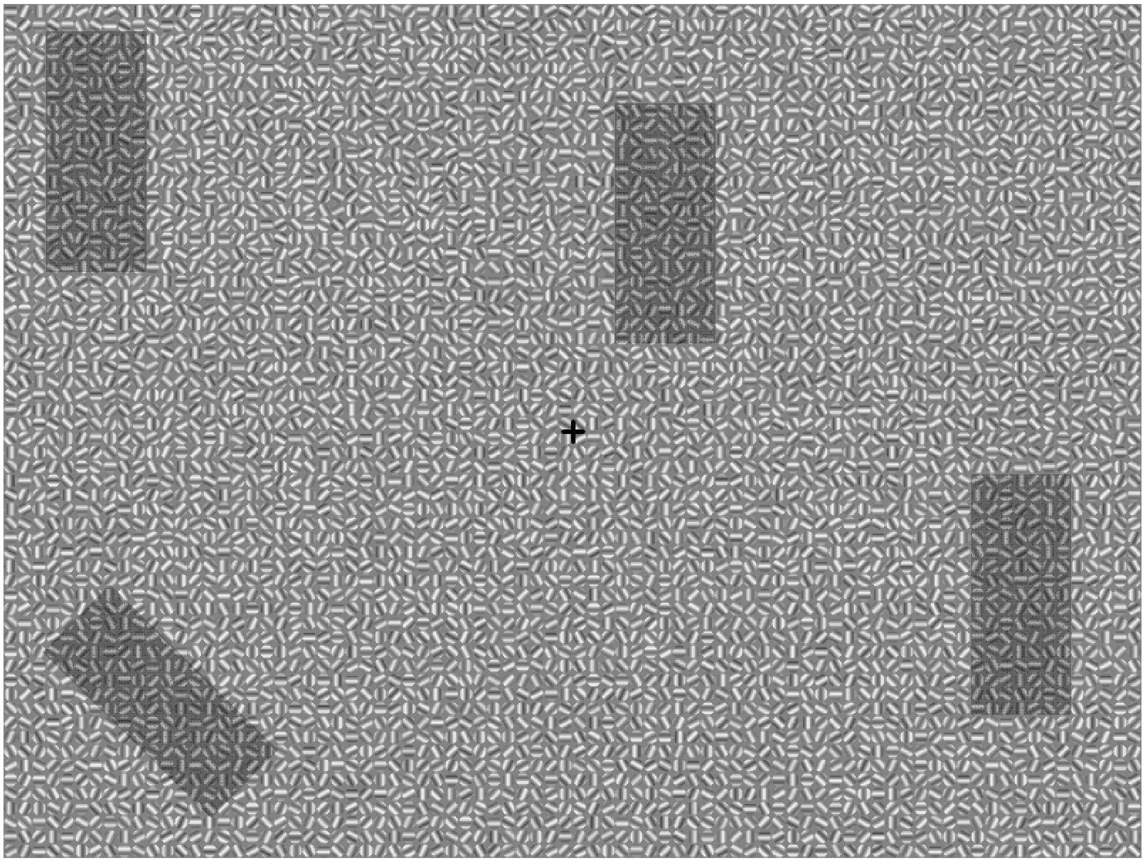


Figure 5.1. Example display of the visual search tasks used. The darker areas represent rectangles that were defined by their unique temporal properties. In the actual displays these areas were not darkened. All sinusoid patches had a randomly varying luminance (between 56 cd/m^2 and 64 cd/m^2) and a randomly varying contrast (between 0.7 and 1). In the Detection version, the task of the participants was to indicate whether a left-tilted rectangle was present, or absent. In the Discrimination version, a tilted target was always present, and participants indicated whether it was left- or right- tilted.

Design & Procedure: Participants sat at approximately 90 cm from the monitor, with their index fingers resting on the z- and m-key which were used as the response buttons. The experiment consisted of ten blocks, each containing thirty trials. On each trial between two, four or eight bars were presented. In the Detection task, on half of the trials all of the bars were oriented vertically (target absent condition), on the other half of the trials one of the bars was tilted to the left (target present condition). These conditions were randomly mixed within blocks. The task was to determine if a bar tilted to the left was present (by pressing "z") or absent (by pressing "m"). In the Discrimination task, a target bar was always present, and could be tilted left (press "z") or right (press "m"). Participants were instructed to keep the eyes fixated at the cross in the center of the screen and to keep in mind that both speed and accuracy were important. The first five blocks were practice blocks, the other five were included in the analysis. The experiment took approximately 45 minutes, with breaks between the blocks.

Results

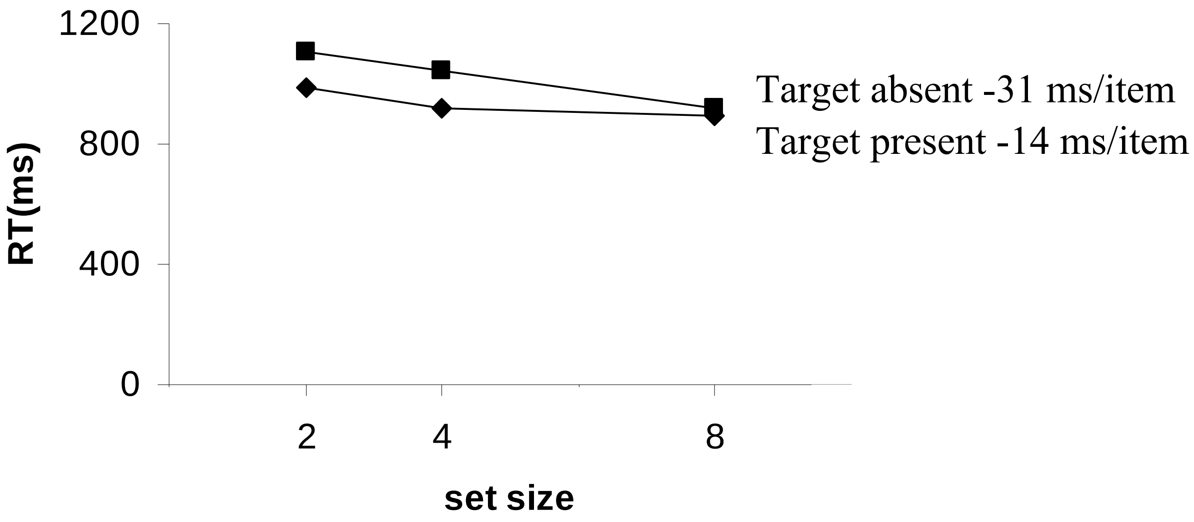
Trials on which RTs were 3 standard deviations away from the mean were excluded from analysis, resulting in a loss of approximately 2.5% of the trials in the Detection task, 3% in the Discrimination task. See Table 5.1 for an overview of the error percentages. A two-way ANOVA on mean accuracy for each participant with condition (target absent or target present) and set size (2, 4 or 8) as factors revealed a main effect of condition [$F(1,10) = 5.84$, $MSE = 0.011$, $p < 0.05$] in the Detection task. Participants made more errors when the target was present compared to when it was absent. No other effects in any of the versions approached significance ($Fs < 1.6$, $ps > 0.25$).

Figure 5.2a depicts the RT results for the Detection task. A two-way ANOVA on mean RT for each participant in the Detection task, with condition (target absent or target present) and set size (2, 4 or 8) as factors revealed that RTs were significantly elevated when the target was absent [$F(1,10) = 9.50$, $MSE = 13475.06$, $p = 0.01$], and that RTs significantly decreased with set size [$F(2,20) = 11.27$, $MSE = 9276.37$, $p = 0.001$]. There was a trend towards a more negative search slope when the target was absent compared to when it was present [condition x set size interaction, $F(2,20) = 3.45$, $MSE = 4856.97$, $p = 0.052$].

Figure 5.2b depicts the RT results for the Discrimination task. A one-way ANOVA on mean RT for each participant with set size (2, 4 or 8) as a factor revealed no significant effects ($F = 0.01$, $p = 0.99$). At first sight then, unlike in the Detection task, in the Discrimination task search slopes were not negative. However, an examination of the RT data per participant (see Table 5.2) reveals that this was mainly due to one participant with a rather high positive search slope (61 ms/item).Without this participant, the average slope was -6 ms/item. In any case, across participants, both RTs and error rates did not significantly increase with set size.

Finally, to assess the effect of training, we compared performance in the first half to performance in the second half of the experiment. For both tasks, accuracy was higher and average RTs were lower in the second half of the experiment (all $ps < 0.01$). However, in both tasks, search slopes did not differ significantly between halves, (all $ps > 0.45$). This suggests that only factors unrelated to selection were affected by training.

A. Detection Task



B. Discrimination Task

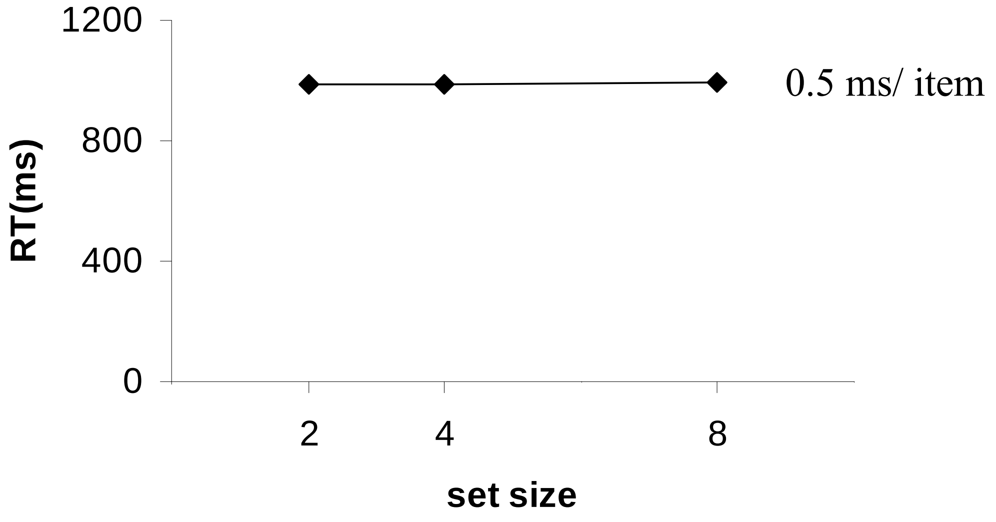


Figure 5.2. A) Mean reaction time for target absent and target present conditions of the Detection task, as a function of Set Size. B) Mean reaction time as a function of Set Size in the Discrimination version. The legend includes the mean search slopes.

	Set Size		
	2	**4**	**8**
Detection task			
target absent	6.16	5.80	5.24
target present	11.82	10.25	13.97
Discrimination task	6.07	6.07	5.52

Table 5.1. Average error percentages in both the Detection and the Discrimination tasks of the experiment.

	Set Size			**Slope (ms/item)**
Subject	**2**	**4**	**8**	
1	1009	1034	949	**-12**
2	1295	1310	1638	**61**
3	821	872	807	**-4**
4	1062	966	984	**-11**
5	881	954	891	**-1**
6	1004	1006	889	**-21**
7	809	852	863	**8**
8	1038	1036	978	**-11**
9	992	917	938	**-7**
10	984	929	987	**2**

Table 5.2. Reaction times as a function of Set Size per participant in the Discrimination task.

Discussion

There were no signs that focused attention is required to distinguish objects defined by temporal grouping. RTs did not increase with set size (instead it decreased for by far the largest proportion of participants). Furthermore, in the Detection version of the task, RTs did not diverge between present and absent trials with increasing set size. The results therefore point towards parallel search.

One objection against parallel search could be that perhaps participants systematically scanned each area of the display, regardless whether or not this area contained an object. Such a strategy would also predict RTs that do not increase with set size. However there are two arguments against such a conjecture. First, if participants indeed inspected the display area by area, then it is expected that on target present trials, on average, they found the target after scanning half of the areas, whereas on target absent trials they needed to scan all areas before they could decide that the target was not present. RTs on target absent trials were indeed slightly higher than on target present trials (88ms on a total of approximately 1 second). However, this finding can also be explained by some participants adopting a more conservative search strategy. With such a strategy participants are inclined to double-check when they do not see a target, to make sure they did not miss it, which also predicts elevated RTs in the target absent condition. To determine whether the slower RTs in the target absent condition were due to a conservative strategy employed by some participants, or the need to focally attend each region in all cases, we looked at the fastest half of participants, since they presumably adopt a less conservative strategy. Indeed, consistent with the strategy idea, this group showed no reliable difference in RT between target absent and target present conditions (33 ms, $F < 1$, $p > 0.4$).

Second, search slopes were found to be overall negative. Such negative search slopes are indicative of increasing contrast between the target and distractors, with higher set sizes, resulting in relatively higher salience of the target (Sagi & Julesz, 1987). As argued by Sagi and Julesz (1987) finding a negative slope indicates that target and distractors are processed in parallel, so that display-wide target-distractor comparisons can be made. The negative search slopes also argue against the possibility of observers making use of the residual contrast and/or motion artefacts that could occasionally occur despite the precautions described in the Method section[1].

Footnote 1: For each grating element, we varied both luminance and contrast randomly from frame to frame. Furthermore, no more than four consecutive phase shifts in the same direction or four consecutive changes in motion direction were allowed. In general this makes it difficult for a contrast or luminance filter to pick up on an object defined by temporal grouping. However, when the object elements undergo four consecutive shifts in the same direction and the background elements undergo four consecutive changes in motion direction (or vice versa), then a perfect contrast filter (averaging over exactly the correct five frames) could detect the object, allowing for the relatively rare and brief emerging of an individual object (on average 16ms per 256ms). However, our participants reported to perceive all items continuously being there, rather than individual objects popping into visibility one at a time. Together with the negative search slopes this makes it unlikely that the perception of temporally defined objects is entirely due to a contrast filter.

Such artefacts might randomly make one or two of the items visible at a time, and although this might explain relatively efficient search, it does not explain the negative search slopes found here, for which items need to be continuously present (as would be the case if temporal grouping creates the items). All in all then, the results indicate that the segmentation of an object from its surroundings purely based on temporal cues takes place largely in parallel across the visual display, without the need for focused attention.

The validity of visual search tasks for investigating focused attention

Note that we do not wish to argue that no attention at all is needed to perceive these displays. Parallel search does not mean pre-attentive search, nor does it mean that it is completely unlimited in capacity. The fact that about 25% of participants have trouble discerning these temporally defined objects puts obvious limits on conclusions regarding the automaticity, early level, or hardwiredness of such grouping processes. Instead, it is likely that some distributed attention is necessary across the displays. What we argue here is that such distributed attention is sufficient for temporal grouping to occur: There is no need for focused attending (be it serial or limited-capacity parallel) to construct each individual temporal group, as there is, for instance, for the construction of other groups such as mirror symmetries (Olivers & Van der Helm, 1998). Also, by referring to focused attention, we refer to *selection* of the target and not *access* to the target once it is selected. Thus, the results here suggest that for detecting a temporal group focused attention is not required. However, it may be that after the temporal group has been selected, focused attention is shifted towards the target for further access (e.g. in order to determine the response).

We emphasize again that positive search slopes can have other causes than attentional shifts. Therefore, one should be cautious with conclusions about the need for focused attention in selecting the target if a positive search slope is found. However, the reverse case (that no focused attention is needed in selecting a target if there is no positive search slope) seems less contaminated (e.g. Townsend 1972). There are several possible reasons for positive search slopes, yet it is hard to imagine how focused attention can serially shift from object to object without RTs increasing with the number of items in the display. Although there is no evidence that search slopes can be flat when focused attention is required for selection, it has been shown that focused attention can be directed to the target after an effortless search (Kim & Cave, 1995). Again, we see this as a case of accessing the object for response purposes only *after* the object is detected. Kim and Cave's (1995) study does not show that the detection itself requires attention to be focused on the object. In any case, our current research does not show that focused attention is never directed towards the target, it shows that focused attention is not needed for detecting a temporal group. Importantly, this implies that focused attention is not required to separate temporal groups from the background.

Temporal grouping: sufficient but not necessary for object perception

The present results reveal that temporal synchrony is sufficient for object perception. However, this does not imply that synchrony is necessary. In this light, it is interesting to regard the work of Fahle and Koch (1995). They presented participants with bistable displays consisting of six pacmans from which two overlapping Kanizsa triangles could be formed. However, if participants had a percept of one of the triangles the other percept disappeared. Normally participants flipped back and forth between the two triangles. Fahle and Koch (1995) investigated if temporal synchrony played an important role in determining which of the percepts became dominant. They presented five of the six pacmans simultaneously, and one up to 50 ms later. They hypothesized that if temporal synchrony is important, the simultaneously presented triangle would be dominant over the asynchronously presented triangle. However, they found that the temporal asynchrony did not affect the relative dominance of either of the triangles. Fahle and Koch (1995) concluded that temporal synchrony is not necessary for object perception. Thus, on the one hand the breaking of temporal synchrony does not break the grouping of elements within an object, whereas on the other hand, as shown here, the presence of temporal synchrony does create grouping. In other words, temporal synchrony appears to be a sufficient, but not a necessary condition for object perception.

How are temporal groups detected?

A possible explanation to how the visual system is able to perceive temporal groups without focused attention, may involve the existence of a class of low-level detectors that do not respond to motion or motion change per se, but that respond to motion change in relation to the surroundings. That is, these low-level detectors only become active when the item changes motion at the same time its neighbors do (see also Kandil & Fahle, 2004 for a similar idea). Future research, for instance employing single-cell recordings, should be conducted to test whether these low-level detectors really exist.

A second explanation might be that patches changing in synchrony constitute a surface medium in which features can appear. Cavanagh, Arguin and Treisman (1990) found that size and orientation features, such as a tilted bar among vertical bars, were detected in parallel in most surface media that defined these features. This result held for the surface media defined by luminance, color, texture or motion (e.g. such displays could consist of green bars against a red background, or bright bars against a dim background). The current results might fit into this larger picture, and synchronous change should perhaps be considered as a surface medium within which objects can be defined (whereby the bars consist of synchronously changing elements against a background of non-synchronously or different-synchronously changing elements).

Another tentative, but interesting possibility is that temporal binding plays a role in the perception of temporal groups. The temporal binding hypothesis suggests that neuronal synchrony underlies object perception. According to this hypothesis, neurons which represent features belonging to the same object start firing at the same frequency (Singer & Gray, 1995). According to this theory, the typical frequency range in which the temporal binding is most effective, is the gamma range, between 30 and 80 Hz. In our experiments motion direction reversed on average every 16ms, which is 62.5 Hz. It could be argued that our fast changing displays caused the neurons that represent the reversals in motion direction of the temporally defined rectangles, to adopt firing frequencies of approximately 60 Hz. This behaviour of the neurons may lead the visual system to automatically bind the underlying features (the fast changing patches) into one object (see also Alais, Blake & Lee, 1998). However, the temporal binding hypothesis is not undisputed (Shadlen & Movshon, 1999). Interesting in this respect is that the visual system also appears able to group non-synchronous elements. The work by Fahle and Koch (1995) has already been mentioned. More recently, Pinto, Olivers & Theeuwes (2006) presented participants with a search task in which participants had to detect a static target among randomly (i.e. non-synchronously) blinking or moving distractors. Participants could do so efficiently, which may imply that the non-synchronous elements were rejected together.

Summing up, we conclude that temporal grouping is applied in parallel across the visual field, independent of focused attention. This ability might be based on the synchronous firing of neurons or on low-level synchrony detectors.

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Target uncertainty does not lead to more distraction by singletons: intertrial priming does

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Abstract

Two experiments examined why a singleton distractor has a stronger interfering effect in visual search when the target identity is uncertain. When participants searched for a shape, a color singleton distractor had a larger slowing effect in a mixed block, in which the target shape could change from trial to trial, than in a pure block, in which the target shape remained the same. Importantly, this increased singleton distractor effect could be traced back entirely to intertrial priming, as the increased costs only occurred on trials when target and singleton distractor swapped identity (Experiment 1, allowing for priming between targets and singleton distractors) or on trials when the target alone changed identity while the singleton distractor remained constant (Experiment 2, allowing for priming between targets only). This suggests that target uncertainty itself does not lead to strategic changes in the attentional selection of singletons. Instead, selection is affected by relatively automatic priming mechanisms which may be enhanced by competition for attention.

In our everyday lives we are presented with a wide variety of visual stimuli. For adaptive behavior it is both important to select objects relevant to our goals and objects that might not be directly relevant but have an intrinsic importance. A key discussion in attention research is the interaction between these goals and the intrinsic qualities of objects in the visual field. The discussion evolves around the concept of attentional capture, defined as the involuntarily drawing of attention.

According to the bottom-up view, objects carrying a unique feature may automatically capture attention as a result of their relative salience (Theeuwes, 1991). These objects are often referred to as singletons, as they are unique on a certain dimension (Pashler, 1988). For instance, in Theeuwes' (1991) task people searched for either a diamond among circles or a circle among diamonds. These display types were randomly mixed so participants would not know beforehand which shape to look for. Although the task was to look for the odd shape, reaction times were about 150 ms longer when a differently colored singleton distractor was also present. Since the singleton was completely irrelevant to the task, Theeuwes concluded that it captured attention automatically.

In a subsequent series of experiments, Theeuwes (1992) replicated his earlier findings except now throughout a block the target remained the same – that is, within one block, the target was always a diamond amongst circles, and, within another block it was always a circle amongst diamonds – while a singleton distractor could be present. Participants were still distracted by the singleton distractor, but now it had a slowing effect of only about 20 ms (compared to the 150 ms found by Theeuwes, 1991).

These findings appear difficult to explain from a pure bottom-up view. Note that the stimuli were exactly the same in both studies, the only difference being that in Theeuwes' (1991) target types were mixed and thus participants did not know beforehand what the target would be. Instead, Theeuwes' (1991, 1992) findings suggest that attentional capture by the singleton is task-dependent, as target pre-knowledge influences the distracting effect of the singleton. This seems more in accordance with a top-down view of attentional capture (see also Folk, Remington, & Johnston, 1992; Yantis & Egeth, 1999). Presumably, when the target is uncertain, participants adopt a less restrictive attentional set to accommodate for the differences in target appearance. This less restrictive attentional set then makes participants more susceptible to singleton distractors. This notion of a more or less restrictive attentional set is in accordance with what Bacon and Egeth (1994) referred to as the difference between the *feature search mode* and the *singleton detection mode of attention*. Bacon and Egeth (1994) also found an irrelevant singleton distractor to interfere with search, but only if the target itself was also a singleton, namely the odd shape. In contrast, when trials were intermixed with trials on which there was no single unique shape target, the singleton distractor lost its interfering effect. Bacon and Egeth argued that when the target itself is a unique singleton, as was the case in Theeuwes' (1991, 1992) experiments, it may be beneficial to adopt a singleton search strategy, in which the observer looks for "any" singleton. This would then also include the singleton distractor. In contrast, when the target is not unique, the observer may adopt a feature search strategy, in which selection is confined to a specific feature to the exclusion of other singletons. Important for the present study, Bacon and Egeth (1994) argued that people are forced to adopt a singleton detection strategy when the target is uncertain, as people do not know the specific features of the target. Thus, the wider attentional set associated with singleton detection mode, may explain the increased singleton distraction found in the mixed condition of Theeuwes (1991).

However, there is an alternative explanation, more in line with Theeuwes' original stimulus-driven account of events. According to this view the differential singleton distractor effects found by Theeuwes (1991, 1992) can be explained by assuming a role for intertrial priming. According to the intertrial priming account previous trials have an automatic effect on the current trial: Features associated with the target get facilitated, whereas features associated with a distractor get inhibited (Maljkovic & Nakayama, 1994; 2000; Müller, Heller & Ziegler, 1995; Olivers & Humphreys, 2003; see also the literature on negative priming for similar carry-over effects in non-search tasks: e.g. Tipper, 1985). This relative activation and inhibition automatically carries over to the next trial. In a mixed block then, features of a distractor on one trial can become features of the target on the next trial, resulting in a relative slowing of target detection. Conversely, features of the target on one trial can become features of the singleton distractor on the next, possibly leading to a relative boost of its salience due to carried over activation. For instance, in Theeuwes' (1991) study on one trial the target may have been a circle while the singleton distractor was a diamond. On the next trial this may have been reversed, so that the target (now a diamond) receives carried over inhibition from the previous singleton distractor whereas the singleton distractor (now a circle) receives facilitation from the previous target. This causes larger interference of the singleton distractor and less efficient search for the target. In a pure block, features of a distractor on one trial never become features of the target on the next trial or vice versa. Therefore, target features can be maximally activated from trial to trial, whereas distractor features can be maximally inhibited, leading to a reduced singleton distractor effect.

The purpose of the present study was to first replicate Theeuwes (1991, 1992) within a single experiment and determine if people are indeed more distracted by an irrelevant color singleton when target types are mixed. Second, we analyzed intertrial effects to determine whether the increased singleton distractor effect can at least partially be explained by intertrial priming. In the mixed condition of Experiment 1, the target shape and the non-target shape could switch from trial to trial, and on an intertrial priming account, priming could operate between targets alone, between non-targets alone, and between targets and non-targets. In the mixed condition of Experiment 2 the target shape could change identity while the non-target shape remained the same throughout a block, not allowing for priming between targets and non-targets. If the priming between targets and singleton distractors is an important contributor to the increased singleton distractor effect, then we should see this effect reduced in Experiment 2. But if priming between targets alone is also important, then we should see at least some residual intertrial effects reemerge.

Experiment 1

In the first experiment we presented participants with three conditions. In the “pure diamond condition”, participants looked for a diamond among circles, in the “pure circle condition”, participants looked for a circle among diamonds. In the “mixed condition”, participants looked for either a diamond among circles or a circle among diamonds. Thus the task was always to look for an odd shape, but in the pure conditions participants knew beforehand what the target would be, whereas in the mixed condition they did not. The participants performed a so called compound search task, in which they responded to the line segment inside the target.

A second important manipulation involved the presence of a singleton distractor. On the basis of Theeuwes (1991, 1992), we expected an irrelevant color singleton to result in a larger slowing of RTs in the mixed condition than in the pure conditions. Importantly, to assess whether this increased singleton distractor effect was due to an overall change in search strategy (i.e. the adoption of a broader attentional set), due to intertrial priming, or due to both, we looked at intertrial relationships within the mixed block. *Switch* trials were defined as trials on which the target differed from the target on the previous trial, and *same* trials were defined as those on which the target was the same as on the previous trial. See figure 6.1 for example displays of a same and a switch trial. Note that on switch trials the singleton distractor too changed identity. If intertrial priming plays a role in causing the increased singleton distractor effect, then it is expected that RT costs resulting from the presence of a singleton distractor are larger on switch than on same trials, since on switch trials the singleton distractor may receive activation carried over from the previous target shape, while the target may receive inhibition carried over from the previous singleton distractor shape. If, in addition to any intertrial priming, there is also an *overall* change in search strategy between pure and mixed conditions, then we may expect an increased singleton distractor effect not only on switch trials, but on same trials too.

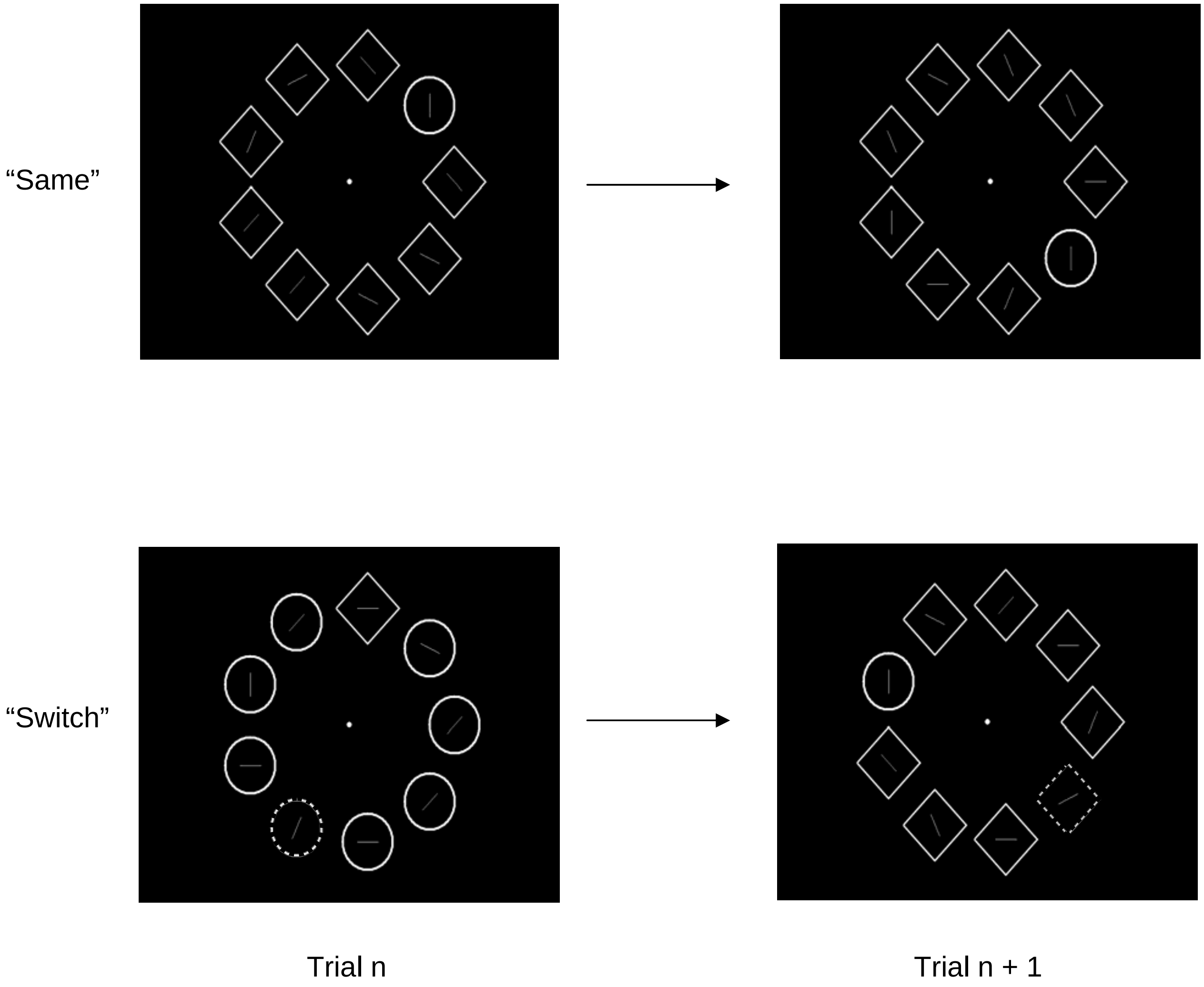

Figure 6.1. Example of a stimulus display from Experiment 1. The top panel depicts a "same" trial without a singleton distractor, the bottom panel a "switch" trial with a singleton distractor. The target was always the odd shape (circle or diamond), and participants responded to the orientation of the line segment inside it. All items were grey except for the singleton distractor, which deviated in color (red or green; as indicated here by a dotted outline).

Method

Participants: Eight participants, ranging in age from 21 to 31 years, average 24.3 years, took part as paid volunteers. All participants completed all of the conditions. All had normal or corrected-to-normal vision.

Apparatus and Stimuli: The experiment was conducted on a computer with a Pentium II processor, a 17 inch monitor and a standard QWERTY keyboard. The software package E-Prime was used for the layout and timing of the experimental trials. The stimulus field consisted of nine elements equally spaced on an imaginary circle (diameter 11˚), around the fixation point (diameter 0.32˚). The elements were open diamonds (diameter 3.5˚), and open circles (diameter 2.8˚) that were either red (.607 , .351), green (.245, .577) or gray (.259, .314) (Commission Internationale de l'Eclairage [CIE] x, y coordinates between brackets). All colors were equiluminant (7 cd/m^2), as measured with a Tektronix photometer. The fixation spot was white (51.2 cd/m^2) and the background black (0 cd/m^2). All elements contained gray line segments (diameter of 1.2˚), that were randomly tilted horizontally, vertically or 22.5˚ to either side of the horizontal or vertical. In the target element the line segment was oriented either horizontally or vertically. The position of the target element was randomly chosen from the nine possible positions.

Procedure: Participants sat at approximately 90 cm from the monitor, with their fingers resting on the z- and m-key which were used as the response buttons. The experiment consisted of five clusters of six blocks, each containing sixteen trials. The order of the blocks within a cluster was random. In each cluster there were three *singleton distractor absent* blocks, in which no singleton distractor was present on any trial: In the *circle* condition participants looked for a gray circle among gray diamonds. In the *diamond* condition participants looked for a gray diamond among gray circles . In the *mixed* condition participants looked either for a gray diamond among gray circles or a gray circle among gray diamonds. Targets were randomly mixed so that participants would not know beforehand what the target element would be. In the *singleton distractor present* condition, the stimuli were the same as in the *singleton distractor absent* condition, the only difference being that one of the non –target elements was replaced by a uniquely colored singleton distractor element on every trial. Singleton distractor presence was blocked for direct compatibility with Theeuwes (1991, 1992). In the circle condition the singleton distractor was a red or green diamond. In the diamond condition the singleton distractor was a red or green circle. In the mixed condition the singleton distractor depended on the target, a red or green diamond when the target was a circle, and a red or green circle when the target was a diamond. The position of the singleton distractor was randomly determined out of the eight possible positions left – one position being filled by the target element. In every condition participants were instructed to determine the orientation of the line segment in the target element. They pressed "z" for vertical, and "m" for horizontal segments. The task was assumed to require focal attention to be directed to the target element. Before every block there appeared a text on the screen instructing the participants which was the type of target, either "circle", "diamond" or "mixed". Participants were told to use this information. At the start of the experiment participants were told that a singleton distractor could be present during trials but that this singleton distractor was irrelevant to the task. Participants were instructed that both speed and accuracy were important. The first cluster of blocks was disregarded as practice. The other four clusters were included in the analyses. The experiment took approximately 30 minutes and was performed without breaks.

Results and Discussion

Error percentages were overall low (see Table 6.1), and an ANOVA revealed no significant effects. We will therefore concentrate on the mean RTs of the correct trials.

Overall RTs. Trials on which RTs were greater than 3000 ms were excluded from analysis, resulting in a loss of less than 1% of the trials. An initial ANOVA revealed that participants found it overall easier to look for a circle among diamonds than for a diamond among circles [$F(1,7) = 31.7$, $MSE = 1406.2$, $p = 0.001$]. However since there was no interaction between singleton distractor presence and target shape ($F < 1$), we averaged the circle and diamond conditions together to form the "pure" condition for the following analyses. Figure 6.2 shows the overall RTs in pure and mixed conditions (in the mixed conditions the average mixed condition and the mixed condition split up in "switch" and "same" trials is shown) when a singleton distractor was either present or absent. A two-way ANOVA on mean RT for each participant with condition (mixed or pure), and singleton distractor (present or absent) as factors revealed a main effect for condition [$F(1,7) = 131.6$, $MSE = 3352.1$, $p < 0.001$], a main effect for singleton distractor [$F(1,7) = 79.9$, $MSE = 834.8$, $p < 0.001$], and a significant interaction [$F(1,7) = 32.4$, $MSE = 601.2$, $p = 0.001$]. The overall pattern of results is very similar to Theeuwes (1991, 1992). Participants were significantly slower in the mixed condition than in the pure condition and they were significantly slower when a singleton distractor was present than when it was absent. Finally, as can be seen in Figure 6.2, a singleton distractor had a significantly greater effect in the mixed condition (a cost of 141 ms) than in the pure condition (a cost of 42 ms; both costs are comparable to those reported by Theeuwes, who found 150 ms and 20 ms respectively). Student t-tests revealed that all pair wise comparisons were significant (all ts > 4.4, all ps < 0.005).

Intertrial effects. To assess the source of the increased singleton distractor effect in the mixed condition, a two-way ANOVA was performed on RTs of trial n, as a function of trial n-1. One main factor was intertrial relationship: a trial could either contain the same target as the previous trial (*same* trials) or a different target (*switch* trials). The other factor was the presence of a singleton distractor (present or absent). See Figure 6.2 for a graphical depiction of the findings. Main effects were found for intertrial relationship [F(1,7) = 79.0, MSE = 2096.1 , p < 0.001], for singleton distractor presence [F(1,7) = 79.4 , MSE = 1873.1 , p < 0.001]. The interaction was also significant [F(1,7) = 21.5 , MSE = 1679.6 , p < 0.005]. Participants were significantly slower on “switch” trials than on “same” trials. They were also significantly slower when a singleton distractor was present compared to when it was absent. Furthermore the significant interaction reflects that on “switch” trials participants were more slowed by the singleton distractor (a cost of 204 ms) than on “same” trials (a cost of 69 ms). All pair wise comparisons were significant, as revealed by t-tests (all ts > 3.6, all ps < 0.01). Apparently then, intertrial effects are a major contributor to the differential singleton distractor effect. Performance suffered more from a singleton distractor on switch trials than on same trials. This result is in accordance with the notion of priming playing an important role: the switching of the target and singleton distractor identities causes a relative decrease of target activation and a relative increase of singleton distractor activation. It is also in accordance with previous work demonstrating the contribution of intertrial effects to visual search (Maljkovic & Nakayama, 1994; Müller et al. 1995; Olivers & Humphreys, 2003).

In addition to the target and singleton distractor interchanging shape, the singleton distractors themselves could change color (from red to green). This enabled us to see if priming between singleton distractor colors also played a role. Although there was indeed a small cost for a color change (6 ms, averaged across pure and mixed condition), it was far from significant, and did not interact with condition (mixed or pure; alls Fs < 1).

An important question is whether the intertrial effects were the only contributors to the increased singleton distractor effect in the mixed condition or whether there were any additional, overall differences. Such overall differences between the mixed and the pure condition, if present, may provide evidence for differences in top-down strategic settings affecting attentional capture, such as the overall widening of the attentional set to incorporate the uncertainty of the target. One way to assess such potential strategic effects is to look at same trials only in the mixed condition and compare them to the pure condition. After all, the pure condition consists only of “same” trials. If there are any strategic overall changes that lead to increased singleton distractor interference then, comparing the mixed condition to the pure condition, we should expect an increased singleton distractor effect not only on switch trials, but on same trials too. In fact, it turned out that the costs associated with the singleton distractor were somewhat higher for the same trials in the mixed condition (69 ms) than in the pure condition (42 ms). However, this difference was not significant ($t(7) < 1.18$, $p > 0.25$). Moreover, the increase in the mixed condition may actually not have been due to an overall strategy change, but due to remnants of priming effects dating from switches occurring more than one trial back. Indeed, the singleton distractor costs in the mixed condition were further reduced when there was more than one consecutive same trial (58 ms for two, and 44 ms for three consecutive same trials), which suggests that the priming effects require some time/trials to build up to their maximum level. Together, the findings imply that strategic differences between the pure and the mixed condition play no role in causing the differential singleton distractor effect. This effect seems to be solely due to intertrial priming.

	Singleton distractor Absent	**Singleton distractor Present**
Experiment 1		
Circle	4.9	3.1
Diamond	3.7	3.7
Mixed	4.7	3.7
Experiment 2		
Circle	3.6	4.7
Diamond	4.9	5.3
Mixed	5.9	7.4

Table 6.1. Average error percentages for the different conditions of Experiment 1 and 2

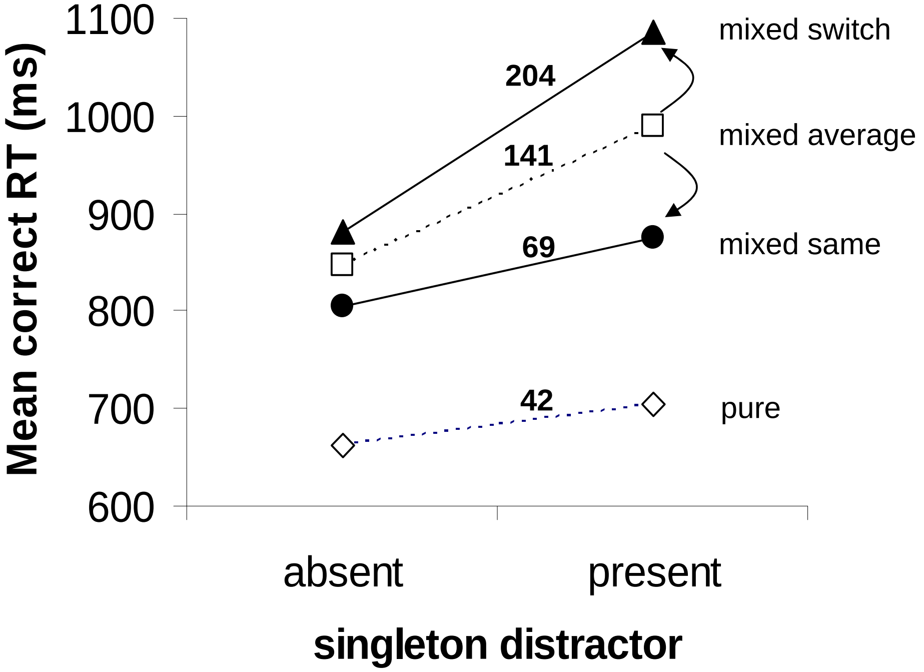

Figure 6.2. Mean reaction time results of Experiment 1 as a function of singleton distractor presence. Open symbols reflect the overall mean RTs for the pure and mixed conditions. Filled symbols reflect the mean RTs in the mixed condition, broken down for the different intertrial relationships (same vs. switch). Adjacent to each line, the numerical value of the singleton distractor effect in ms is printed.

Experiment 2

In the mixed condition of Experiment 1, the target and the singleton distractor shape could swap identity. This allowed for priming to occur directly between the target and the singleton distractor, as well as between targets themselves and the singleton distractors themselves. To assess the effects of target uncertainty on singleton capture in more detail, Experiment 2 eliminated priming between targets and singleton distractors. The target was again uncertain (i.e. it could be a circle or a diamond), but now the singleton distractor remained a constant heptagon (see Figure 6.3 for an example display). This way the singleton distractor shape could not be primed by the target shape or vice versa. If increased singleton distractor effects are due to changes in overall strategy related to target uncertainty, then we should see these increased singleton distractor effects prevail here (since the target is still uncertain). In contrast, if priming between targets and singleton distractors plays a major, or even the only role, then we should see the differential singleton distractor costs between mixed and pure conditions being much reduced or even disappear.

A factor that remains is the priming between targets themselves. Priming between targets may also contribute to differential singleton distractor effects as the different activations carried over from the previous trial may give the target either more or less of an advantage relative to the singleton distractor. The second aim of Experiment 2 was therefore to assess if there were any remaining intertrial effects, which, if present, may then be attributed to priming between targets.

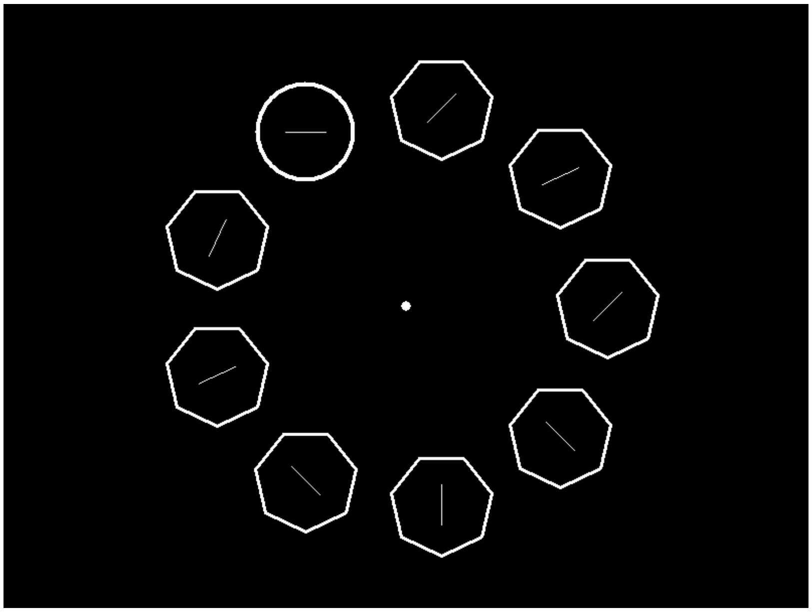

Figure 6.3. Example display from Experiment 2, which contained heptagons as nontargets. In this particular display the target was a circle, but it could also be a diamond.

Method

Participants: Twenty participants, ranging in age from 18 to 28 years, average 20.5 years, took part as paid volunteers. All participants completed all of the conditions. All had normal or corrected to normal vision.

Apparatus, Stimuli and Procedure: The apparatus, stimuli and procedure were the same as in Experiment 1, except for the following changes. All non-targets were now heptagons (diameter 2.9˚). In the singleton distractor present condition one of the heptagons changed color (to green or red), to become the singleton distractor. The target was a circle or a diamond. As before, within the pure condition the target did not change, whereas in the mixed condition the target could vary from trial to trial.

Results and Discussion

Error percentages were overall low (see Table 6.1), and an ANOVA revealed no significant effects. We will therefore concentrate on the mean RTs of correct trials.

Overall RTs. Trials on which RTs were greater than 3000 ms were excluded from analysis, resulting in a loss of less than 1% of the trials. Figure 6.4 shows the main RT results. There were no significant effects related to the different target shapes ($Fs < 2$, $ps > 0.15$) so we again averaged the circle and diamond conditions together to form the pure condition for the remaining analyses. A two-way ANOVA on mean RT for each participant with condition (mixed or pure), and singleton distractor (present or absent) as factors revealed a main effect of condition [$F(1,19) = 107.1$, $MSE = 5823.8$, $p < 0.001$], a main effect for singleton distractor [$F(1,19) = 24.3$, $MSE = 1405.1$, $p < 0.001$], and a trend for the interaction [$F(1,19) = 3.13$, $MSE = 1135.2$, $p < 0.1$]. Participants were overall significantly slower in the mixed condition than in the pure condition and they were significantly slower when a singleton distractor was present than when it was absent. Finally, although not significant, there was a tendency towards an increased singleton distractor effect in the mixed condition (cost 55 ms) relative to the pure condition (28 ms). All pair wise comparisons were significant, as revealed by t-tests (all $ts > 3.2$, all $ps < 0.005$). The results support the idea that the increased singleton distractor costs in the mixed condition in Experiment 1 were to a large extent caused by priming between targets and singleton distractors. In Experiment 2 priming between targets and singleton distractors was eliminated and the differential singleton distractor effect was reduced to a nonsignificant trend (despite the fact that this experiment had more participants). The results also argue against the increased singleton distractor costs being caused by a change in overall search strategy associated with the uncertainty of the target identity. In Experiment 2, the identity of the target was as uncertain as in Experiment 1, yet the effect of the singleton distractor was much reduced.

Intertrial effects. Even though the differential singleton distractor effect was much reduced (as expected on the basis of priming between targets and singleton distractors being eliminated), there was still a trend towards increased singleton distractor interference in the mixed condition. To see if any of these costs might be explained by an overall strategy change, intertrial effects were calculated in the same way as in Experiment 1. Figure 6.4

presents a graphical depiction of the findings. Main effects were found for intertrial relationship [$F(1,19) = 7.58$, $MSE = 5682.6$, $p < 0.05$], for singleton distractor presence [$F(1,19) = 13.4$, $MSE = 3742.1$, $p < 0.005$]. Importantly, the interaction was also significant [$F(1,19) = 7.48$, $MSE = 3632.3$, $p < 0.05$]. Participants were significantly slower on "switch" trials than on "same" trials. They were also significantly slower when a singleton distractor was present compared to when it was absent. Furthermore, the interaction reflects that on "switch" trials participants were more distracted by the singleton distractor than on "same" trials, with respective costs of 87 ms and 13 ms. Student t-tests showed a significant effect for intertrial relationship for singleton distractor present but not for singleton distractor absent trials (present : $t(19) = 3.69$, $p < 0.005$; absent : $t(19) = 0.46$, $p > 0.5$). To assess whether there were any residual overall increases in singleton distractor costs, the same trials of the mixed condition were compared to the trials of the pure condition (which only contained same trials). There was no significant difference between these trials ($p > 0.45$), and if anything, the singleton distractor costs in the mixed condition were smaller than in the pure condition. Thus, whatever trend there was towards a differential singleton distractor effect, it can again be traced back entirely to intertrial differences, leaving no room for overall strategy changes

The fact that the singleton distractor interfered more on switch than on same trials is interesting, because the differential intertrial priming mechanisms thought to apply here are limited to only those operating between the targets (since we eliminated the relationship between targets and singleton distractors), and the same targets were used whether a singleton distractor was present or not. This raises the possibility that intertrial priming effects are enhanced by the presence of a singleton distractor, even if the singleton distractor itself is not primed (and does not in turn prime the target). The presence of a singleton distractor increases the competition for selection and this may require more attentional weight to be applied to the target, leading to stronger activation on the subsequent trial.

As in Experiment 1, the singleton distractor, when present, could be either red or green. This allowed us to assess priming between the singleton distractors themselves. On average, across the singleton distractor present blocks of the mixed and pure conditions, the costs of a color change were now a significant 26 ms, $F(1,19) = 8.44$, $MSe = 1651.7$, $p < 0.01$. There were no interactions with condition, $F < 1$. Thus, distractor-distractor priming also appeared to operate, but its magnitude was not affected by mixing target types.

Finally, we should mention that even though the increased *singleton distractor* costs in the mixed condition were not due to an overall effect, the *RTs as a whole* were overall increased in the mixed condition relative to the pure condition. We will return to this in the General Discussion.

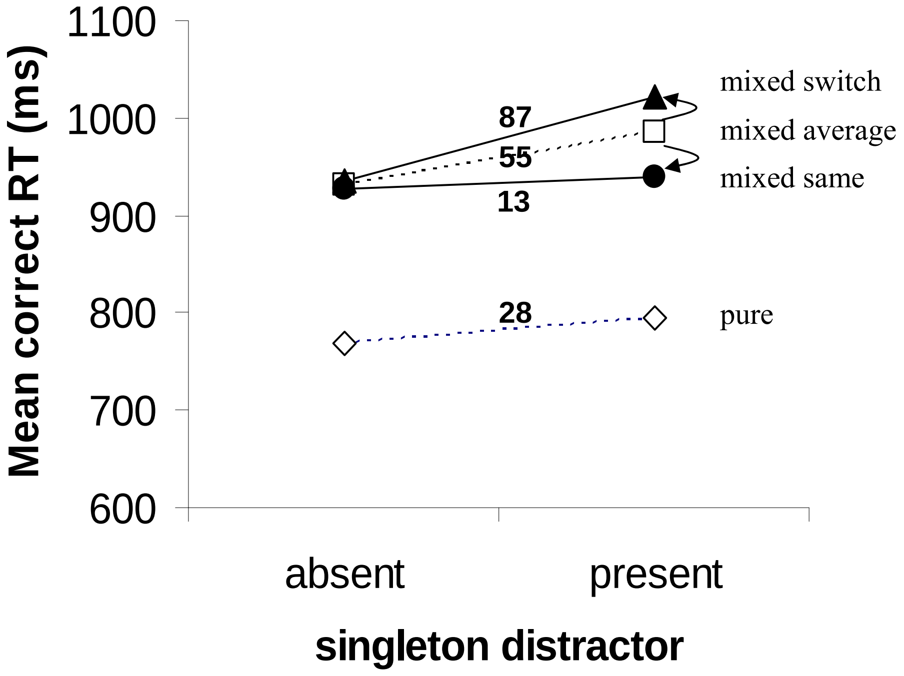

Figure 6.4. Mean reaction time results of Experiment 2 as a function of singleton distractor presence. Open symbols reflect the overall mean RTs for the pure and mixed conditions. Filled symbols reflect the mean RTs in the mixed condition, broken down for the different intertrial relationships (same vs. switch). Adjacent to each line, the numerical value of the singleton distractor effect in ms is printed.

General Discussion

The goal of our study was to examine how target uncertainty affects attentional capture by irrelevant singleton distractors. We presented observers with pure blocks, throughout which the shape of the targets and singleton distractors stayed the same, and mixed blocks, in which the shape of the targets and singleton distractors switched randomly from trial to trial. Confirming earlier findings (Theeuwes, 1991, 1992) we found that the costs associated with the presence of a singleton distractor were increased in the mixed condition. By comparing the singleton distractor effect on switch and same trials in the mixed condition to the singleton distractor effect in the pure condition we assessed the relative contributions of intertrial and overall effects to this increase. In both Experiment 1 and Experiment 2 the differential singleton distractor effect could solely be explained by intertial effects, with negligible to non-existent residual overall increases in singleton distractor effects. In Experiment 1 the target and the singleton distractor could swap identity, allowing for priming between target and singleton distractor. In Experiment 2 the singleton distractor and target shapes were always different and priming between targets and singleton distractors was therefore eliminated. We still found an interaction between singleton distractor presence and intertrial effects, indicating that priming between targets alone also contributes to the efficiency with which a target is selected and a singleton distractor is ignored. Nevertheless, the differential singleton distractor costs were strongly reduced relative to Experiment 1, indicating that the priming between targets and singleton distractors in Experiment 1 was a major cause of the increased singleton distractor effects.

Intertrial priming

An important question is whether the intertrial effects found here are the result of automatic processes or whether they may be traced back to on-line top-down strategy changes. So far, we have referred to these effects as stemming from priming, which implies an automatic process. Support for this comes from Maljkovic and Nakayama (1994; see also Olivers & Humphreys, 2003; Hillstrom, 2000), who showed that the intertrial effects can go back as far as 8 trials. It is unlikely that observers consciously base their search strategy on these distant trials. Indeed, Maljkovic and Nakayama (2000) have shown that observers hardly remember what they saw on the immediately preceding trial. A second argument against conscious switching of search strategy comes from another experiment from Maljkovic and Nakayama (1994) in which observers could explicitly expect a switch trial (because they alternated regularly with same trials). This did not eliminate the costs associated with switch trials, indicating that intertrial priming effects could not be overcome by top-down settings. A recent study by Theeuwes, Reimann, and Mortier (2006) offers further support for the automatic priming account. In one of their visual search experiments, participants were required to look for either a shape- or a color-defined target (with target types randomly mixed). The search displays were preceded by a cue, which consisted of one of the two target types (i.e. the actual target shape or color). The cue was valid on 80% of the trials. The results showed that search was speeded on valid trials relative to invalid trials, suggesting that observers made active use of the cue. However, a subsequent experiment indicated otherwise. In this experiment, the cue was valid on only 16.6% of the trials. That is, a shape cue was now actually predictive of a color target (and, vice versa, a color cue implied that a shape target would be most likely). Still, the benefit for valid trials was virtually the same as in the first experiment. This indicates that search was driven more by the just previously processed stimulus (i.e. the cue) than by what this stimulus actually meant – in line with an automatic priming account.

Priming and competition

Interestingly, we also found an interaction between intertrial relationship and singleton distractor presence in Experiment 2, where target and singleton distractors always had different shapes and priming could thus only operate between the targets themselves. Apparently, singleton distractor presence enhances the role of intertrial priming even when the singleton distractor itself is not primed. To account for this finding, we start from Müller et al.'s (1995) idea that intertrial effects are caused by weight shifting. Features associated with the target receive more weight, whereas features associated with the distractor lose weight. What we propose here is that when there is more competition for attention (e.g. when a singleton distractor is present) larger weights will need to be assigned to features associated with the target in order for it to win this competition. The larger weight results in stronger intertrial priming effects, measurable on the subsequent trial. This way, intertrial priming may be argued to be an automatic adjustment mechanism, contingent upon task requirements such as the need for competitive selection (cf. Olivers & Humphreys, 2003; Wolfe, Butcher, Lee & Hyle, 2003). We would therefore like to propose that intertrial priming is not a strict top-down process (in the sense that it is under the voluntary control of the observer), but nor is it a strict bottom-up process (in the sense that it is fully driven by the current stimulus). Instead, it lies somewhere in between, automatically adapting the organism to a changing environment.

It is worth noting that the results obtained in Experiment 1 in our visual search task are comparable to the outcome of studies on negative priming which use words or letters or even semantic categories as primed objects (Milliken, Joordens, Merikle & Seiffert,1998; Fox, 1995 for a review). Furthermore, DeSchepper and Treisman (1996) found negative priming, in a non-search task, with a month interval between prime and probe while participants showed no explicit recollection of the prime. Milliken, Lupianez, Debner and Abello (1999) showed, also in a non-search task, that negative priming depended on task demands, with no negative priming when either the frequency of the prime correctly predicting the probe was low or when the probe was accompanied by distractors. Both studies support the view that priming is an automatic top-down process comparable to implicit learning, since neither only bottom-up factors nor a conscious strategy of the particapants can explain the obtained results. However, a difference in our search task and previous research in non-search tasks is that in Experiment 2 in our study we observed target-target priming to be influenced by the presence of a distractor. This occurred when the distractor itself was not primed and the distractor did not prime the target.

Features or dimensions

In our experiments, priming occurred on the feature-level (i.e. the specific target shape). This is in accordance with Maljkovic and Nakayama (1994), who also found intertrial priming to influence attentional processes on a feature-level (in their case color). However, Müller et al. (1995) have found intertrial effects to mainly operate on a dimension-level rather than on a feature-level (see also Olivers and Humphreys, 2003, who found evidence for dimension-priming together with small feature-priming effects). The difference between our findings and Müller et al. (1995) might be the result of their participants performing a cross-dimension search task, whereas our participants performed a within-dimension search task. We speculate that in a cross-dimension search task priming operates on a dimension level (as this is the level on which the competition takes place), whereas in a within-dimension search task intertrial priming takes place on a feature level. If this indeed turns out to be the case, then it would again suggest that intertrial priming mechanisms are adjusted on the basis of task requirements.

The task dependency of intertrial priming is further suggested by Kumada (2001), who found intertrial priming to play a role in a standard present/absent search task, but not in a compound search task. Kumada (2001) argued that intertrial priming does not influence selective attention but plays a role at the response-level (see Mortier, Theeuwes, & Starreveld, 2005, for similar issues). However, note that we too had participants perform a compound search task, but contrary to Kumada, still found an effect on RTs as a result of intertrial priming. Also Maljkovic and Nakayama (1994, 2000) as well as Olivers & Humphreys (2003) found intertrial priming to affect compound search. Together with its effects on singleton distractor interference (as shown in the present study), this suggests that intertrial priming does affect attentional processes after all and not just response-related processes.

Target uncertainty

Regardless of any singleton distractor effects, RTs in the mixed condition were overall slower than in the pure condition. Because this slowing was not affected by the presence of a singleton distractor, it is unlikely that it was caused by a general widening of the attentional selection process. Instead, the overall character of the slowing suggests that additional processing *after* selection is responsible. One such process may be the comparison of the selected item to a target-template in visual short-term memory (VSTM; Duncan and Humphreys, 1989; Hodsoll and Humphreys, 2001). When a target template is extended to include more target types, matching of the items in VSTM to the target template takes more time (cf. Sternberg, 1966).

Conclusion

Two separate mechanisms appear to play a role when the target is uncertain in visual search. One mechanism, presumably involving the matching of the target, causes RTs to be overall longer, but does not influence the effect of a singleton distractor on selective attention. The other mechanism, intertrial priming, does influence selective attention by differentially (de)activating the target and possible distractors. However, target uncertainty does not change attentional capture by irrelevant singletons beyond the influence of preceding trials. Importantly, a lack of knowledge of the target does not cause participants to be more distracted by irrelevant yet salient objects.

Nederlandse samenvatting

Aandacht

Stel je bent op een feestje en je hebt een interessant gesprek met iemand die je al tijden niet meer hebt gesproken. De verhalen van deze oude bekende zijn dusdanig interessant dat je eigenlijk nergens anders meer aandacht voor hebt. Wat herinner je je een week later nog van deze avond? Waarschijnlijk veel van dit gesprek, en weinig van andere zaken die speelden. Maar stel je voor dat er diezelfde avond een onverwachtse gebeurtenis was, zoals een plotsklapse luide knal. Deze opvallende gebeurtenis zou waarschijnlijk je aandacht hebben getrokken en daarom later door je worden herinnerd.

Aandachtsonderzoek heeft de intuïties gebaseerd op dit voorbeeld grotendeels bevestigd. Het "veranderingsblindheid"-onderzoek van O'Regan, Rensink en anderen gedurende de jaren negentig heeft aangetoond dat aandacht essentieel is voor wat we ons later herinneren. Verder wordt het richten van de aandacht bepaald door doelen van de persoon enerzijds (willen luisteren naar een bepaald verhaal) en omgevingsfactoren anderzijds (de luide knal). Hedendaags onderzoek bestudeert hoe deze waarnemersgestuurde en omgevingsgestuurde factoren interacteren. Het onderzoek richt zich voornamelijk op visuele aandacht. Er zijn drie belangrijke theorieën ontstaan. De "relatieve omgevingsgestuurde" theorie zegt dat aandacht in eerste instantie door de omgeving wordt bepaald, en wel dat aandacht gaat naar die objecten die het meest verschillen van de omgeving. Deze theorie vindt bevestiging in experimenten gedaan door Jan Theeuwes (1991, 1992). Theeuwes toonde aan dat mensen automatisch hun aandacht richten op een groen object tussen rode objecten (of omgekeerd) ook als ze het doel hebben dit object te negeren. De "absolute omgevingsgestuurde" theorie zegt ook dat aandacht in eerste instantie getrokken wordt de omgeving, maar volgens deze theorie kunnen niet alle unieke objecten de aandacht trekken. Alleen objecten die uniek en dynamisch zijn, zijn hiertoe in staat. Met dynamisch wordt hiermee een object bedoelt dat een verandering ondergaat. Voorbeelden hiervan zijn beweging (verandering van plaats), knipperen (verandering van aanwezigheid) en flikkeren (verandering van helderheid). Deze theorie wordt gesteund door onderzoek van Yantis en Jonides (1984, 1988) die hebben laten zien dat in een ingewikkelde zoektaak, mensen automatisch hun aandacht richten op unieke objecten, mits deze dynamisch zijn. Tot slot is er de “waarnemersgestuurde” theorie. Volgens deze theorie wordt aandacht nooit getrokken door de omgeving, maar wordt aandacht volledig bepaald door de doelen die iemand heeft.

Het huidige onderzoek heeft geprobeerd deze fundamentele vraag te beantwoorden door te onderzoeken hoe aandacht zich gedraagt in dynamische situaties. We hebben vooral gekeken naar het lot van een statisch object in een dynamische omgeving. Volgens de “absolute omgevingsgestuurde” theorie is het niet mogelijk je aandacht direct op zo’n object te richten. Volgens de “waarnemersgestuurde” theorie gaat je aandacht alleen direct naar zo’n object als je dat wilt. Wij hebben ontdekt dat je aandacht direct naar het statische object in een dynamische omgeving gaat, onafhankelijk van je zoek-doelen. Deze resultaten vormen een bevestiging voor de “relatieve omgevingsgestuurde” theorie.

Verder hebben we de rol van aandacht in twee andere dynamische situaties onder de loep genomen. Lee en Blake (1999) hebben aangetoond dat je een object kan onderscheiden van de achtergrond puur gebaseerd op temporele cues. Dat wil zeggen, als alles verandert, maar sommige elementen veranderen gelijktijdig, dan groepeer je deze elementen samen tot één object (het zogeheten “temporeel groeperen”). Ons onderzoek heeft aangetoond dat temporeel groeperen geen aandacht vereist, maar automatisch plaatsvindt.

Tot slot hebben we onderzocht hoe aandacht wordt beïnvloed als de situatie van moment tot moment verandert, maar mensen in alle situaties een uniek object zoeken. Ons onderzoek toonde aan dat in dat geval je minder wordt afgeleid naarmate je zoekdoel eenduidiger is. Echter, deze afname in afleiding kan niet toegeschreven worden aan intenties van de waarnemer, maar blijkt het gevolg te zijn van priming gebaseerd op externe factoren.

Statisch object in een dynamische omgeving

Verschillende onderzoekers (Jonides & Yantis, 1988; Abrams & Christ, 2003; Franconeri & Simons, 2003) hebben beargumenteerd dat dynamische objecten speciaal geschikt zijn om onze aandacht te trekken. Evolutionair gezien zou dit komen doordat mogelijk belangrijke gebeurtenissen, zoals het verschijnen van een vijand, meestal dynamisch van aard zijn. Daarom hebben we een aangeboren neiging om op dynamische objecten te letten. Deze theorie komt goed overeen met onze alledaagse intuïtie. Als een vriend ons zoekt op een druk perron dan gaan we naar hem zwaaien. Ambulances zijn uitgerust met knipperlichten om onze aandacht te trekken.

Wat gebeurt er nu als er niet één maar vele dynamische objecten zijn, en er slechts één object is dat niet-dynamisch is? Uitgaande van het idee dat we automatisch geneigd zijn op dynamische objecten te letten, zou je verwachten dat het heel moeilijk is je aandacht op het statische object te richten. In **Hoofdstuk 2** van dit proefschrift hebben we deze vraag onderzocht. We lieten proefpersonen een zoektaak doen waarbij de taak was een niet-schuine lijn te vinden tussen allemaal schuine lijnen. Deze niet-schuine lijn was verticaal of horizontaal, en de taak van de proefpersoon was aan te geven of het doel-object (de niet-schuine lijn) verticaal of horizontaal was. Als alle lijntjes stilstonden was het lastig om de schuine lijnen van de niet-schuine lijnen te onderscheiden, hetgeen er voor zorgde dat hoe meer schuine lijnen er waren, des te langer mensen over de taak deden. De cruciale manipulatie was dat in de experimentele condities de schuine lijnen knipperden, of roteerden. Als het nu zo is dat dynamische objecten de aandacht trekken dan zou je verwachten dat de schuine lijnen nu nog meer zouden afleiden, wat er toe zou leiden dat mensen nog langzamer zouden worden als er meer schuine lijnen aanwezig zijn. Echter, dat is niet wat we vonden. Als de schuine lijnen knipperden of roteerden, dan werd het ineens erg gemakkelijk om het doel-object (de niet-schuine lijn) te vinden. De hoeveelheid afleiders (de schuine lijnen) had nauwelijks invloed op de reactie snelheden, wat aangaf dat aandacht direct naar het enige niet-dynamische object ging. Dit resultaat gaat dus lijnrecht in tegen het idee dat we altijd geneigd zijn om op dynamische objecten te letten. Het lijkt er eerder op dat we in het dagelijks leven onze aandacht richten op dynamische objecten, omdat de wereld overwegend bestaat uit statische objecten en dynamische objecten daarom de uitzondering zijn. Echter zodra de meeste objecten dynamisch zijn, kunnen we onze aandacht heel gemakkelijk naar het statische (en nu dus unieke object) sturen.

Een belangrijke bezwaar tegen ons onderzoek zou kunnen zijn dat we wel claimen dat we hebben laten zien dat een statisch object *in het algemeen* goed te detecteren is in een dynamische omgeving, maar dat we het maar hebben laten zien voor twee gevallen (knipperen en roteren). Dit probleem is des te erger omdat het misschien zo is dat roteren en knipperen gebaseerd zijn op hetzelfde basismechanisme. Wellicht horen zowel knipperen als roteren tot “beweging” en zijn we uitgerust met een bewegings-filter, dat ons in staat stelt om objecten met elke willekeurige snelheid (dus ook snelheid nul) te selecteren (zie bijvoorbeeld McLeod et al., 1988 wiens resultaten lijken te bevestigen dat er inderdaad zo’n bewegingsfilter is). Om te onderzoeken in hoeverre onze resultaten algemeen geldend zijn, danwel terug te voeren op een bewegingsfilter, hebben we in **Hoofdstuk 3** onderzocht of er omstandigheden zijn waarin proefpersonen anders reageren op knipperende dan op bewegende afleiders. Immers als beide soorten afleiders volgens één mechanisme behandeld worden dan zou zo'n dissociatie niet moeten optreden. Deze dissociatie vonden we wel. Met name, als de objecten even helder werden gemaakt als de achtergrond, dan waren proefpersonen nog wel in staat om een statisch object gemakkelijk te vinden tussen knipperende afleiders, maar niet tussen bewegende afleiders. Dit suggereert dat het efficiënte vinden van een statisch object berust op een meer algemeen principe, en niet slechts het gevolg is van een bewegingsfilter.

Een vervolgvraag is of een statisch object in een dynamische omgeving de aandacht automatisch vangt, of dat mensen hun aandacht alleen op het statische object richten als ze dat willen. In **Hoofdstuk 4** onderzochten we deze vraag door het doel-object meestal dynamisch te maken. Dat wil zeggen, proefpersonen moesten een doel-object zoeken tussen allemaal afleiders (bijvoorbeeld een niet-schuine lijn tussen allemaal schuine lijnen), waarbij alle objecten behalve één dynamisch waren. Het statische object was af en toe het doel-object, maar in de meeste gevallen niet. Proefpersonen wisten dit, en hadden dus geen reden om een statisch object te zoeken. Als het desalniettemin zo is dat de aandacht automatisch naar het statische object gaat, hoewel dit niet het doel is van de proefpersoon, dan zouden mensen sneller moeten reageren als het doel-object toevallig statisch is. Dit is wat we vonden. Zowel tussen bewegende als knipperende objecten bleek een statisch object automatisch de aandacht te trekken.

Temporeel groeperen

Temporeel groeperen vindt plaats in een *geheel* dynamische situatie. Lee en Blake (1999) presenteerden proefpersonen met elementen die allemaal in verschillende richtingen bewogen. Verder veranderde elk element op een onvoorpelbaar moment van bewegingsrichting. Echter, een aantal elementen veranderde op hetzelfde moment. Deze elementen werden door proefpersonen als één object waargenomen. Het fenomeen dat tegelijk veranderende objecten als één object worden waargenomen noemden Lee en Blake "temporeel groeperen". Een belangrijke vraag met betrekking tot temporeel groeperen is wat de rol van aandacht is in dit proces. In het algemeen geldt dat als objecten of groepen genoeg verschillen van hun omgeving, aandacht niet vereist is om de groep van de omgeving te onderscheiden. Dit impliceert dat als temporeel groeperen geen aandacht vereist, het visuele systeem de verschillen in temporele eigenschappen van de waargenomen objecten nauwkeurig bijhoudt. Dit is precies wat je zou verwachten als het visuele systeem met name is geïnteresseerd in verschillen tussen objecten (zoals de “relatieve omgevingsgestuurde” theorie suggereert). In **Hoofdstuk 5** bestudeerden we deze vraag door proefpersonen een zoektaak te geven waarbij er meerdere temporele groepen aanwezig waren. De zoektaak behelsde het detecteren van een temporele groep die een schuine balk definieerde, omringd door temporele groepen die verticale balken definieerden. Als elke temporele groep aandacht vereist om te worden gedetecteerd, dan zou de zoektaak meer tijd vereisen naarmate er meer temporele groepen aanwezig zijn. Echter, als de proefpersonen de temporele groepen allemaal ineens zien, dan is de verwachting dat de schuine balk eruit springt (omdat schuine balken in het algemeen erg gemakkelijk zijn te onderscheiden van verticale balken), en dat daarom het aantal verticale balken niet uitmaakt voor hoe lang proefpersonen over de zoektaak doen. Dit laatste is wat we vonden. Sterker nog, proefpersonen waren zelfs iets sneller naarmate er meer verticale balken aanwezig waren, omdat dit het verschil tussen het doel-object en de afleiders groter maakte (en dus het detecteren van het doel-object vergemakkelijkte). Deze resultaten lieten zien dat temporeel groeperen automatisch plaatsvindt en bevestigen het idee dat voor het visuele systeem verschillen in temporele eigenschappen van groot belang zijn.

Priming of kennis?

Naast dynamiek binnen een situatie is er ook nog de mogelijkheid van dynamiek tussen situaties. Ook deze dynamiek kan sterke gevolgen hebben voor hoe aandacht gericht wordt. Een goed voorbeeld hiervan komt naar voren uit het werk van Theeuwes (1991, 1992). Theeuwes (1991) liet mensen zoeken naar een unieke vorm, bijvoorbeeld een ruit tussen cirkels. Alle objecten waren groen, maar soms was een van de afleiders rood. Proefpersonen wisten dat dit niet van belang was voor de taak. Desalniettemin waren ze langzamer wanneer één van de afleiders rood was. Dit resultaat geeft aan dat mensen door opvallende objecten (zoals een uniek gekleurd object) worden afgeleid, ook als ze dat proberen te negeren. In de studie van Theeuwes (1991) waren mensen ongeveer 150 milliseconden langzamer wanneer er een uniek gekleurde afleider aanwezig was. Belangrijk is dat in Theeuwes’ (1991) studie mensen niet vantevoren wisten of ze een ruit of een cirkel moesten zoeken, alleen dat ze het unieke object moesten vinden. In 1992 repliceerde Theeuwes het onderzoek uit 1991, echter nu wisten mensen vantevoren of ze een ruit of een cirkel moesten zoeken, doordat gedurende een blok van trials het doel-object constant bleef. Dus gedurende één blok was het doel-object bijvoorbeeld altijd een ruit (tussen cirkels). Mensen waren wederom langzamer als er een unieke gekleurde afleider aanwezig was, echter nu waren proefpersonen maar ongeveer 20 ms langzamer. Het leek er dus op dat mensen in de studie van Theeuwes uit 1992 veel minder werden afgeleid dan in zijn studie uit 1991.

In **Hoofdstuk 6** onderzochten we ten eerste of je inderdaad meer wordt afgeleid als je niet weet wat het doel-object gaat worden (ten slotte kunnen de verschillen in de twee studies van Theeuwes ook komen doordat er andere proefpersonen aan beide studies meededen), en ten tweede of dit verschil in afleiding komt door kennis of *priming*. Priming is het fenomeen dat eigenschappen die in het verleden geassocieerd waren met een zoekdoel je aandacht trekken, terwijl eigenschappen geassocieerd met een afleider automatisch genegeerd worden. Als je bijvoorbeeld eerst je trui zocht en die was rood, en je zoekt nu je auto, dan vindt je je auto gemakkelijker als die toevallig ook rood is. Priming kan het afleider-effect beïnvloeden, want als het doel-object verandert, dan kan het zo zijn dat een vorm die eerst geassocieerd werd met het zoekdoel nu geassocieerd wordt met de afleider (waardoor die afleider meer de aandacht trekt).

We lieten proefpersonen twee verschillende blokken van trials uitvoeren. In een puur blok bleef het doel-object steeds hetzelfde. In een gemixt blok kon het doel-object van trial tot trial veranderen (danwel een ruit tussen cirkels of vice versa). Verder manipuleerden we de aanwezigheid van een uniek gekleurde afleider. We vonden inderdaad dat proefpersonen veel meer werden afgeleid door een uniek gekleurde afleider in een gemixt blok (als ze niet wisten wat het doel-object precies zou zijn) dan in een puur blok. Om te onderzoeken wat de onderliggende oorzaak van dit effect was keken we naar *repetitie-trials* in het gemixte blok. Een repetitie-trial wil zeggen dat het doel-object op de huidige trial hetzelfde is als het doel-object op de vorige trial. Een puur blok omvat dus alleen maar repetitie-trials. Vanuit een kennis-oogpunt is een repetitie-trial niets bijzonders, vantevoren wist je namelijk nog steeds niet welke doel-object er zou komen, dus je was even onzeker als op alle andere trials in het gemixte blok. Echter vanuit een priming-oogpunt is een repetitie trial hetzelfde als een trial in het puur blok. Eigenschappen geassocieerd met het doel-object blijven bij het huidige doel-object horen, en eigenschappen geassocieerd met de afleider blijven bij de afleider horen. Als het dus zo is dat priming ten grondslag ligt aan het grotere afleider-effect in het gemixte blok dan zou je verwachten dat op een repetitie-trial dit grotere afleider-effect is verdwenen. Dit is precies wat we vonden. Op repetitie-trials waren mensen veel minder afgeleid dan op andere trial in het gemixte blok. Sterker nog, op repetitie-trials waren ze even weinig afgeleid als gedurende het pure blok. Dit suggereert dat niet kennis maar priming ervoor zorgt dat mensen minder worden afgeleid als het doel-object constant blijft.

Conclusies

Onze onderzoeken hebben een aantal belangrijke zaken met betrekking tot aandacht blootgelegd. Dynamische objecten trekken niet altijd de aandacht. Sterker nog, als de situatie geheel dynamisch wordt, dan trekken statische objecten automatisch de aandacht. Verder is het zo dat het visuele systeem automatisch bijhoudt welke temporele verschillen er tussen objecten zijn, hetgeen ertoe leidt dat objecten met dezelfde temporele eigenschappen automatisch worden gegroepeerd. Tot slot, kennis over het zoekdoel voorkomt niet dat je wordt afgeleid door een irrelevant, maar opvallend (want uniek gekleurd) object. Al deze bevindingen samen vormen ondersteuning voor de “relatieve omgevingsgestuurde” theorie. De omgeving lijkt in eerste instantie inderdaad te bepalen waar je aandacht naar toe gaat. Verder geldt dat het dan niet zozeer gaat om specifieke eigenschappen van objecten, maar om verschillen tussen objecten onderling.

References

Abrams, R. A., & Christ, S. E. (2003). Motion onset captures attention. *Psychological Science, 14,* 427-432.

Adelson, E. & Farid, H. (1999). Filtering reveals form in temporally-structured displays. *Science, 286,* 2331

Alais, D., Blake, R., & Lee, S. H. (1998). Visual features that vary together over time group together over space. *Nature Neuroscience, 1,* 160-164.

Albright, T. D. (1984). Direction and orientation selectivity of neurons in visual area MT of the macaque. *Journal of Neurophysiology, 52,* 1106-1130.

Andersen, R. A. (1997). Neural mechanisms of visual motion perception in primates. *Neuron, 18(6),* 865 - 872.

Aslin, C., Blake, R., & Chun, M. M. (2002). Perceptual learning of temporal structure. *Vision Research, 42(28),* 3019-3030.

Bacon, W. F., & Egeth, H. E. (1994). Overriding Stimulus-Driven Attentional Capture. *Perception & Psychophysics, 55(5),* 485-496.

Bauer, B., Jolicoeur, P., & Cowan, W. B. (1996). Visual search for colour targets that are or are not separable from distractors. *Vision Research, 36,* 1439-1465.

Becker, M. W., Pashler, H., & Anstis, S. M. (2000). The role of iconic memory in change-detection tasks. *Perception, 29(3),* 273-286.

Belopolsky, A.V., Zwaan, L., Theeuwes, J., & Kramer, A.F. (2007). The size of an attentional window modulates attentional capture by color singletons. *Psychonomic Bulletin and Review, 14,* 934-934.

Blake, R., & Yang, Y. (1997). Spatial and temporal coherence in perceptual binding, *Proceedings of the National Academy of Sciences, 94,* 7115-7119.

Breitmeyer, B. G., & Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review, 83,* 1-36.

Breitmeyer, B. G., & Williams, M. C. (1990). Effects of isoluminant-background color on metacontrast and stroboscopic motion: Interactions between sustained (P) and transient (M) channels. *Vision Research, 30,* 1069-1075.

Burt, P., & Sperling, G. (1981). Time, distance and feature trade-offs in visual apparent motion. *Psychological Review, 88,* 171-195.

Carrasco, M., Evert, D. L., Chang, I. & Katz, S. M. (1995). The eccentricity effect: target eccentricity affects performance on conjunction searches. *Perception and Psychophysics, 57(8),* 1241-1261

Cavanagh, P., Tyler, C. W., & Favreau, O. E. (1984). Perceived velocity of moving chromatic gratings. *Journal of the Optical Society of America A - Optics Image Science and Vision, 1,* 893-899.

Cavanagh, P., Arguin, M. & Treisman, A. (1990). Effects of surface medium on visual search for orientation and size features. *Journal of Experimental Psychology: Human Perception & Performance, 16,* 479-491.

Chapman, C., Hoag, R. & Giaschi, D. (2004). The effect of disrupting the human magnocellular pathway on global motion perception. *Vision Research, 44,* 2551–2557.

Chastain, G., & Cheal, M. (1999). Time course of attention effects with abrupt-onset and offset single- and multiple-element precues. *American Journal of Psychology, 112,* 411-436.

Cleland, B. G., Dubin, M. W., & Levick, W. R. (1971). Sustained and transient neurons in the cat's retina and laterate geniculate nucleus. *Journal of Physiology, 217,* 473-496.

Clifford, C. W. G., Arnold, D. H., & Pearson, J. (2003). A paradox of temporal perception revealed by a stimulus oscillating in colour and orientation. *Vision Research, 43,* 2245-2253.

Cole, G. G., Kentridge R. W., & Heywood, C. A. (2004). Visual salience in the change detection paradigm: The special role of object onset. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 464-477.

Cole, G. G., Kentridge, R. W., & Heywood, C. A. (2005). Object onset and parvocellular guidance of attentional allocation. *Psychological Science, 16,* 270-274.

D'Zmura, M. (1991). Color in visual search. *Vision Research, 31,* 951-966.

Davis, G., & Leow, M. C. (2005). Blindness for unchanging targets in the absence of motion filtering - A response to Theeuwes (2004). *Psychological Science, 16(1),* 80-82.

DeSchepper, B., & Treisman, A. (1996). Visual memory for novel shapes: Implicit coding without attention. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22,* 27-47.

Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research, 36(12),* 1827-1837.

Di Lollo, V., Enns, J. T., Yantis, S., & Dechief, L.G. (2000). Response latencies to the onset and offset of visual stimuli. *Perception & Psychophysics, 62,* 218-225.

Donk, M., & Theeuwes, J. (2003). Prioritizing selection of new elements: Bottom-up versus top-down control. *Perception & Psychophysics, 65(8),* 1231-1242.

Driver, J. (2001). A selective review of selective attention research of the past century. British Journal of Psychology, 92, 53-78.

Duncan, J., & Humphreys, G.W. (1989). Visual Search and Stimulus Similarity. *Psychological Review, 96,* 433-458.

Eagleman, D. J., Jacobson, J. E., & Sejnowski, T. J. (2004). Perceived luminance depends on temporal context. *Nature, 428,* 854-856.

Eckstein, M. P., Thomas, J. P., Palmer, J. & Shimozaki, S. S. (2000). A signal detection model predicts the effects of set size on visual search accuracy for feature, conjunction, triple conjunction, and disjunction displays. *Perception and Psychophysics, 62(3),* 425-451

Engel, A. K. & Singer, W. (2001). Temporal binding and the neural correlates of sensory awareness. *Trends in Cognitive Sciences, 5,* 16-25.

Enns, J. T., Austen, E. L., Di Lollo, V., Rauschenberger, R., & Yantis, S. (2001). New objects dominate luminance transients in setting attentional priority. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 1287-1302.

Enroth-Cugell, C., & Robson, J. G. (1966). The contrast sensitivity of retinal ganglion cells of the rat. *Journal of Physiology, 187,* 517-552.

Fahle, M. (1993). Figure-ground discrimination from temporal information. *Proceedings of the Royal Society of London Series B - Biological Sciences, 254,* 199-203.

Fahle, M., & Koch, C. (1995). Spatial displacement, but not temporal asynchrony, destroys figural binding. *Vision Research, 35,* 491–494.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1030-1044.

Folk, C. L., Remington, R. W., & Wright, H. W. (1994). The structure of attentional control: contingent attentional capture by apparent motion, abrupt onset and color. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 317-329.

Forte, J., Hogben, J. H. & Ross, J. (1999). Spatial limitations of temporal segmentation. *Vision Research, 39,* 4052-4061.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review, 2,* 145-173.

Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics, 65(7),* 999-1010.

Franconeri, S. L., Hollingworth, A., & Simons, D.J. (2005). Do new objects capture attention? *Psychological Science, 16,* 275-281.

Gegenfurtner, K. R., & Hawken, M. J. (1995). Temporal and chromatic properties of motion mechanisms. *Vision Research, 35,* 1547-1563.

Gibson, B. S., & Kelsey, E. M. (1998). Stimulus-driven attentional capture is contingent on attentional set for displaywide visual features. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 699-706.

Gottlieb, J. P., Kusunoki, M., & Goldberg, M. E. (1998). The representation of visual salience in monkey parietal cortex. *Nature, 391,* 481-484.

Green, M. (1981). Psychophysical Relationships among Mechanisms Sensitive to Pattern, Motion and Flicker. *Vision Research, 21(7),* 971-983.

Guttman, S. E., Gilroy, L. A., & Blake, R. (2005). Mixed messengers, unified message: spatial grouping from temporal structure. *Vision Research, 45(8),* 1021-1030.

Hillstrom, A. P. (2000). Repetition effects in visual search. *Perception & Psychophysics, 62,* 800-817.

Hillstrom, A. P., & Yantis, S. (1994). Visual motion and attentional capture. *Perception and Psychophysics, 55,* 399-411.

Hodsoll, J., & Humphreys, G.W. (2001). Driving attention with the top down: the relative contribution of target templates to the linear separability effect in the size dimension. *Percerption & Psychophysics, 63,* 918-926.

Irwin, D. E. (1991). Information integration across saccadic eye-movements. *Cognitive Psychology, 23,* 420-456.

Irwin, D. E. (1992). Memory for Position and Identity across Eye-Movements. *Journal of Experimental Psychology-Learning Memory and Cognition, 18(2),* 307-317.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research, 40(10-12),* 1489-1506.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience, 2(3),* 194-203.

Ives, H. E. (1912). Studies of the photometry of different colours: I. Spectral luminosity curves obtained by equality of brightness photometer and the flicker photometer under similar conditions. *Philosophical Magazine, 24,* 149-188.

Jiang, Y. H., Chun, M. M., & Marks, L. E. (2002). Visual marking: Selective attention to asynchronous temporal groups. *Journal of Experimental Psychology-Human Perception and Performance, 28(3),* 717-730.

Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye's movement. *In J. B. Long, & A. D. Baddeley(Eds.), Attention and Performance IX (pp. 187-203).* Hillsdale, NJ: Erlbaum.

Jonides, J., & Yantis, S. (1988). Uniqueness of Abrupt Visual Onset in Capturing Attention. *Perception & Psychophysics, 43(4),* 346-354.

Kahneman, D., Treisman, A. & Gibbs, B. J. (1992). The reviewing of object files : object-specific integration of information. *Cognitive Psychology, 24,* 175-219

Kandil, F., I., & Fahle, M. (2004). Figure-ground segregation can rely on differences in motion direction. *Vision Research, 44,* 3177-3182.

Kim, M. S., & Cave, K. R. (1995). Spatial attention in visual search for features and feature conjunctions. *Psychological Science, 6,* 376-380.

Kiper, D. C., Gegenfurtner, K. R., & Movshon, J. A. (1996). Cortical oscillatory responses do not affect visual segmentation. *Vision Research, 36,* 539-544.

Kumada, T. (2001). Feature-based control of attention: evidence for two forms of dimension weighting. *Perception & Psychophysics, 63,* 698-708.

Kristjánsson, Á., & Tse, P. U. (2001). Curvature discontinuities are cues for rapid shape analysis. *Perception & Psychophysics, 63,* 390-403.

Lamme, V. A. F. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences, 7(1),* 12-18.

Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences, 23(11),* 571-579.

Landman, R., Spekreijse, H., & Lamme, V. A. F. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research, 43(2),* 149-164.

Lee, S. H., & Blake, R. (1999). Visual form created solely from temporal structure. *Science, 284(5417),* 1165-1168.

Lee, S. H., & Blake, R. (1999b). Response to: Adelson and Farid. *Science, 286,* 2231.

Leonards, U., Singer, W., & Fahle, M. (1996). The influence of temporal phase differences on texture segmentation. *Vision Research, 36,* 2689-2697.

Leventhal, A, Rodieck, R.W., & Dreher, B. (1981), Retinal ganglion cell classes in the old world monkey: Morphology and central projections. *Science, 213,* 1139-1142.

Livingstone, M., & Hubel, D. (1988). Segregation of Form, Color, Movement, and Depth - Anatomy, Physiology, and Perception. *Science, 240(4853),* 740-749.

Maljkovic, V., & Nakayama, K. (1994). Priming of Pop-Out .1. Role of Features. *Memory & Cognition, 22(6),* 657-672.

Maljkovic, V., & Nakayama, K. (1995). Short-Term Priming of Pop-out Summates Linearly over Trials and Is Independent for Feature and Position. *Investigative Ophthalmology & Visual Science, 36(4),* S14-S14.

Maljkovic, V., & Nakayama, K. (1996). Priming of pop-out .2. The role of position. *Perception & Psychophysics, 58(7),* 977-991.

Maljkovic, V., & Nakayama, K., (2000). Priming of pop-out: III. A short-term implicit memory system beneficial for rapid target selection. *Visual cognition, 7,* 571-595.

Mandler, M. B. (1984). Temporal frequency discrimination above treshold. *Vision Research, 24,* 1873-1880.

McLeod, P., Driver, J., & Crisp, J. (1988). Visual search for a conjunction of movement and form is parallel. *Nature, 332,* 154-155.

Milliken, B., Joordens, S., Merikle, P. A., & Seiffert, A. E. (1998). Selective attention: A reevaluation of the implications of negative priming. *Psychological Review, 105,* 203-229.

Milliken, B., Lupianez, J., Debner, J. & Abello, B. (1999). Automatic and controlled processing in Stroop negative priming: The role of attentional set. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1384-1402.

Mitroff, S. R., Scholl, B. J., & Wynn, K. (2004). Divide and conquer? How object files adapt when a persisting object splits into two. *Psychological Science, 15,* 420-425.

Moore, C. M., & Egeth, H. (1997). Perception Without Attention: Evidence of Grouping Under Conditions of Inattention. *Journal of Experimental Psychology: Human Perception & Performance, 23,* 339-352

Morgan, M., & Castet, E. (2002). High temporal frequency synchrony is insufficient for perceptual grouping. *Proceedings of the Royal Society of London. Series B, Biological Science, 269,* 513-516.

Mortier, K., Theeuwes, J., & Starreveld, P. (2005). Response selection modulates visual search within and across dimensions. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 542-557.

Moutoussis, K., & Zeki, S. (1997). A direct demonstration of perceptual asynchrony in vision. *Proceedings of the Royal Society of London. Series B, Biological Sciences, 264,* 393-399.

Mowbray, G. H., & Gebhard, J. W. (1955). Differential sensitivity of the eye to intermittent white light. *Science, 121,* 173-175.

Müller, H.J., Heller, D., & Ziegler, J. (1995). Visual search for singleton feature targets within and across feature dimensions. *Perception & Psychophysics, 57,* 1-14.

Müller, H., J., & Found, A. (1996). Visual search for conjunctions of motion and form : display density and asymmetry reversal. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 122 - 132.

Müller, H., J., & von Mühlenen (1999). Visual search for conjunctions of motion and form : The efficiency of attention to static versus moving items depends on practice. *Visual Cognition, 6,* 385-408.

Nishida, S., & Sato, T. (1994). Motion aftereffect with flickering test patterns reveals higher stages of motion processing. *Vision Research, 35,* 477-490.

Nothdurft, H. C. (1993). The role of features in preattentive vision - comparison of orientation, motion and color cues. *Vision Research, 33,* 1937-1958.

O'Keefe, L. P., & Movshon, J. A. (1998). Processing of first- and second-order motion signals by neurons in area MT of the macaque monkey. *Visual Neuroscience, 15(2),* 305-317.

O’Regan, J. K., Rensink, R. A., & Clark, J. J. (1999). Change-blindness as a result of "mudsplashes." *Nature, 398,* 34.

Olivers, C. N. L., & van der Helm, P. A. (1998). Symmetry and selective attention: A dissociation between effortless perception and serial search. *Perception & Psychophysics, 60(7),* 1101-1116.

Olivers, C.N.L., & Humphreys, G.W., (2003). Attentional guidance by salient feature singletons depends on intertrial contingencies. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 650-657.

Pashler, H. (1988). Cross-Dimensional Interaction and Texture Segregation. *Perception & Psychophysics, 43(4),* 307-318.

Pashler, H. (1988). Familiarity and visual change detection. *Perception and Psychophysics, 44,* 369-378.

Pashler, H. (1998). The psychology of attention. *Cambridge, MA: MIT Press.*

Pashler, H. (2001). Involuntary orienting to flashing distractors in delayed search? *In C. L. Folk & B. Gibson (Eds.), Attraction, Distraction and Action: Multiple Perspectives on Attentional Capture (pp. 77 - 92).* Amsterdam: Elsevier Science.

Pashler, H., & Harris, C. R. (2001). Spontaneous allocation of visual attention: Dominant role of uniqueness. *Psychonomic Bulletin and Review, 8(4),* 747-752.

Phillips, W. A. (1974). Distinction between sensory storage and short-term visual memory. *Perception and Psychophysics, 16,* 283-290.

Pinto, Y., Olivers, C. N. L., & Theeuwes, J. (2005). Target uncertainty does not lead to more distraction by singletons: Intertrial priming does. *Perception & Psychophysics, 67(8),* 1354-1361.

Pinto, Y, Olivers, C. N. L., & Theeuwes, J. (2006). When is search for a static target among dynamic distractors efficient? *Journal of Experimental Psychology: Human Perception and Performance, 32,* 59-72.

Pinto, Y., Olivers, C. N. L., & Theeuwes, J. (in press-a). Selecting from dynamic environments: Attention distinguishes between blinking and moving. *Perception and Psychophysics.*

Pinto, Y., Olivers, C. N. L., & Theeuwes, J. (in press-b). Static items are automatically prioritized in a dynamic environment. *Visual Cognition.*

Pinto, Y., Olivers, C. N. L., & Theeuwes, J. (in press-c). The detection of temporally defined objects does not require focused attention. *Quarterly Journal of Experimental Psychology.*

Remington, R. W., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. *Perception and Psychophysics, 51,* 279-290.

Rensink, R. A. (2002). Change Detection. *Annual Review of Psychology, 53,* 245-277.

Sagi, D., & Julesz, J. (1987). Short-range limitations on detection of feature differences. *Spatial Vision, 2,* 39-49.

Saumier, D., & Arguin, M. (2003). Distinct mechanisms account for the linear non-separability and conjunction effects in visual shape encoding. *Quarterly Journal of Experimental Psychology Section A – Human Experimental Psychology, 56,* 1373-1388.

Scholl, B. J., & Pylyshyn, Z. W. (1999). Tracking multiple items through occlusion: clues to visual objecthood. *Cognitive Psychology, 38,* 259-290.

Sekuler, A. B., & Bennett, P. J. (2001). Generalized common fate: grouping by common luminance changes. *Psychological Science, 12,* 437-444.

Shadlen, M. N., & Movshon, J. A. (1999). Synchrony unbound: A critical evaluation of the temporal binding hypothesis. *Neuron, 24,* 67-77.

Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science, 7,* 301-305.

Singer, W., & Gray, C. M. (1995). Visual feature integration and the temporal correlation hypothesis. *Annual review of neuroscience, 18,* 555-586.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74 (11, Whole No. 498),* 1-29.

Sternberg, S. (1966). High-speed scanning in human memory. *Science, 153(736),* 652-654.

Stone, J., & Fukuda, Y. (1974). Properties of cat retinal ganglion-cells - comparison of w-cells with x-cells and y-cells. *Journal of Neurophysiology, 37,* 722-748.

Tassinari, G., Marzi, C.A., Lee, B.B., Di Lollo, V., & Campara, D. (1999). A possible selective impairment of magnocellular function in compression of the anterior visual pathways. *Experimental Brain Research, 127,* 391-401.

Theeuwes, J. (1991). Cross-Dimensional Perceptual Selectivity. *Perception & Psychophysics, 50(2),* 184-193.

Theeuwes, J. (1991). Exogenous and endogenous control of attention: the effect of visual onsets and offsets. *Perception and Psychophysics, 49,* 83-90.

Theeuwes, J. (1992). Perceptual Selectivity for Color and Form. *Perception & Psychophysics, 51(6), 599*-606.

Theeuwes, J. (1995). Abrupt luminance change pops out; abrupt color change does not. *Perception & Psychophysics, 57,* 637-644.

Theeuwes, J. (2004). No blindness for things that do not change. *Psychological Science, 15(1),* 65-70.

Theeuwes. J. (2004) Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin and Review, 11(1),* 65-70.

Theeuwes, J., Kramer, A. F., Hahn, S., & Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of eyes by new objects. *Psychological Science, 9,* 379-385.

Theeuwes, J., Atchley, P., & Kramer, A. F. (2000). On the time course of top-down and bottom-up control of visual attention. *In S. Monsell & J. Driver (Eds.), Attention and Performance (Vol. 18, pp. 105 - 125).* Cambridge, MA: MIT Press.

Theeuwes, J., Reimann, B., Mortier, K. (2006). Visual search for featural singletons: No top-down modulation, only bottom-up priming. *Visual Cognition, 14,* 466-489.

Tipper, S. P., & Weaver, B. (1998). The medium of attention: Location-based, object-centered, or scene-based? *In R. Wright (Ed.), Visual attention (pp. 77-107).* London: Oxford University Press.

Tipper, S.P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 37A,* 571-590.

Todd, J. T., & van Gelder, P. (1979). Implications of a Transient-Sustained Dichotomy for the measurement of Human Performance. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 625-638.

Todd, S., & Kramer, A. F. (1979). Attentional misguidance in visual search. *Perception and Psychophysics, 56,* 198-210.

Townsend, J. T. (1972). Some results concerning the identifiability of parallel and serial processes. *British Journal of Mathematical and Statistical Psychology, 25,* 168-199.

Treisman, A. M., & Gelade, G. (1980). Feature-Integration Theory of attention. *Cognitive Psychology, 12,* 97-136.

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision - evidence from search asymmetries. *Psychological Review, 95,* 15-48.

Usher, M., & Donnelly, N. (1998). Visual synchrony affects binding and segmentation in perception. *Nature, 394,* 179-182.

Vaina, L. M., Cowey, A., & Kennedy, D. (1999). Perception of first- and second-order motion: Separable neurological mechanisms? *Human brain mapping, 7,* 67-77.

Vaina, L. M., Makris, N., Kennedy, D., & Cowey, A., (1998). The selective impairment of the perception of first-order motion by unilateral cortical brain damage. *Visual Neuroscience, 15,* 333-348.

van Santen, J. P. H., & Sperling, G. (1985). Elaborated Reichardt detectors. *Journal of the Optical Society of America, 2,* 300-321.

van Zoest, W., Donk, M., & Theeuwes, J. (2004). The role of stimulus-driven and goal-driven control in saccadic visual selection. *Journal of Experimental Psychology-Human Perception and Performance, 30(4),* 746-759.

von Mühlenen, A., Rempel, M. I., & Enns, J. T. (2005). Unique temporal change is the key to attentional capture. *Psychological Science, 16(12),* 979-986.

Watson, D. G., & Humphreys, G. W. (1995). Attention Capture by Contour Onsets and Offsets - No Special Role for Onsets. *Perception & Psychophysics, 57(5),* 583-597.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review, 104(1),* 90-122.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt. *Psychologische Forschung, 4,* 301-355.

Wolfe, J. M. (1994). Guided Search 2.0 - a Revised Model of Visual-Search. *Psychonomic Bulletin & Review, 1(2),* 202-238.

Wolfe, J. M. (2001). Asymmetries in visual search: An introduction. *Perception & Psychophysics, 63,* 381–389.

Wolfe, J. M., Friedman-Hill, S. R., Stewart, M. L., & O'Connell, K. M. (1992). The role of categorization in visual search for orientation. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 34-49.

Wolfe , J., M., Butcher, S. J., Lee, C. & Hyle, M. (2003). Changing your mind: on the contributions of top-down and bottom-up guidance in visual search for feature singletons. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 483-502.

Yantis, S. & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 601-621.

Yantis, S. & Johnson, D. N. (1990). Mechanisms of attentional priority. Journal of Experimental Psychology: *Human Perception and Performance, 16,* 812-825.

Yantis, S. & Jonides, J. (1990). Abrupt visual onsets and selective attention - voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 121-134.

Yantis, S. & Jones, E. (1991). Mechanisms of attentional selection - temporally modulated priority tags. *Perception and Psychophysics, 50,* 166-178.

Yantis, S., & Gibson, B. S. (1994). Object continuity in apparent motion and attention. *Canadian Journal of Experimental Psychology, 48,* 182-204.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 95-107.

Yantis, S. (1998) Control of visual attention. *In: Attention, ed. H. Pashler.* Psychology Press/Erlbaum/Taylor & Francis.

Yantis, S., & Egeth, H. E. (1999). On the distinction between visual salience and stimulus-driven attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 661-676.

Yeshurun, Y. (2004). Isoluminant stimuli and red background attenuate the effects of transient spatial attention on temporal resolution. *Vision Research, 44,* 1375-1387.

Yeshurun, Y., & Levy, L. (2003). Transient spatial attention degrades temporal resolution. *Psychological Science, 14,* 225-231.

Zeki, S. M. (1974). Functional organization of a visual area in the posterior bank of the superior temporal sulcus of the rhesus-monkey. *Journal of Physiology, 236,* 549-573.

Zeki, S., Watson, J. D. G., Lueck, C. J., Friston, K. J., Kennard, C., & Frackowiak, R. S. J. (1991). A direct demonstration of functional specialization in human visual cortex. *Journal of Neuroscience, 11,* 641-649.

Zihl, J., von Cramon, D., & Mai, N. (1983). Selective disturbance of movement vision after bilateral brain damage. *Brain, 106,* 313-340.

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