When Are Abrupt Onsets Found Efficiently in Complex Visual Search?: Evidence from Multi-Element Asynchronous Dynamic Search

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Running Title: Luminance Onsets in MAD Search

Abstract

Previous work has found that search principles derived from simple visual search tasks do not necessarily apply to more complex search tasks. Using a Multi-element Asynchronous Dynamic (MAD) visual search task, where high numbers of stimuli could either be moving, stationary and/or changing in luminance, Kunar and Watson (2011) found that, unlike previous work, participants missed a high number of targets with search for moving items worse than for static and no benefit for finding targets that showed a luminance onset. Here we investigate why luminance onsets do not capture attention and whether luminance onsets can ever capture attention in MAD search. Experiment 1 investigated whether blinking stimuli, which abruptly offset for 100 ms before re-onsetting again – conditions known to produce attentional capture in simpler visual search tasks - captured attention in MAD search, while Experiments 2 – 5 investigated whether giving participants advance knowledge and pre-exposure to the blinking cues produced efficient search for blinking targets. Experiments 6 – 9 investigated whether unique luminance onsets, unique motion or unique stationary items captured attention. The results found that luminance onsets only captured attention in MAD search when they were unique, consistent with a top-down unique feature hypothesis.

Introduction

People often have to search the world for a particular item, ranging from looking for a pen on a messy desk to finding a friend in a crowd. Other search tasks have more socio-important functions such as a doctor looking for a tumour in a mammogram or a security guard searching CCTV images for something suspicious. There are many different aspects of search that determine how successful a person is at finding what they are looking for. For example, search difficulty can depend on how many distracting items there are (Treisman & Gelade, 1980, Wolfe, 1998), the distinctiveness of the item to be found (Wolfe & Horowitz, 2004) and the search expectancies of the individual (e.g., Folk et al., 1994, Wolfe et al., 2007, Wolfe, 2007). Scientists can investigate how people perform in these search tasks in the laboratory by asking people to search for a pre-specified target item among competing distractor items (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, Cave & Franzel, 1989). By measuring the reaction time (RT) to find the target and the number of errors made, scientists can build up an accurate representation of how people search the world. In particular, the RT x Set size (number of items in the display) function or *search slope* is used to give a measure of search efficiency, with shallower slopes indicating a more efficient search (Treisman & Gelade, 1980).

Typical laboratory search tasks are run in tightly controlled conditions. With good reason scientists have tended to manipulate only one or two important variable(s) at a given time. From these search tasks we have learned many important points about how the human visual system operates. For example, we have derived a list of features that capture attention in a search task (e.g. abrupt onsets, motion onsets, color etc., see Wolfe & Horowitz, 2004, for a review). However, these highly controlled experimental protocols can also mean that lab based displays may not reflect many of the search complexities encountered in everyday life. Take the example of searching for a friend on a crowded high street. Here you would have to search through a high number of distracting items (e.g., other people, cars, lamp posts, post boxes etc.). Some of these items will be moving (e.g., cars) while others would be stationary (e.g., post boxes). Some of the items may also undergo luminance transients as they pass through shadows or even disappear from view when they become occluded by other objects. Search can become even more complex if we change the example to a security guard searching CCTV footage for ‘something suspicious’ because suspicious behaviour can take a number of different forms. In this situation target uncertainty is introduced because the security guard has no clear target template of what to search for at any given time or even if there is anything suspicious to be found.

In contrast, these important aspects of search are often not reflected in typical laboratory search tasks. For example, in the laboratory people are often told exactly what to look for (e.g. a green vertical bar) among a relatively small number of items (such tasks often have set sizes of less than 20 items, e.g. Chun & Jiang, 1998; Duncan & Humphreys, 1989; Horowitz & Wolfe, 1998; Hubner & Malinowski, 2001; Jonides, 1981; Joseph et al., 1997; Kunar & Humphreys, 2006; Kunar, Humphreys & Smith 2003; Tong & Nakayama, 1999; Treisman & Sato, 1990; Smilek et al., 2006; Von Mühlenen et al., 2003; Watson & Humphreys, 1999; Wolfe & Friedman-Hill, 1992; Wolfe, Klempen & Dahlen, 2000). Furthermore, the distracting items are likely to be uniform in their movement or luminance properties, often with the distracting items all remaining static and unchanging in luminance over time (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980, although, see Pinto et al., 2006 and 2008, for an exception). It is clear that these types of laboratory based search tasks are very different, and much simpler, than many search tasks which are encountered in the real world.

Kunar and Watson (2011) recently investigated how well the search principles found in simpler lab based tasks apply to more dynamic and unpredictable search tasks mimicking more closely those encountered in the real world. In their work they created a Multi-element Asynchronous Dynamic (MAD) search task specifically designed to act as a hybrid between lab based search and real world search. Although MAD search was a lab based task it contained several dynamic and unpredictable elements of real world search. First, within MAD search participants were asked to search for a target within a high number of distracting items (set sizes were higher than previous typical visual search tasks and consisted of 16, 24 and 32 items). Second, heterogeneous motion properties were introduced to some of the stimuli. That is, half of the items remained stationary while the other half moved in random directions at random speeds. Third, heterogeneous luminance properties were introduced to some of the stimuli. Here half of the display items did not change in luminance while the other half gradually changed in luminance so that they offset and re-onset again (i.e. blinked) throughout the experiment. To increase the display complexity, all items blinked asynchronously, had randomly generated offset timings and were out of phase. Lastly, target uncertainty was introduced as from trial to trial the target (i) could be among any of the moving, stationary or blinking items (ii) could be any of five possible letters (the target was a vowel among consonant letters) or (iii) may not even be there (the target was only present 50% of the time).

The MAD search results from Kunar and Watson (2011) were surprising because they were inconsistent with predictions from previous simpler lab based tasks. For example, error rates in MAD search were much higher than in standard visual search tasks. In a typical visual search task, participants miss approximately 5-10% of targets (Wolfe, 1998) while in MAD search participants missed the target on average 30% of the time. If we extrapolate this back to the example of a security guard looking for a ‘target’ of suspicious behaviour the miss rate of 30% is alarmingly high. Furthermore other search efficiency principles did not apply in this type of task. Previous work found that moving items were either found more efficiently than static items (Abrams & Christ, 2003, 2005; Franconeri & Simons, 2003; 2005, McLeod et al., 1988; 1991; Royden et al., 2001) or that adding motion to the search stimuli did little to affect search slopes (Hulleman, 2009). However, within the more complex MAD task it was instead found that search slopes to find moving targets were *worse* than those to find static targets.

Kunar and Watson (2011) concluded that with high set sizes, due to the complexity of the display, participants used an inhibitory strategy to tag the locations of the static items preventing them from being searched again (see also Kristjansson, 2000). This led to a reduction in search slopes. However, as the moving items were constantly changing their positions, their locations could not be inhibited and so they might be searched more than once (especially as our ability to track multiple moving items is limited, e.g. Pylyshyn, 2001; Pylyshyn & Storm, 1988). Of note, the use of memory (i.e. inhibitory tagging) for static items only occurred when set sizes were high. At the lower set sizes, participants appeared to search both static items and moving items from vision, perhaps as vision is thought to be the default search strategy and is more efficient than search from memory (Kunar et al., 2008a, see also Oliva et al., 2004, Wolfe et al., 2000 and Horowitz & Wolfe, 1998). This led overall to equivalent search slopes for both moving and stationary items (Kunar & Watson, 2011).

Moreover and of particular relevance to the present paper, Kunar and Watson (2011) found that when using MAD displays there was no benefit of having the target change in luminance. This contrasts with previous work which found that items appearing with a luminance onset captured attention (Christ & Abrams, 2006; Schreij, Owens, & Theeuwes, 2008; Theeuwes, 1994; Yantis & Jonides, 1984; 1996; but see also Martin-Emerson & Kramer, 1997, Miller, 1989 and Watson & Humphreys, 1995). However in MAD search there was no benefit of having the target blink (i.e., the search efficiency to find a blinking target was no different to that of finding non-blinking targets). If luminance onsets produce efficient search in simpler visual search tasks, why do they not produce efficient search in a more complex search? We investigate this here by examining whether targets showing a luminance onset can ever capture attention in MAD search. We approach this question from three different angles: first by having the blinking stimuli appear under abrupt (rather than gradual) onset conditions which are known to strongly capture attention (e.g., Yantis & Jonides, 1984; Yantis & Gibson, 1994), second, by giving participants more time and increased top-down knowledge in MAD search, and third by creating conditions in which the blinking item is unique in the field.

Taking the first approach, one reason why blinking targets did not capture attention in MAD search might have been that the luminance changes were gradual and not abrupt. Kunar and Watson (2011) used gradual, asynchronous onsets to mimic the luminance changes occurring in real world search (e.g., items are most likely to gradually disappear and reappear from view in the real world rather than suddenly appear/disappear with an abrupt change). However, Yantis and Gibson (1994) found that for an item to capture attention it needed to offset for 100 ms before abruptly re-appearing. It is possible that the gradual changes used by Kunar and Watson (2011) were simply not abrupt enough to drive the type of attentional capture seen in previous work. We tested this possibility in Experiment 1 by having items blink off for 100 ms, in synchrony, before reappearing again with an abrupt onset for 300 ms. To preview the results, even with these optimal onset capture conditions, search for blinking targets was no more efficient than search for non-blinking targets.

A second reason why blinking items did not capture attention in MAD search might be that more time was needed to process the display due to its complexity. Recent research has suggested that, in some situations, attentional guidance needs time to develop (e.g. Kunar et al., 2008b; Wolfe et al., 2009). Knowing this, if participants were given more time to process the blinking items they might be able to guide their attention to them more efficiently. We investigated this in Experiments 2 to 5, in which we gave participants pre-exposure to the dynamic properties of the stimuli (e.g. whether they were moving or blinking etc.) using a placeholder technique prior to the search items appearing. Furthermore, in Experiments 3, 4 and 5 we also increased the participants' top-down knowledge by giving explicit instruction of what to search for in each block of trials. Previous work has shown that, in simpler search tasks, if people were told in advance what to look for they can restrict their search to the relevant subset of items (e.g. if told to look for a green target, participants will restrict their search only to green stimuli in a display, e.g. Egeth, Virzi, & Garbart, 1984). Does this form of top-down guidance also work in MAD search? The results found that although this extra time and top-down knowledge improved search for a moving target (so that search slopes were no longer worse than static targets) there was still no search benefit for finding blinking items.

Finally, we examined whether abrupt onsets were able to capture attention in MAD search if they were unique (Experiments 6-9). Von Muhlenen et al., (2005) proposed a *unique event* *hypothesis* that suggests in order for a feature change to capture attention it needs to be presented in temporal isolation. They further suggested that attentional capture was strongest when the unique event occurred in an otherwise static background (Von Muhlenen et al, 2005). We investigated this here by asking whether unique events capture attention in MAD search when the surrounding background was never entirely static (i.e. some distractor items were always changing – either in motion or in luminance). Within these studies, we also explored exactly what properties need to be unique to capture attention. There are four possible hypotheses. The first suggests that unique items (e.g. unique luminance onsets, unique motion etc.) will not capture attention in MAD search. We call this the *no capture hypothesis*. This would be in line with previous studies which showed that search principles obtained in simple visual search tasks do not necessarily apply to more complex MAD conditions (Kunar & Watson, 2011).

The second hypothesis suggests that for an item to capture attention it has to be uniquely represented in the magnocellular pathway. We call this the *unique magnocellular hypothesis*. The magnocellular pathway is known to respond to dynamic properties of stimuli meaning that both luminance changes and motion signals cause activation of these neurons (e.g. Breitmeyer & Ganz, 1976, Chapman et al., 2004, Green, 1981, Livingstone & Hubel, 1988). Furthermore, the visual system is sometimes known to treat both blinking and moving items similarly as adaptation to motion leads to a deficit in the processing of blinking items (and vice versa, e.g. Chapman et al., 2004, see also Green, 1981). Given this difficulty in differentiating between moving and blinking properties, if a target has to be uniquely represented in the magnocellular pathway, to capture attention, we would not expect attentional capture of a blinking item in MAD search if the display also contained moving items (or vice versa). To clarify, this hypothesis predicts that stimuli represented in the magnocellular pathway (e.g. moving and/or blinking stimuli) can capture attention over stationary stimuli (e.g. McLeod, Driver & Crisp, 1988, Royden, Wolfe & Klempen, 2001), however a moving and/or blinking target cannot be selectively boosted to capture attention in the presence of other moving and/or blinking stimuli (see Pinto et al., 2008, for a similar argument).

The final two hypotheses are based on the extent to which the target is a unique item within the scene. The *unique item hypothesis* proposes that any unique item will be processed efficiently whether or not it contains a salient visual feature. Importantly, the item simply has to be unique in some respect, such as being the only stationary item in the field. This hypothesis seems plausible in light of work by Pinto et al. (2006) who found that a static item can be efficiently searched for if it was unique in the field of homogenously blinking items. We test if this is also the case in MAD search in which the distractors are heterogeneous, with some distractors moving and some distractors blinking.

In contrast, the *unique feature hypothesis*, suggests that for an item to capture attention it needs to fulfil two criteria: first it needs to be unique in some respect and second the uniqueness of the item has to be signalled by the possession of a salient visual feature (e.g. a unique abrupt onset, a unique moving item). Wolfe and Horowitz (2004) put forward several ways to define whether an item possesses a salient feature which can be used to guide attention. One way is to measure the cost of adding additional distractors to a search task with the premise that if a target possesses a guiding feature it would be found efficiently (with search slopes for the target nearing 0 ms/item, and less than 10 ms/item, Wolfe & Horowitz, 2004, see also Treisman & Gelade, 1980). Furthermore, search asymmetries can also be used to identify if some property of an item acts as a feature, with the idea that the presence of a feature can be found more efficiently than its absence (Treisman & Souther, 1985, Wolfe, 2001, Royden et al, 2001, Wolfe & Horowitz, 2004). In terms of motion, Royden, Wolfe and Klempen, (2001) found that a moving target among stationary items produced highly efficient search slopes, (around 0 ms/item, see also McLeod, Driver & Crisp, 1988), however the asymmetrical case of finding a stationary target among moving distractors did not produce efficient search (search slopes were much higher than 0 ms/item, Royden et al., 2001). This suggests that motion acts as a feature but the absence of motion (e.g. a stationary target) does not. A similar case can be made for luminance onsets (e.g. a luminance onset among stationary distractors produces search slopes of approximately 0 ms/item, e.g. Yantis & Jonides, 1984, whereas a stationary target among blinking distractors produces search slopes greater than 10 ms/item, e.g., Pinto et al., 2006). Based on this, according to the unique feature hypothesis, a unique abrupt onset or a unique moving item (being classified as features) would capture attention in MAD search but a unique static item (being classified as the absence of a feature) would not.

Experiments 6 to 8 tested these hypotheses. Experiment 6 contained an item that had a unique abrupt onset within a MAD display, Experiment 7 contained an item that had a unique moving item within a MAD display and Experiment 8 contained a unique static item within a MAD display. The results showed that within this more complex and dynamic search task both a unique blinking item and a unique moving item captured attention. However, in contrast to Pinto et al. (2006) a unique static item did not capture attention. The results favoured the unique feature hypothesis.

Lastly, Experiment 9 investigated whether a unique feature captured attention, in MAD search, via automatic bottom-up processes. Experiment 6 showed that when the target was a unique blinking item it captured attention leading to efficient search. However in this experiment, the unique blinking item was also the target item on one third of trials. It may be that with these proportions, participants formed a top-down intentional strategy to search the blinking item first, with the likelihood that it would also be the target on a large percentage of trials. Experiment 9 investigated whether unique blinking items captured attention in MAD search when, instead, the target was *equally* likely to be the blinking stimulus or any one of the other non-blinking stimuli. Yantis and Jonides (1984) used this technique to show that attentional capture of abrupt onsets was automatic in more simplistic search tasks. As the target was only the abrupt onset on a small subset of trials ($1/n$ trials where n equals the set size) participants were unlikely to form a top-down attentional set to prioritise search for the onset stimulus. Despite this, Yantis and Jonides (1984) found that abrupt onsets were prioritized for attentional processing over no-onset stimuli, suggesting that onset capture was a bottom-up process. We investigated whether the same effect would be found using complex MAD displays. In Experiment 9, using set sizes of 5 and 9, we investigated whether a unique blinking item would still capture attention when it was the target item on only $1/5^{th}$ or $1/9^{th}$ of displays, respectively. The results showed that under these more complex and dynamic conditions, when the blinking stimulus was equally likely to be a target or distractor, it no longer captured attention. This suggests that any attentional capture of unique blinking stimuli in MAD search was a result of intentional goal-directed mechanisms, rather than bottom-up processes.

Experiment 1

Method

Participants:

Twenty-two participants (5 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 20 years (M = 18.8 years, SD = 0.8 years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

Displays were generated and responses recorded by custom written computer programs running on a PC attached to a Sony 19" CRT monitor running at 75Hz. Stimuli were letters of the alphabet and were white presented on a black background (see Figure 1). Participants were instructed to search for a target vowel (A, E, I, O or U) among distractor consonants and to respond whether the target was present or absent by pressing 'm' or 'z', respectively (please note, the letter 'W' was not included in the display as it's dimensions were wider than the other consonants). Fifty percent of trials contained a target (on any given trial only one target was presented), on the remaining trials there was no target. When present, the target was equally likely to be any one of the five vowels. Set sizes of 16, 24 or 32 items were used and participants were given a short practice session before the experiment proper.

Figure 1 and Table 1 about here

Half the stimuli were stationary and remained in the same locations throughout the trial. The rest of the stimuli were moving and could move in any direction and each item's speed was randomly generated from a range of 1.9 to 3.3 degrees/second (from a viewing distance of 57 cm). Moving stimuli passed transparently over each other and bounced off the sides of an invisible rectangle of size 14.5 degrees by 14.5 degrees. Half of the moving stimuli and half of the static stimuli also changed in luminance to offset and re-onset on the screen ('blinking items'). The blinking items continually offset in synchrony for 100 ms and then abruptly re-onset for 300 ms. Items remained blinking until participants made a response. The target was equally likely to be in the stationary, stationary-blinking, moving or moving-blinking set. For each experiment there were 480 trials per participant. Participants were instructed to respond as quickly but as accurately as possible. Error rates and RTs were recorded. No feedback was given for either correct or incorrect responses to mimic many real world conditions (e.g., security guards are not likely to receive immediate feedback if they miss a target during real-time surveillance tasks). A summary of the experimental conditions can be found in Table 1.

Results and Discussion

One participant's data was removed from analysis due to high error rates (above 90% on target absent trials). Data from the remaining twenty-one participants were analysed. Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials, for all experiments, are shown in Table 2. Looking at the RT data, unsurprisingly and consistent with previous research, there was a main effect of target presence (e.g. Chun & Wolfe, 1996; Treisman 1988; Wolfe, 1998). RTs for target present trials were faster than those for target absent trials, $F(1,20) = 78.5$, $p < 0.01$, overall RTs increased with set size, $F(2, 40) = 98.0$, $p < 0.01$, and RTs increased more for target absent trials across set size than for target present trials, $F(2, 40) = 52.9$, $p < 0.01$. As this pattern of data was similar for all the following experiments, and are not important to the questions in hand, in subsequent sections we do not report them further. Our primary interest was to examine whether abrupt onsets in MAD search captured attention. To investigate this, both here and in the ensuing experiments, we separated the target present trials into whether the target was moving or stationary and whether it was blinking or non-blinking[1]. Figure 2a shows mean RTs for target present trials across set size and Figure 2b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of motion type (static vs moving), blinking (blinking vs non-blinking) and set size. RTs to detect static targets were faster than RTs to detect moving targets, $F(1,20) = 38.1$, $p < 0.01$, RTs to detect non-blinking targets were faster than RTs to detect blinking targets, $F(1, 20) = 21.6$, $p < 0.01$ and RTs increased with set size, $F(2, 40) = 52.2$, $p < 0.01$. The Motion type x Set size interaction was significant, $F(2, 40) = 4.9$, $p < 0.05$. RTs increased more across set size when the target was moving compared with when it was static. No other interaction was significant (all Fs < 1, ps > 0.5).

Table 2 and Figures 2 and 3 about here

Similar to other MAD experiments, miss errors were higher than those reported in previous traditional lab search tasks (see Figure 3). In typical lab search experiments participants tend to make miss errors of less than 5% (Wolfe, 1998). In this more complex display participants were missing on average 26% of moving targets, and 22% of static targets. Miss errors were greater for moving stimuli than for static stimuli, $F(1,20) = 11.2$, $p < 0.01$ and there was a main effect of set size, $F(2, 40) = 27.0$, $p < 0.01$, with participants making more miss errors as set size increased. There was no main effect of having the target blink, $F < 1$. Neither were any of the interactions significant (all Fs < 1.3, ps > 0.2). There were very few false alarms (2.4%).

[1] The target absent trials could not be separated into such categorical groups as by definition they had no target.

The results of Experiment 1 are interesting in several ways. First, having the target item appear within the blinking, abrupt onset group did not lead to a benefit in search. This was true even though the blinking items offset for 100 ms before re-onsetting again. As these timings were known to produce effective attentional onset capture in previous studies (e.g., Yantis & Gibson, 1994) then if abrupt onsets could capture attention in MAD search we would expect to see a search benefit here. However, the results showed that having items offset and re-onset abruptly was not enough to cause attentional capture in MAD displays. Please note that Yantis and Johnson (1990, see also and Yantis & Jones, 1991) proposed that there was a limit to the number of abrupt onsets that could capture attention. In their research they found that four items showing abrupt onsets received high processing priority after which all the other stimuli on the screen began to be processed (although see Donk & Theeuwes, 2001, and Donk & Theeuwes, 2003, who suggest that up to 14 abrupt onsets can be prioritized at once). Watson and Kunar (2012) also found a limit on the number of abrupt onsets that could be prioritized. In a manual tagging task, where participants were asked to distinguish between new onsets and previously presented stimuli using both mouse and touch screen responses, they found that participants were able to prioritize up to six or seven items. If there is a limit to the number of abrupt onsets that can be prioritized in search then we may not expect to witness a perfect reduction in search slopes to find blinking items here. Nevertheless, if participants could efficiently group and search even a subset of the blinking items we would still expect a reduction in the search slopes of onset stimuli as the effective set size of this group would be reduced (with the efficient prioritization of up to at least seven items, Watson & Kunar, 2012). However, despite this no such reduction was observed, again suggesting that abrupt onsets do not capture attention in MAD search.

Second, the data have implications for the use of motion cues to help benefit search. The results show that although search was no more efficient when the target was blinking compared to when it was not blinking, search to find a moving target was less efficient than search to find a static target (replicating the results of Kunar & Watson, 2011). Contrary to findings from simpler search tasks, having an item move does not provide a search benefit in these more dynamic environments (Franconeri & Simons, 2003; 2005; Hillstrom & Yantis, 1994; McLeod et al., 1988; Yantis & Egeth, 1999, although see Abrams & Christ, 2003, who suggest that it is the onset of motion that captures attention, rather than motion cues, per se and Hillstrom & Yantis, 1994, and Yantis & Egeth, 1999, who suggest that attentional capture of moving items depends on search conditions). Neither does it leave the search slopes unaffected (Hulleman, 2009) – search for a moving target was worse than search for a static one. One could argue that search for a moving item was worse than search for a static item because perceptually a moving target may be more difficult to read than a static target. Although possible we do not think this to be the case. Kunar and Watson (2011) showed that when smaller set sizes were used search rates for moving targets were equivalent to those for static targets. If moving targets were harder to perceive then we would still expect search rates for moving items to be less efficient here. However, this did not occur[2]. Instead the data are consistent with Kunar and Watson (2011) suggesting that, given the difficulty and complexity of MAD search at higher set sizes, participants used a mixture of memory and visual search strategies allowing them to inhibit the locations of static items so that they are not re-searched, (leading to relatively efficient search slopes), but not the moving items, whose positions constantly changed (Kunar & Watson, 2011, see also Kristjansson, 2000).

[2] See also Experiment 7, where the results show that search for a moving target can be efficient. If moving items were difficult to identify this should not have occurred.

Pratt et al. (2010) also investigated whether motion captured attention in a display that, similar to MAD search, had multiple moving objects. In their experiments they manipulated the motion of the stimuli so that some of the stimuli appeared animate (they changed direction and/or speed unpredictably, consistent with them having an ‘internal’ power source which made the items appear animate) and some of the stimuli appeared inanimate (they too changed their speed and direction but only after a visible collision with another object). In a series of experiments Pratt et al. (2010) found that participants were faster to respond to animate objects compared to inanimate objects and suggested that items which move in an animate way capture our attention, even when there are multiple moving objects on the screen. Although our results may, initially, appear inconsistent with this finding (as we did not find any attentional capture for moving items) we argue that they are not so dissimilar. First, moving stimuli in our displays all exhibited ‘inanimate motion’ and did not change speed or direction as a result of apparent internal factors. In fact, Pratt et al. (2010) found that there was no attentional capture of inanimate moving cues. Second, in the experiments of Pratt et al. (2010), although all items were moving there was only one item that showed a unique motion change. In contrast, in MAD search there were multiple moving stimuli, all showing similar motion cues. It may be that if the moving item was unique in MAD search it would be able to capture attention. We investigated this further in Experiment 7.

Lastly, results from the miss error rates also replicated the original MAD data where a high percentage of targets went undetected. Similar to the pattern of RT data more moving targets were missed than static targets but there was no difference in error rates between blinking and non-blinking stimuli. The high error rates, concur with the original MAD results of Kunar and Watson (2011) suggesting that previous lab work has greatly overestimated people’s realistic search capability.

The data from Experiment 1 showed that having the target appear with an abrupt onset in MAD search did not lead to an increase in search efficiency. By design MAD search is more complex than other typical laboratory experiments. Given its complexity perhaps the visual system takes longer to parse the display than in simpler search tasks. Recent research has shown that the strength of the guidance signal can increase with time and pre-exposure to the display (Kunar et al., 2008b, Wolfe et al., 2009). If this is the case then giving people more time with the MAD display would lead to an increase in guidance signal, allowing participants to use guidance cues more effectively. We investigate this in Experiment 2. Here we give participants pre-exposure to the motion and/or blinking cues of each upcoming stimulus prior to the search task appearing. In this experiment participants were shown circular placeholders that had the same moving and blinking characteristics as each respective stimulus. After some time, letter stimuli were added to the centre of the placeholders. Importantly, the letter stimuli possessed the same blink/motion properties as the placeholders. If more time is needed for attentional guidance to become fully activated in MAD search we should witness a search benefit for blinking items here when the guidance system has been given sufficient time to prioritize abrupt luminance changes.

Experiment 2

Method

Participants:

Sixteen participants (2 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 20 years (M = 19.0 years, SD = 0.6 years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to that of Experiment 1 except that all the search stimuli were surrounded by an outline of a white circle (of diameter 1.6 deg). These circles acted as placeholders and were used to give advance knowledge of the motion and blinking properties of each stimulus. Each placeholder was presented 2000 ms before the search stimuli appeared and had the same blinking/moving characteristic as the search stimulus. For example, if the search stimulus was to move and blink, the placeholder would also move and blink at the same velocity/frequency as the search stimulus. After the placeholders had been presented for 2000 ms, the search stimuli were presented within the placeholders[3]. Both the placeholders and stimuli were present and displayed their motion/blinking characteristics until the end of the trial. A summary of the experimental conditions can be found in Table 1.

Results and Discussion

Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 2. Figure 4a shows mean RTs for target present trials across set size and Figure 4b shows the search slopes. RTs for target present correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of motion type (static or moving), blinking (blinking or non-blinking) and set size. RTs to detect static targets were faster than RTs to detect

[3] Please note in these experiments, for blinking items, both the placeholder and the stimuli within them showed abrupt luminance onsets.

moving targets, $F(1,15) = 20.1$, $p < 0.01$ and RTs increased with set size, $F(2, 30) = 58.1$, $p < 0.01$. There was a marginally significant effect of blinking with a trend for RTs for non-blinking targets to be faster than RTs for blinking targets, $F(1, 15) = 4.0$, $p = 0.064$. The Blinking x Set size interaction was marginally significant, $F(2, 30) = 3.3$, $p = 0.051$, RTs increased more across set size when the target was blinking compared with when it was non-blinking. None of the other interactions were significant (all $Fs < 1.6$, $ps > 0.2$).

Figures 4 and 5 about here

Again miss errors were higher than in most traditional lab search tasks (see Figure 5). There were very few false alarms (2.2%). Overall, miss errors were greater for moving stimuli (24%) than for static stimuli (18%), $F(1,15) = 12.3$, $p < 0.01$, and miss errors increased with set size, $F(2, 30) = 19.2$, $p < 0.01$. There was no main effect of having the target blink, $F < 1$. Neither were any of the interactions significant (all $Fs < 1.4$, $ps > 0.2$). The high error rates replicate previous findings from MAD experiments to suggest that previous lab work has greatly overestimated people’s realistic search capability.

The results of Experiment 2 showed that giving participants a preview of the blinking and motion types of the stimuli did not help blinking targets to capture or guide attention– in fact, if anything, participants were slightly worse at finding the target when it was blinking. Clearly advance exposure to the blinking and motion types of each stimulus alone did not enable guidance to use luminance cues to find the target.

Interestingly, however, giving participants advance time with the motion/blinking type of the stimuli did eradicate the difference in search slopes between the moving and static targets. Previous work using MAD search found that search for moving targets was less efficient than search for static targets (Kunar & Watson, 2011, see also Experiment 1 here). However giving people advance time and pre-exposure to the stimuli motion/blinking types removed this difference so that search for a moving target was now as efficient as search for a static one. We examine this further in the General Discussion. Again, similar to previous studies using MAD search, miss errors were high.

Experiment 2 showed that giving participants extra time so that guidance to the set of blinking items could be potentially increased did not lead to efficient search for blinking targets. In these more dynamic displays search for items that showed an abrupt luminance onset was no more efficient than those that did not. Note that in the experiments so far there was no rationale for participants to adopt any particular top-down set for any of the groups of stimuli – the target was equally likely to be stationary, blinking, moving or moving and blinking. Thus any difference in target detection would most likely have been driven by bottom up signals alone. However, one could argue that due to the complexity of MAD search the bottom up signals that normally drive automatic attentional capture (such as abrupt onsets) are simply not strong enough to be effective. In Experiments 3 to 5 we consider whether introducing top-down guidance can enhance the detection of abrupt onsets within these more complex displays. This was achieved by giving participants advance knowledge of the target's motion/blinking status *and* pre-exposure to the display. In these experiments the target status (in terms of blinking and moving type) was blocked so in each block participants knew what to look for. If luminance onsets can be prioritized in MAD displays (given specific top-down knowledge) we would expect to see an increase in search efficiency when people were told to look for a blinking item and given pre-exposure to the blinking characteristics of the stimuli.

Experiment 3 replicates and extends work from Kunar and Watson (2011) who investigated the effect of top-down knowledge on search efficiency using displays where the blinking stimuli onset gradually and asynchronously (mimicking the complexity of onsets in the real world). In their experiment, Kunar and Watson (2011) presented the blinking/moving characteristics of target type across separate blocks and gave participants top-down knowledge of what to look for (e.g. in this block of trials the target will always be static and blinking). Despite this, the results showed that giving people top-down knowledge of what to look for in each block of trials did not affect the overall pattern of MAD search: search for a moving target was less efficient than search for a static one and there was no benefit of having the target blink. Experiment 3 extends this work by asking whether participants can prioritize these more realistic gradual and asynchronous onsets when they are given top-down knowledge and time with the motion/blinking characteristics of the stimuli. Given the complexity of MAD search it may be that participants need more time with the display before they can implement top-down guidance in these realistic displays. However, to preview the results the data suggest that even with top-down guidance and pre-exposure to the display there was no search benefit for blinking targets in MAD search.

Experiment 3

Method

Participants:

Sixteen participants (4 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 22 (M = 19.2 years, SD = 1.1 years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to those of Experiment 2 except that the luminance changes of the blinking items were gradual and asynchronous (following the more realistic onsets used by Kunar & Watson, 2011). Across the trial the blinking items changed from a luminance value of 38.2 cd/m^2 to 0.0 cd/m^2 and back again, so that when the stimuli re-appeared they showed a full (but gradual) luminance onset. Items that changed in luminance all smoothly faded in and out, with a random transition time ranging from one luminance cycle of 1 second to 3 seconds. Luminance values were manipulated by varying the alpha (transparency) level between the values of 1 and 0 at a rate between 0.0263 units per display retrace for 1s oscillations to 0.0088 units per retrace for 3s oscillations. Stimuli with alpha values of less than 0.075 were not visible on the screen. Thus, a blinking stimulus was invisible for anywhere between a minimum of approximately 80 ms (6 screen retraces), corresponding to the oscillating frequency of 1 second, to a maximum of 240 ms (18 retraces) corresponding to the oscillating frequency of 3 seconds. Placeholders displaying the motion/blinking characteristics of the upcoming search stimuli appeared 1000 ms before the search stimuli[4], to give people advance exposure to the motion and stimulus type. Furthermore, each of the conditions were blocked so that in each block participants would know what motion and blinking subset the target would fall in (e.g. in one block the target would always appear in the static items and not be blinking, in another the target would be static and blinking, in another the target would be moving and not blinking and in another

[4] Please note that although this is a shorter time than Experiment 2, 1000 ms still gives participants time to guide their attention to relevant sets (e.g. see Kunar et al., 2008b, who found a benefit in guidance after only 800 ms pre-exposure to the display context).

condition the target would be moving and blinking). In each block there were 120 trials of which fifty percent contained a target. As in Experiment 1 there were three set sizes of 16, 24 and 32 items. The order of the blocks was randomized. A summary of the experimental conditions can be found in Table 1.

Results and Discussion

Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 2. Figure 6a shows mean RTs for target present trials across set size and Figure 6b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of motion type (static or moving), blinking (blinking or non-blinking) and set size. RTs to detect static targets were faster than RTs to detect moving targets, $F(1,15) = 24.3$, $p < 0.01$ and RTs increased with set size, $F(2, 30) = 39.2$, $p < 0.01$. RTs to detect non-blinking targets were faster than RTs for blinking targets, $F(1, 15) = 33.7$, $p < 0.01$. The Blinking x Set size interaction was also significant, $F(2, 30) = 3.7$, $p < 0.05$ with RTs increasing more with increasing set size when the target was blinking compared with when it was non-blinking. None of the other interactions were significant (all $Fs < 1$, $ps > 0.5$).

Figures 6 and 7 about here

Again miss errors were higher than in most traditional lab search tasks (see Figure 7). There were very few false alarms (1.8%). Overall, miss errors were greater for blinking stimuli (25%) than for non-blinking stimuli (15%), $F(1, 15) = 0.5$, $p < 0.01$, and errors increased with set size, $F(2, 30) = 11.5$, $p < 0.01$. There was no main effect of motion type, $F(1, 15) = 3.0$, $p = 0.1$. Neither were any of the interactions significant (all $Fs < 1.6$, $ps > 0.2$). The high error rates replicate previous findings from MAD experiments to suggest that previous lab work has greatly overestimated people's realistic search capability.

The results showed that even when given advance knowledge of the target's blinking and/or motion status and pre-exposure to the characteristics of the stimuli, participants did not show a search benefit for blinking items. In fact, in this experiment, search for blinking items was less efficient than search for non-blinking stimuli. Interestingly, Kunar and Watson (2011) found that when participants were solely given advance knowledge of a target's motion/blinking characteristics, in the absence of extra time, there was no advantage of having the target blink. This extends the work further to show that even with more time, top-down knowledge does not provide blinking items with an attentional advantage.

There do seem to be some benefits of top-down knowledge, however. Giving participants advance knowledge and pre-exposure to the stimuli removed the search cost for moving targets (see also Experiment 2). In contrast to the work of Kunar and Watson (2011, see also Experiment 1 here) search for moving targets was no different to search for static targets. The difference between the original MAD results and those reported here is most likely because participants were given extra time with the display. In one of their experiments Kunar and Watson (2011) gave people advance knowledge of the target type by blocking the target status, without giving extra time. In this case, search for moving items was worse than search for static items, suggesting that it is the extra time with the display that reduced the search slopes for the moving items.

As mentioned earlier search for blinking targets was less efficient than search for non-blinking items, in this experiment. One of the reasons this may have occurred was that the blinking items were offsetting asynchronously. Although these asynchronous offsets and onsets were used to mimic the complexity and heterogeneity of items disappearing and re-appearing in real-world search (see also Kunar & Watson, 2011), the asynchronous blinking might have also been harder to group and so search within that set may have been compromised. In addition, the items gradually changed luminance rather than abruptly on/offsetting (again to resemble aspects of search in the real world). It is possible that top-down knowledge can only boost the detection of abrupt onsets (perhaps in combination with bottom up capture) and not gradual changes. We investigate this further in Experiments 4 and 5, in which we repeated Experiment 3 but changed the blinking items to offset and re-onset synchronously and abruptly, similar to the luminance changes of Experiments 1 and 2 here. Given the complexity of these search displays, in Experiment 4, in order to maximise the time for participants to use top-down strategies, we also lengthened the pre-exposure time to 2000 ms (similar to that of Experiment 2) and 4000 ms in Experiment 5. Again, if people can prioritize abrupt onsets in MAD search we would expect to see a benefit in search efficiency here.

Experiment 4

Method

Participants:

Sixteen participants (7 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 19 to 56 ($M = 24.1$ years, $SD = 9.3$ years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to those of Experiment 2 except that conditions were blocked and participants knew which motion and blinking type the target would have in each block. Thus, similar to Experiment 3 participants had advance knowledge *and* pre-exposure to the target's motion/blinking characteristics. A summary of the experimental conditions can be found in Table 1.

Results and Discussion

One participant's data was removed from analysis due to high error rates (above 88% on target present trials). Data from the remaining fifteen participants were entered into analysis. Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 2. Figure 8a shows mean RTs for target present trials across set size and Figure 8b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of motion type (static or moving), blinking (blinking or non-blinking) and set size. RTs to detect static targets were faster than RTs to detect moving targets, $F(1,14) = 31.2$, $p < 0.01$ and RTs increased with set size, $F(2, 28) = 72.3$, $p < 0.01$. RTs to detect non-blinking targets were faster than RTs for blinking targets, $F(1, 14) = 7.7$, $p < 0.05$. None of the interactions were significant (all $Fs < 2.5$, $ps > 0.1$).

Figures 8 and 9 about here

Again miss errors were higher than in most traditional lab search tasks (see Figure 9). There were very few false alarms (0.9%). Overall, miss errors were greater for moving targets (18%) than for static targets (14%), $F(1, 14) = 5.7$, $p < 0.05$. Miss errors increased with set size, $F(2, 28) = 11.7$, $p < 0.01$, and were marginally greater for non-blinking targets (17%) than for blinking targets (15%), $F(1,14) = 4.5$, $p = 0.051$. There was a marginally significant Motion type x Set size interaction, $F(2,28) = 3.3$, $p = 0.053$, where there was a greater difference in miss errors between moving and static targets at set size 32 than at set sizes 16 and 24. None of the other interactions were significant (all $Fs < 2.5$, $ps > 0.1$). The high error rates replicate previous findings from MAD experiments.

The results are similar to those of Experiment 3. Even with advance knowledge of the target properties and pre-exposure to the motion and blinking of each stimulus, search for a blinking target was no more efficient than search for a non-blinking target. Interestingly, however, unlike that of Experiment 3, search for a blinking item was not worse than that for a non-blinking item. The main difference between the two experiments was the offsetting behaviour of the blinking items. As in this experiment, all the items offset and re-onset in synchrony, they could be more easily grouped (see also Pashler, 2001), which would mean that participants were better able to guide their attention within this set. However, note that even with the combination of bottom-up activation from abrupt onsets and top-down activation the blinking group could not be prioritized over the non-abruptly changing items.

Experiment 4 found that giving participants top-down, advance knowledge of the blinking/motion characteristics of the display did not enable people to guide their search to the blinking items. Here, people were given pre-exposure to the placeholders for 2000 ms, which should be more than enough time for guidance to accumulate (e.g. Kunar et al., 2008b). However, given the complexity of MAD search it might be that even more time is needed for participants to use guidance strategies. To investigate this we doubled the placeholder presentation to 4000ms in Experiment 5.

Experiment 5

Method

Participants:

Twenty participants (1 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 44 (M = 21.0 years, SD = 7.9 years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to those of Experiment 4 except that each placeholder was presented for 4000 ms before the search stimuli appeared. The placeholders had the same blinking/moving characteristics of the search stimuli. Due to the increase in placeholder exposure time only two set sizes were used (set sizes 24 and 32) so that the duration of the experiment was similar to that of Experiment 4. A summary of the experimental conditions can be found in Table 1.

Results and Discussion

Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 2. Figure 10a shows mean RTs for target present trials across set size and Figure 10b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of motion type (static or moving), blinking (blinking or non-blinking) and set size. RTs to detect static targets were faster than RTs to detect moving targets, $F(1,19) = 34.2$, $p < 0.01$ and RTs increased with set size, $F(1, 19) = 52.6$, $p < 0.01$. There was no main effect of having the target blink, $F < 1$. None of the interactions were significant (all $Fs < 2.9$, $ps > 0.1$).

Figures 10 and 11 about here

Again miss errors were higher than in most traditional lab search tasks (see Figure 11). There were very few false alarms (1.2%). Overall, miss errors were greater for moving targets (19%) than for static targets (14%), $F(1, 19) = 4.9$, $p < 0.05$, and miss errors increased with set size, $F(1, 19) = 14.1$, $p < 0.01$. There was no main effect of having the target blink, $F < 1$. None of the interactions were significant (all $Fs < 2.0$, $ps > 0.1$). The high error rates replicate previous findings from MAD search experiments.

The results were similar to those of Experiment 4. Even with advance knowledge of the target properties and an increased pre-exposure to the motion/blinking characteristics of each stimulus (4000 ms), search for a blinking target was no more efficient than search for a non-blinking target. Taken together, the main findings from Experiments 2 to 5 suggest that in these more complex displays participants are unable to prioritize abrupt (or gradual) onsets in search. Why might this be the case? One possibility relates to the repeating and continuous nature of the changes. In previous experiments that have shown an attentional advantage for single (Yantis & Jonides, 1984) or multiple abrupt onsets (Yantis & Johnson, 1990; Yantis & Jones, 1991) the abrupt onset(s) only appeared once per trial. In the present work the items were continuously changing so that the stimuli would offset and re-onset throughout the trial until the participants made a response. It is possible that such continuous changes are less effective than a single change, especially in the complex type of task presented here. We return to this in the General Discussion.

Related to this possibility, Von Muhlenen et al. (2005) proposed that color and motion changes will only capture attention when they are presented in temporal isolation. Furthermore, there is also an added search advantage for abrupt onsets, which are known to capture attention already, if they are unique to the display. Von Muhlenen et al. (2005) proposed a unique event hypothesis where a unique change to an item will capture attention, particularly if the rest of the display was unchanging. It follows that a unique onset presented within a MAD display context might capture attention effectively. We investigate this possibility in Experiments 6 to 8 where we present unique events in MAD search, in which the background distractors are largely changing and in constant flux. In Experiment 6, we present a uniquely blinking item among moving and static distractors. In Experiment 7, we present a uniquely moving item among static and blinking distractors, while in Experiment 8, we present a uniquely static item among blinking and moving distractors. In all of these experiments the target was equally likely to be the unique item or fall within the other two types of distractor sets.

As mentioned in the introduction there are four potential outcomes. First the *no capture hypothesis* suggests that given the complexity of the display, and the presence of changing background distractors, unique items will not capture attention in MAD search. Second the *unique magnocellular hypothesis* suggests that for a luminance change to capture attention it will need to be the only stimulus that is processed by the magnocellular pathway. Thus a unique blinking item will not be prioritized in the presence of moving distractors (and vice versa, see also Pinto et al., 2008, who discuss whether there is a distinction between the processing of moving and blinking stimuli). Third, the *unique item hypothesis* suggests that any item that is unique in the field will be found efficiently. This will occur even if the item is not uniquely defined by a feature, i.e., a uniquely static item (Pinto et al., 2006). Fourth, the *unique feature hypothesis* suggests that a unique item will only capture attention if its unique property is also a feature. Thus a unique abrupt onset or moving item would be found efficiently but a unique static item would not. To preview the results, the data from Experiments 6 to 8 are consistent with the unique feature hypothesis.

Experiment 6

Method

Participants:

Twelve participants (3 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 28 (M = 20.2 years, SD = 2.7 years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to that of Experiment 1 except that in this condition there was only ever one static blinking item. Half of the remaining stimuli were static and non-blinking (static items), while the other half were moving and non-blinking (moving items). In these displays the blinking item was unique. The experiment was comprised of 360 trials per participant. The target was equally likely to appear in the static set, the moving set or to be the blinking item. When the target was in either the static or the moving set a distractor was the blinking item. In this experiment set sizes of 17, 25 or 33 items were used, so that there were equal numbers of static items and moving items (plus the one blinking stimulus) in each display. A summary of the experimental conditions can be found in Table 3.

Table 3 about here

Results and Discussion

One participant's data was removed from analysis due to high error rates (80% on target absent trials). Data from the remaining eleven participants were entered into analysis. Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 2. Figure 12a shows mean RTs for target present trials across set size and Figure 12b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of target type (blinking, static or moving) and set size. There was a main effect of target type, $F(2, 20) = 25.0$, $p < 0.01$, where RTs for blinking targets were faster than those for static and moving targets and RTs increased with set size, $F(2, 20) = 26.7$, $p < 0.01$. There was also a significant Target type x Set size interaction, $F(4, 40) = 7.1$, $p < 0.01$, with search for blinking targets being more efficient than search for static or moving targets. This was confirmed in two further ANOVAs comparing both the static and moving conditions, respectively, to the blinking condition. Taking the static and blinking conditions, RTs for blinking targets were faster than those for static targets, $F(1, 10) = 30.4$, $p < 0.01$ and RTs increased with set size, $F(2, 20) = 9.3$, $p < 0.01$. Search was also more efficient in the blinking condition compared to the static condition, $F(2, 20) = 4.9$, $p < 0.05$. Taking the moving and blinking conditions, RTs for blinking targets were faster than those for moving targets, $F(1, 10) = 29.6$, $p < 0.01$ and RTs increased with set size, $F(2, 20) = 30.9$, $p < 0.01$. Search was also more efficient in the blinking condition compared to the moving condition, $F(2, 20) = 12.6$, $p < 0.01$.

Figures 12 and 13 about here

Again miss errors were higher than in most traditional lab search tasks (see Figure 13). There were very few false alarms (1.0%). Overall, miss errors were greater for moving and static stimuli than for blinking stimuli, $F(2, 20) = 33.9$, $p < 0.01$ and there was a main effect of set size, $F(2, 20) = 6.0$, $p < 0.01$, where miss errors increased with set size. The Target type x Set size interaction was marginally significant, $F(2, 20) = 2.4$, $p = 0.065$, most likely reflecting that miss errors for moving targets were higher than those for static ones at set size 25 but not for 17 or 33. Miss errors for blinking targets were low.

The results showed that search for abrupt onsets was highly efficient in MAD search, providing that the blinking item was unique. The data are difficult to account for by the no capture hypothesis or the unique magnocellular hypothesis as both of these theories would predict inefficient search for a unique blinking item (especially in the presence of moving distractors). However, the data are consistent with the unique item hypothesis and the unique feature hypothesis. Both these theories predict efficient search for a unique blinking target. Experiment 7 further examines this by having a unique moving item in the display.

Please note that in Experiment 6 the target appeared in the unique blinking set a third of the time. This differs from previous work by Yantis and Jonides (1984, see also Jonides, 1981) where the target was only the abrupt onset 1/*n* of the times, where *n* equalled the set size. In these past studies because the abrupt onset was equally likely to cue the target or a distractor there was no incentive to prioritize the abrupt onset and the efficient search produced was attributed purely to bottom-up processing. In contrast, in the experiment presented here the target was the unique item on a third of the trials, which may have encouraged participants to develop a top-down strategy to search the abrupt onset first. Thus, the efficient search witnessed here may be due to both bottom-up and/or top-down factors (see also Folk et al., 1992, for examples of how these two strategies interact). We test this further in Experiment 9 where, as the target was only the blinking item 1/*n* of times, where *n* equals the set size, people would have little incentive to form a top-down set to search the blinking item first.

Participants also have the same potential to develop top-down settings in Experiments 7 and 8, as they do in Experiment 6, as in each experiment, the target was likely to be the unique item on a third of the trials. The crucial difference is that the unique item in Experiments 6 and 7 is also a salient feature, whereas the unique item in Experiment 8 is not. Experiments 7 and 8 will determine whether, even with the potential for top-down control, an item has to be a unique feature in order to produce efficient search.

Experiment 7

Method

Participants:

Seventeen participants (9 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 30 (M = 21.2 years, SD = 3.1 years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to that of Experiment 6 except that in this condition there was only ever one moving stimulus. Half of the remaining stimuli were static and non-blinking (static items) while the other half were static and blinking (blinking items). In these displays the moving item was unique. The experiment was comprised of 360 trials. The target was equally likely to appear in the static set, the blinking set or to be the moving item. When the target was in either the static or the blinking set a distractor was the moving item. In this experiment set sizes of 17, 25 or 33 items were used, so that there were equal numbers of static and blinking items (plus the one moving stimulus) in each display. A summary of the experimental conditions can be found in Table 3.

Results and Discussion

Two participants' data were removed from analysis due to high error rates (one participant showed 100% errors in blinking target trials and another participant showed above 90% errors on target absent trials). Data from the remaining fifteen participants were entered into analysis. Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 2. Figure 14a shows mean RTs for target present trials across set size and Figure 14b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of target type (blinking, static or moving) and set size. There was a main effect of target type, $F(2, 28) = 26.9$, $p < 0.01$, where RTs for moving targets were faster than those for static and blinking targets and RTs increased with set size, $F(2, 28) = 43.7$, $p < 0.01$. There was also a significant Target type x Set size interaction, $F(4, 56) = 11.6$, $p < 0.01$, where search for moving targets was more efficient than search for static and blinking targets. This was confirmed in two further ANOVAs comparing the static and blinking conditions to the moving condition. Taking the static and moving conditions, RTs for moving targets were faster than those for static, $F(1, 14) = 22.9$, $p < 0.01$ and RTs increased with set size, $F(2, 28) = 23.0$, $p < 0.01$. Search was also more efficient in the moving condition compared to the static condition, $F(2, 28) = 12.3$, $p < 0.01$. Taking the moving and blinking conditions, RTs for moving targets were faster than those for blinking, $F(1, 14) = 31.4$, $p < 0.01$ and RTs increased with set size, $F(2, 28) = 32.5$, $p < 0.01$. Search was also more efficient in the moving condition compared to the blinking condition, $F(2, 28) = 20.1$, $p < 0.01$.

Figures 14 and 15 about here

Again miss errors were higher than in most traditional lab search tasks (see Figure 15). There were very few false alarms (1.5%). Overall, miss errors were greater for blinking and static stimuli than for moving stimuli, $F(2, 28) = 17.3$, $p < 0.01$ and there was a main effect of set size, $F(2, 28) = 6.6$, $p < 0.01$, where miss errors increased with set size. The Target type x Set size interaction was not significant, $F<1$.

Similar to the results of Experiment 6 the data showed that a unique moving item can be found efficiently in MAD displays. This is again contrary to a no capture hypothesis and a unique magnocellular hypothesis which would predict no attentional capture for unique moving items (especially in the presence of blinking distractors). In contrast a unique item hypothesis and a unique feature hypothesis would predict a benefit in search. Experiment 8 compared these two hypotheses by asking whether any item that is unique in some respect can guide attention efficiently (the unique item hypothesis). If so, a uniquely defined static item would show a search benefit (as it was the only non-dynamic stimulus on the screen). Pinto et al., (2006) have shown that a static target could be found efficiently among moving distractors if it was the only static item. In Experiment 8 we determine whether a unique static item can be found efficiently in conditions of high distractor heterogeneity as is present in MAD search (e.g., displays containing *both* blinking and moving distractors).

Experiment 8

Method

Participants:

Nineteen participants (3 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 44 ($M = 20.9$ years, $SD = 6.6$ years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to that of Experiment 6 except that in this condition there was only ever one static, non-blinking stimulus (static item). Half of the remaining stimuli were moving (moving items) while the other half were static and blinking (blinking items). In these displays the static item was unique. The experiment was comprised of 360 trials. The target was equally likely to appear in the moving set, the blinking set or to be the static item. When the target was in either the moving or the blinking set a distractor was the static item. In this experiment set sizes of 17, 25 or 33 items were used, so that there were equal numbers of moving and blinking items (plus the one static stimulus) in each display. A summary of the experimental conditions can be found in Table 3.

Results and Discussion

Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 2. Figure 16a shows mean RTs for target present trials across set size and Figure 16b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of target type (blinking, static or moving) and set size. There was a main effect of target type, $F(2, 36) = 6.2$, $p < 0.01$, RTs for static targets were faster than those for moving and blinking targets and RTs increased with set size, $F(2, 36) = 39.9$, $p < 0.01$. However, there was no significant Target type x Set size interaction, $F(4, 72) = 2.0$, p

= 0.1. There was no difference in search efficiency for the static target compared to the blinking and moving target conditions.

Figures 16 and 17 about here

Again miss errors were higher than in most traditional lab search tasks (see Figure 17). There were very few false alarms (1.2%). Overall, miss errors were greater for blinking and moving stimuli than for static stimuli, $F(2, 36) = 6.8$, $p < 0.01$ and there was a main effect of set size, $F(2, 36) = 9.9$, $p < 0.01$, where miss errors increased with set size. The Target type x Set size interaction was not significant, $F<1$.

Contrary to the results of Experiments 6 and 7, when the target was a unique but static item search was inefficient. Indeed, search for the unique static item was no more efficient than search for a blinking item or search for a moving item. This is contrary to the unique item hypothesis which would predict that having any item that was unique in some respect would lead to efficient search. The data instead suggest that for a unique item to capture attention it also needs to contain a feature, consistent with the unique feature hypothesis. We discuss this further in the General Discussion.

The results from Experiments 6 to 8 suggest that an item containing a unique feature can capture attention in MAD search. There are two reasons why this could be. First, similar to the findings of simpler visual search tasks, unique features (e.g. blinking items) might capture attention in a bottom-up fashion. For example, Yantis and Jonides (1984) found that a single abrupt onset captured attention even if there was no top-down incentive to prioritize it (i.e., the target was no more likely to be the onset item than any of the other items in the display). Alternatively, it could be that unique features captured attention, in MAD search, via the adoption of a top-down attentional set for those features. Given that the target was likely to be the blinking item on a third of trials, in Experiment 6, people may have developed a top-down strategy to search the blinking item first – leading to increased efficiency. We investigated whether attentional capture for unique blinking items in MAD search occurs due to top-down or bottom-up processes in Experiment 9, in which we used the methodology of Yantis and Jonides (1984, i.e. the target was only the blinking stimulus on 1/*n* of trials where *n* was the set size). If top-down processes were responsible for attentional capture of unique features in MAD search then, when there was no top-down incentive to prioritize blinking items, there should be no search benefit for blinking targets. However, if search for a blinking item, in MAD search, relied on bottom up processes, a search advantage for a blinking target should remain.

Experiment 9

Method

Participants:

Twenty participants (2 male) were recruited from the University of Warwick's participant scheme in exchange for course credit or payment. Their ages ranged from 18 to 25 (M = 18.6 years, SD = 1.6 years). All participants had normal or corrected to normal vision.

Stimuli and Procedure:

The stimuli and procedure were similar to that of Experiment 6 except that the target was only static and blinking (a blinking item) on 1/*n* trials, where *n* equals the set size. On the remaining trials the target was equally likely to be one of the moving items or one of the static and non-blinking (static) items on (n-1)/n trials. As this led to an increased number of trials, set sizes were reduced to either 5 or 9 items, which allowed the testing time per participant to be similar to that in the previous experiments[5]. The total number of trials for this experiment was 560. A summary of the experimental conditions can be found in Table 3.

Results and Discussion

Trials with RTs less than 200 ms or greater than 10000 ms were removed as outliers (less than 1% of the data). Overall RTs for present and absent trials are shown in Table 4. Figure 18a shows mean RTs for target present trials across set size and Figure 18b shows the search slopes. RTs for correct trials were entered into a within-participants analysis of variance (ANOVA), with main factors of target type (blinking, static or moving) and set size. RTs increased with set size, $F(1, 19) = 106.8$, $p < 0.01$. However, there was no main effect of target type, $F(2, 38) = 1.2$, $p = 0.3$. Neither was there a significant Target type x Set size interaction, $F(2, 38) = 1.3$, $p = 0.3$. There was no benefit in search efficiency for the blinking target compared to the static and moving target conditions.

Figures 18 and 19 and Table 4 about here

There were very few false alarms (1.5%). Miss errors are shown in Figure 19. Overall, there was a trend for miss errors to be greater for static and moving stimuli compared to blinking

[5] In order to collect 20 data points per set size, for sensible data analysis of blinking targets, with set size 5 there needed to be 40 trials containing a moving target and 40 trials containing a static target. For set size 9, there needed to be 80 trials containing a moving target and 80 trials containing a static target. These trial numbers were then doubled to include target absent trials.

stimuli, $F(2, 38) = 2.7$, $p = 0.08$. There was no main effect of set size, $F < 1$. Neither was the Target type x Set size interaction significant, $F<1$.

Contrary to the findings of Experiment 6, when the unique blinking item was only the target on 1/*n* of trials, where *n* was the set size, it no longer captured attention. Search efficiency for the blinking target was equivalent to that of the moving and static targets. Experiment 6 and Experiment 9 were identical except for the proportion of trials in which the blinking item was the target. In Experiment 6, the blinking item was likely to be the target on a relatively high proportion of trials (a third of the time), giving participants an incentive to adopt a top-down strategy to search the blinking item first. However, in Experiment 9, because the blinking item was no more likely to be a target than a distractor there was little incentive to form an intentional set to prioritize them. In this case for a blinking item to capture attention it would have to rely purely on bottom-up processes. However, no attentional capture was found. The results suggest that under MAD conditions, unique blinking items capture attention via top-down rather than bottom-up processes. We consider this further in the General Discussion.

General Discussion

Previous results from traditional visual search tasks have shown that items possessing luminance onsets capture attention (e.g., Christ & Abrams, 2006; Schreij, Owens, & Theeuwes, 2008; Theeuwes, 1994; Yantis & Jonides, 1984; 1996). However, when the search task was altered to be more complex and include dynamic and unpredictable aspects of real world search (i.e., in MAD search) luminance onsets were no longer prioritized (Kunar & Watson, 2011). The current study investigated whether luminance onsets ever capture attention in MAD search. Experiment 1 found that even when stimuli showed an abrupt onset in MAD search, there was no search slope benefit for blinking items. This occurred even when items offset for 100 ms, conditions known to capture attention in previous work (Yantis & Gibson, 1994). Furthermore, giving participants pre-exposure to the display (Experiments 2 to 5) and advance knowledge of what to look for (Experiments 3 to 5) did not lead to increased efficiency for blinking items. Under these MAD conditions, search slopes for blinking targets were no more efficient than those for non-blinking targets.

Despite this, search for a blinking stimulus was highly efficient in MAD search when it was unique within the field (Experiment 6). This occurred even when the background distractors were changing and dynamic. We tested four hypotheses: the no capture hypothesis, the unique magnocellular hypothesis, the unique item hypothesis and the unique feature hypothesis. The fact that search for a unique blinking item (Experiment 6) and a unique moving item (Experiment 7) was efficient in the presence of other dynamic distractors ruled out a no capture hypothesis and the unique magnocellular hypothesis. Furthermore, Experiment 8 found that an item had to be unique in terms of a having a particular feature in order to produce efficient search, ruling out the unique item hypothesis. An item that was unique because it was the only static item in the display was not able to guide attention efficiently (contrary to the results of Pinto et al., 2006). Von Muhlenen et al., (2005) proposed that unique events capture attention provided they are temporally isolated and the background to the display is largely unchanging. The experiments presented here tested this theory to address what unique events, in particular, captured attention and whether they could still capture attention in more dynamic conditions, where the background distractors were constantly changing. Our results differed from those of Von Muhlenen's et al. (2005) in that even with heterogeneous dynamic backgrounds, if an item has a distinctive feature it will be prioritized for search. The data are consistent with the unique feature hypothesis suggesting that unique features can efficiently guide attention in much more unpredictable and dynamic conditions than previously thought.

Experiment 9 determined whether unique features captured attention in MAD search via top-down or bottom-up processes. Previous work has shown that, in simpler visual search tasks, abrupt onsets capture attention in a bottom-up fashion (see Yantis & Jonides, 1984, Jonides, 1981, Remington et al., 1992). Yantis and Jonides (1984) found that an abrupt onset captured attention even when it was no more likely to be a target than any other item in the display. Furthermore, in simpler visual search tasks, abrupt onsets have been found to capture attention even when they never predict the target location (Remington et al., 1992). Our results contrast with these findings – in more complex search when the blinking item was not predictive of the target location it did not capture attention effectively. Taken together Experiments 6 and 9 suggest that although unique features can capture attention in MAD search, with these more complex displays, attentional capture was driven by top-down, rather than bottom-up processes. These findings concur with work by Martin-Emerson and Kramer, (1997) who found reduced effects of stimulus-driven attentional capture of abrupt onsets when they were presented alongside other irrelevant luminance changes in the display. However, similar to our work, they found that participants could still adopt top-down attentional sets to find abrupt onsets amongst other transient distractions.

If abrupt onsets could capture attention in MAD search by top-down strategies, why did they not capture attention in Experiments 1 to 5 here? One reason could be that in these MAD displays, along with the blinking target, there were also blinking distractor items. It might be that, even if the blinking target captured attention, once the target had been found it would be difficult to attend to due to the distracting presence of other blinking items in the display[6] (see also Christ & Abrams, 2006). There is some evidence for this if we examine the data from Experiment 6, as without competing onset distractors, search for a blinking item was efficient. However, this theory cannot easily account for the data in Experiment 7. If blinking distractor items captured attention, preventing full attention to the target item then they should have also disrupted search for a uniquely moving target (Experiment 7). However, search for a unique moving item, even in the presence of distracting blinking items, was efficient.

A second reason why there was no attentional capture of onsets in Experiments 1 to 5 could be that, unlike previous work, the stimuli in these experiments repeatedly disappeared from view for part of the trial (i.e. they repeatedly offset). That is, as the stimuli were not physically visible at some points in the display this might elicit a cost that negates any benefit of having the stimuli blink (e.g. targets may be difficult to identify if they are temporarily invisible). Although possible, there are several reasons why we do not believe this is to be the case. First, previous work has shown that luminance changes still fail to capture attention even when blinking stimuli do not entirely disappear from the display. Kunar and Watson (2011) had onset stimuli increase and decrease in luminance (with luminance changes known to capture attention in simpler search tasks, Rauschenberger, 2003) yet always remain visible on the screen. Despite this, there was no attentional capture of blinking items. Second, the results from Experiments 1 to 5, showed that in most cases although there was an overall RT difference where RTs for blinking targets were slowed compared to RTs for non-blinking targets, (presumably as people had to wait for the item to re-onset if it was not currently visible) there was no difference in search slopes. This suggests that although having the items

[6] We thank Richard Abrams for this suggestion.

disappear from view increased peoples' overall response times it did not affect their search rate (in either a beneficial or a costly manner). Third, Experiment 6 showed that a blinking item could capture attention if it was the only item that was blinking. This occurred even though, like in Experiments 1 to 5, the blinking item repeatedly disappeared from view throughout the trial. Please note that even though we do not believe the repeated offsets impaired search efficiency, due to the nature of MAD search (designed to mimic real-world search characteristics) the blinking onsets (and the motion cues) here varied greatly from those used in more traditional experiments, where items typically onset once. Given these differences, one could argue that our results cannot be directly compared to those of past work. Nevertheless, our data have important implications for how the human visual system searches more realistic environments - within these more complex and dynamic conditions abrupt onsets (and moving items) do not necessarily capture attention.

Let us now examine search for static targets. Pinto et al. (2006) found that search for a unique stationary item could guide attention, if it was presented among dynamic distractors. In contrast our work showed that a unique static item did not capture attention. On face value these results seemingly contradict each other. However, there are several reasons why this difference could have occurred. First, in the experiments presented by Pinto et al. (2006) there was only one type of dynamic distractor per experiment. For example, in one experiment participants searched for a static target among distractors that all showed apparent motion. In another experiment participants searched for a static item among distractors that all blinked. In contrast, MAD search contained more heterogeneous stimuli so that both moving and blinking stimuli appeared in the same display. This difference in distractor similarity between studies could account for the results. According to the Attentional Engagement Theory presented by Duncan and Humphrey's (1989) the largely homogenous distractors from Pinto et al.'s (2006) study would be more easily grouped and rejected as a whole compared to the more heterogeneous distractors presented here. Less competition from the rejected distractors would lead to more efficient search as the target would enter visual short term memory more rapidly – showing a search advantage for unique static targets. In contrast, the more heterogeneous distractor items from the experiments here were less likely to be grouped and rejected, leading to greater competition of distractor items and less efficient search.

Furthermore, in Pinto et al.'s (2006) study the target was always a static item. In contrast in Experiment 8 here, the target was equally likely to be a static, moving or blinking item. Thus although participants in our experiment could have used some top-down guidance in our experiments (as the target was the static item on a third of the trials) the incentive to prioritize static items in Pinto et al.'s work was much greater (as the target was the static item on 100% of trials). If we blocked conditions so that the target was always uniquely static then perhaps we would have found efficient search. Muller and Von Muhlenen (1999) found that although search for a moving item among static distractors was highly efficient from the start, search for a static item among moving distractors only became efficient after participants were given extra training. Thus it may be that search for a static item in MAD search could become efficient if participants were more practiced. Please note, however, that in Experiments 6 and 7 the targets were also equally likely to be static, moving or blinking (and so the target was in the unique set a third of the time) yet, despite this, blinking and moving features efficiently guided attention.

Our work also showed that giving people more time with the display and increasing the opportunity for top-down knowledge to contribute to guidance (via a previewed placeholder display) did not result in the efficient processing of multiple blinking items. However, there was a benefit for moving targets under these conditions. In standard MAD search, search slopes for moving targets were less efficient than search slopes for static targets (Kunar & Watson, 2011, see also Experiment 1 here). However, with time and knowledge search slopes for moving targets were now no different to those of static targets (see also Hulleman, 2009). This benefit to moving search slopes was likely to occur more due to extra time with the display rather than advance knowledge. Kunar and Watson (2011) found that when given advance knowledge on its own search slopes for moving targets were worse than those for static targets. Furthermore this reduction in moving slopes also occurred in Experiment 2 here in which participants were given extra time in the absence of advance knowledge. Please note that participants were still no more efficient at finding moving targets than static targets. Nevertheless the data suggest that with this extra time people were able to guide their attention within the moving set as effectively as they could guide their attention within the static set. The data add to that of other work suggesting that the strength of attentional guidance can become stronger with time (Kunar et al., 2008b, Wolfe et al., 2009).

Now let us examine the error rates. Similar to the work of Kunar and Watson (2011) miss rates to find targets were relatively high. Participants missed 20-30% of the targets in these experiments, a much higher rate than those typically observed in lab based visual search experiments[7]. Recent work has found that a similar percentage of errors has been observed in Low Prevalence (LP) visual search tasks where the target only appears rarely (approximately 1-2% of the time, Wolfe et al., 2005, Fleck & Mitroff, 2007, Kunar et al., 2010, Rich et al., 2008, Russell & Kunar, 2012, Wolfe et al., 2007, and Van Wert et al., 2009). In these LP

[7] When the target was a unique blinking item (Experiment 6) or a unique moving item (Experiment 7), however, miss errors were relatively low, following the trend found in the RT data.

trials the increase in miss errors was likely to occur due to a change in criterion: with the appearance of fewer targets people were less willing to respond target present. In contrast there was little change in sensitivity (Russell & Kunar, 2012, Wolfe et al., 2007, and Van Wert et al., 2009). Given that the miss rates here were similar in numerosity to that of LP experiments one could suggest that a similar process was occurring. However as the target was present on 50% of trials in MAD search it was less likely that participants changed their criteria based on a less frequent target appearance. It will be up to future to work to investigate the source of the high error rates in MAD search and whether they are due to a criterion shift or due to a reduction in sensitivity in these more dynamic displays.

The work in this paper addressed whether luminance changes captured attention in more dynamic search. The results found that unique features captured attention – even in the presence of ever changing distractor items. This attentional capture was driven by top-down, rather than bottom-up, processes. However, attention could not be efficiently guided to a set of luminance changes – even when these changes were abrupt and when participants were given more time and knowledge to process them. In more complex search abrupt onsets are unlikely to capture attention.

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: Temporally modulated priority tags. *Perception and Psychophysics, 50, 166-178*

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Table 1: A summary of conditions for Experiments 1 - 5

Experiment	**Onset Type**	**Onset synchrony**	**Placeholder Duration (in ms)**	**Top-down knowledge of target blinking/motion type**
1	Abrupt	Synchronous	n/a	No
2	Abrupt	Synchronous	2000	No
3	Gradual	Asynchronous	1000	Yes
4	Abrupt	Synchronous	2000	Yes
5	Abrupt	Synchronous	4000	Yes

Table 2: Overall mean correct Reaction Times (ms) for present and absent trials in Experiments 1-8 across set size. (Please note that in Experiments 6 - 8 the set sizes across the columns were 17, 25 and 33 instead of 16, 24 and 32, respectively)

	Present			**Absent**		
	16	**24**	**32**	**16**	**24**	**32**
Experiment 1	1505	1831	2039	2692	3505	4101
Experiment 2	1732	2068	2373	2977	3802	4461
Experiment 3	1487	1867	2004	2780	3382	3801
Experiment 4	1439	1793	2050	2511	3228	3852
Experiment 5	n/a	2037	2342	n/a	3741	4296
Experiment 6	1334	1581	1947	2791	3765	4639
Experiment 7	1307	1586	1789	2779	3538	4106
Experiment 8	1493	1766	2090	3052	4042	4642

Table 3: A summary of conditions for Experiments 6 - 9

Experiment	**Unique Stimulus Type**	**Other stimuli present**	**Proportion of trials the target is the unique item**	**Efficient search for unique item**
6	Blinking	Moving, Static	1/3	Yes
7	Moving	Blinking, Static	1/3	Yes
8	Static	Moving, Blinking	1/3	No
9	Blinking	Moving, Static	1/*n**	No

* where *n* equals the set size

Table 4: Overall mean correct Reaction Times (ms) for present and absent trials in Experiments 9 across set size.

	Present		**Absent**	
	5	**9**	**5**	**9**
Experiment 9	920	1071	1196	1767

<u>Figure Legends</u>

Figure 1. Example display of Multi-element Asynchronous Dynamic (MAD) Search. Arrows represent moving items. Stimuli surrounded by stars represent items that blink on and off. The target (if present) is a vowel.

Figure 2. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 1. Error bars represent the standard error.

Figure 3. Miss errors for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 1. Error bars represent the standard error.

Figure 4. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 2. Error bars represent the standard error.

Figure 5. Miss errors for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 2. Error bars represent the standard error.

Figure 6. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 3. Error bars represent the standard error.

Figure 7. Miss errors for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 3. Error bars represent the standard error.

Figure 8. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 4. Error bars represent the standard error.

Figure 9. Miss errors for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 4. Error bars represent the standard error.

Figure 10. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 5. Error bars represent the standard error.

Figure 11. Miss errors for when the target was Static, Moving, Static-Blinking or Moving-Blinking in Experiment 5. Error bars represent the standard error.

Figure 12. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, or Blinking in Experiment 6. Error bars represent the standard error.

Figure 13. Miss errors for when the target was Static, Moving, or Blinking in Experiment 6. Error bars represent the standard error.

Figure 14. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, or Blinking in Experiment 7. Error bars represent the standard error.

Figure 15. Miss errors for when the target was Static, Moving, or Blinking in Experiment 7. Error bars represent the standard error.

Figure 16. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, or Blinking in Experiment 8. Error bars represent the standard error.

Figure 17. Miss errors for when the target was Static, Moving, or Blinking in Experiment 8. Error bars represent the standard error.

Figure 18. (a) Reaction times (RTs) across set size and (b) search slopes for when the target was Static, Moving, or Blinking in Experiment 9. Error bars represent the standard error.

Figure 19. Miss errors for when the target was Static, Moving, or Blinking in Experiment 9. Error bars represent the standard error.

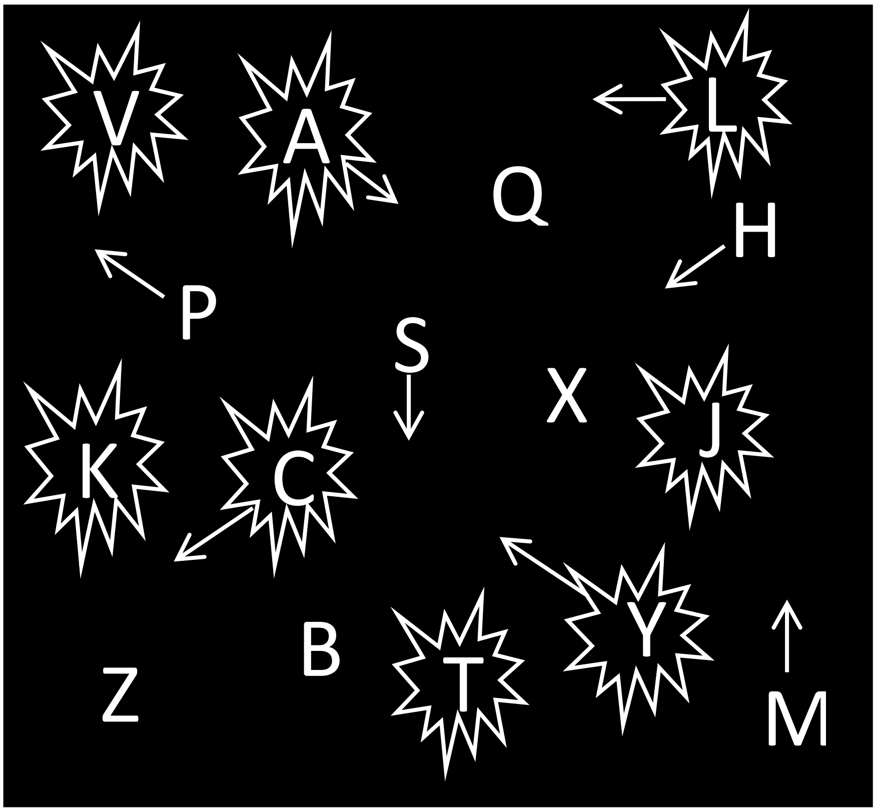
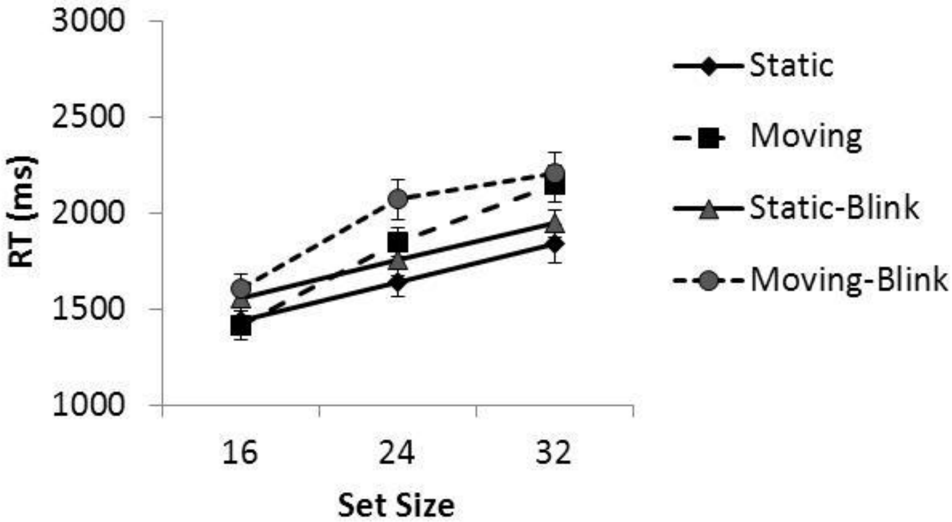


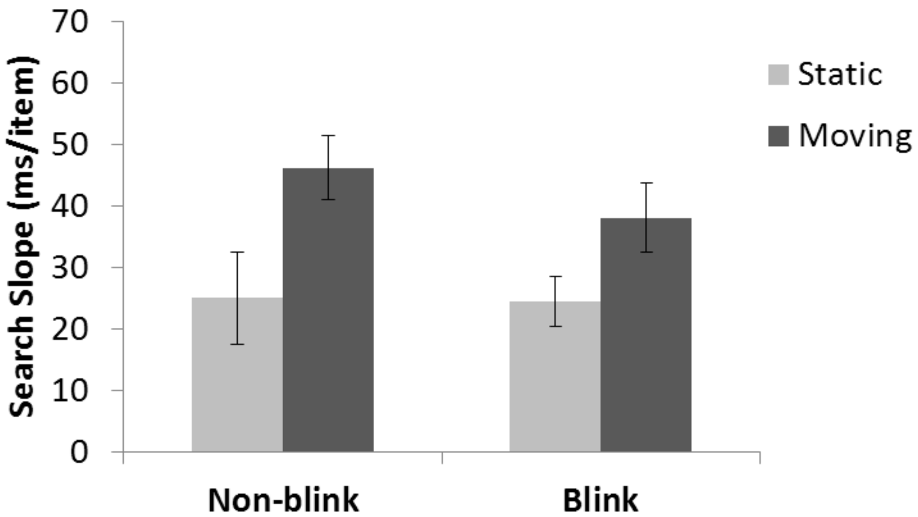
Figure 1

a)



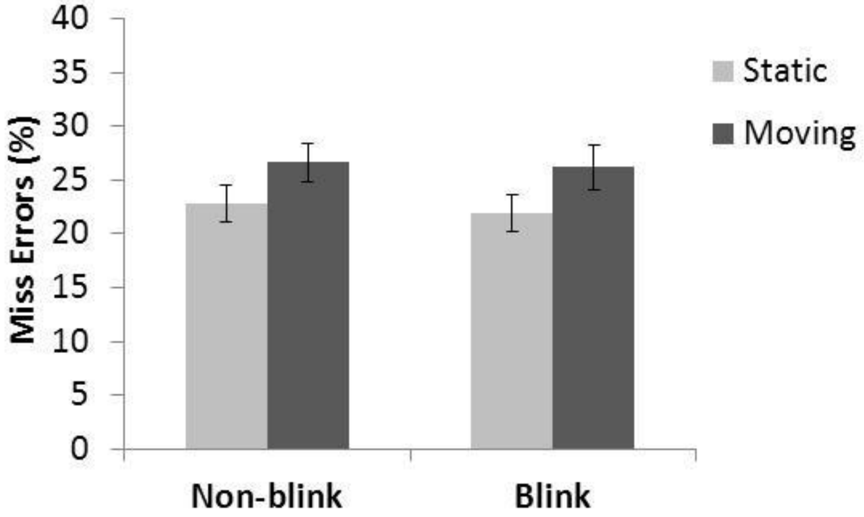
3000
2500
2000
1500
1000
RT (ms)
16
24
32
Set Size
Static
Moving
Static-Blink
Moving-Blink

b)



70
60
50
40
30
20
10
0
Search Slope (ms/item)
Non-blink
Blink
Static
Moving

Figure 2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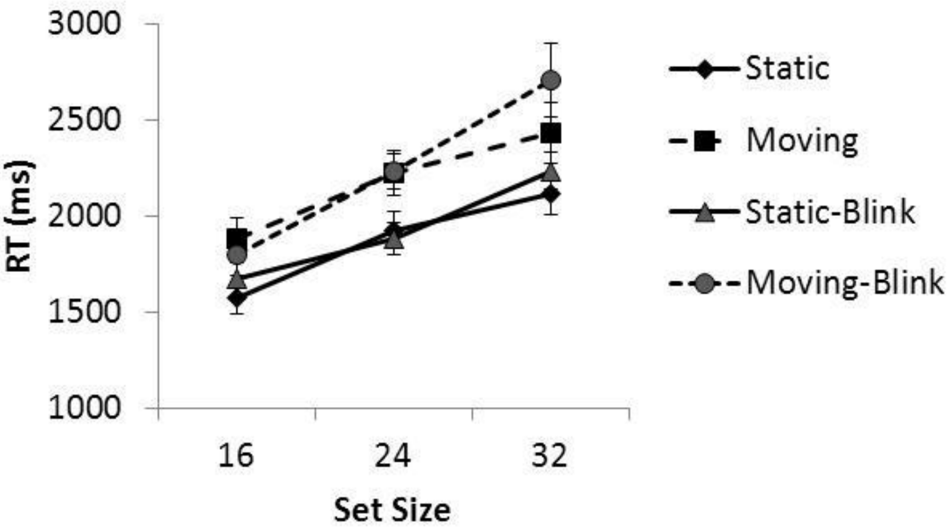
35
30
25
20
15
10
5
0
Miss Errors (%)
Static
Moving
Non-blink
Blink

Figure 3

a)


3000
2500
2000
1500
1000
RT (ms)
16
24
32
Set Size
Static
Moving
Static-Blink
Moving-Blink

b)

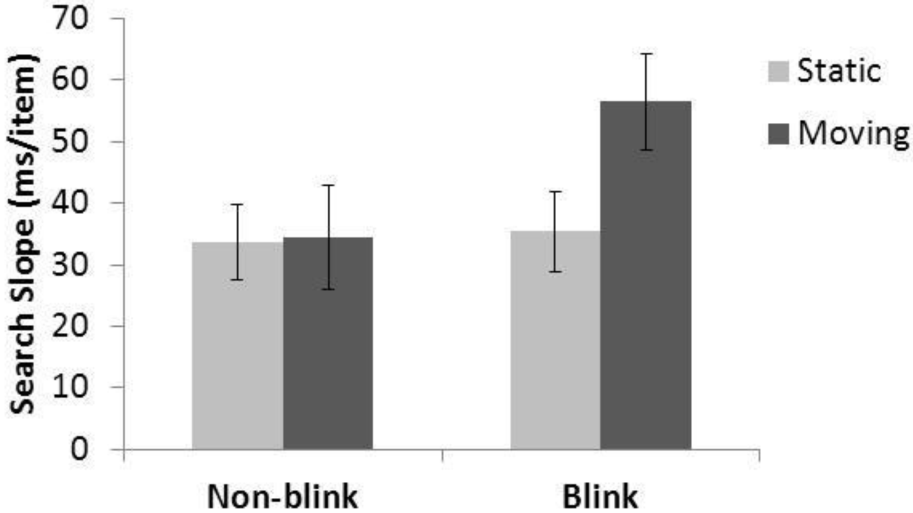
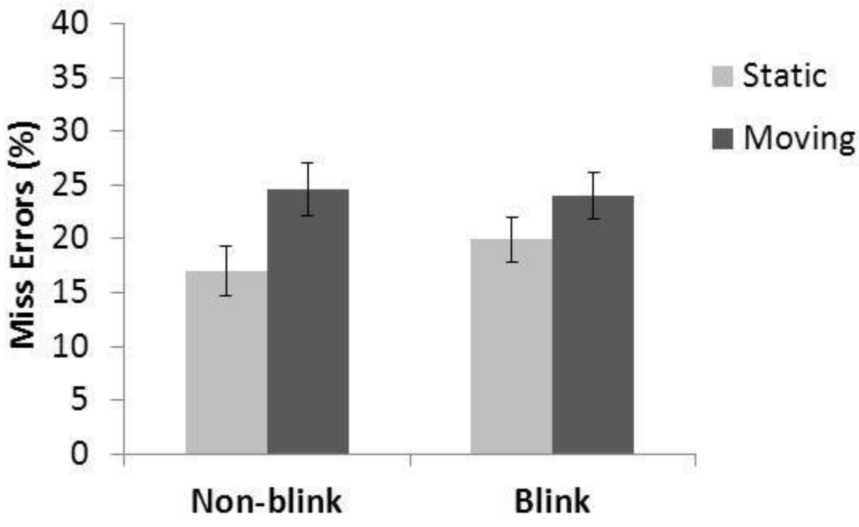

70
60
50
40
30
20
10
0
Search Slope (ms/item)
Non-blink
Blink
Static
Moving

Figure 4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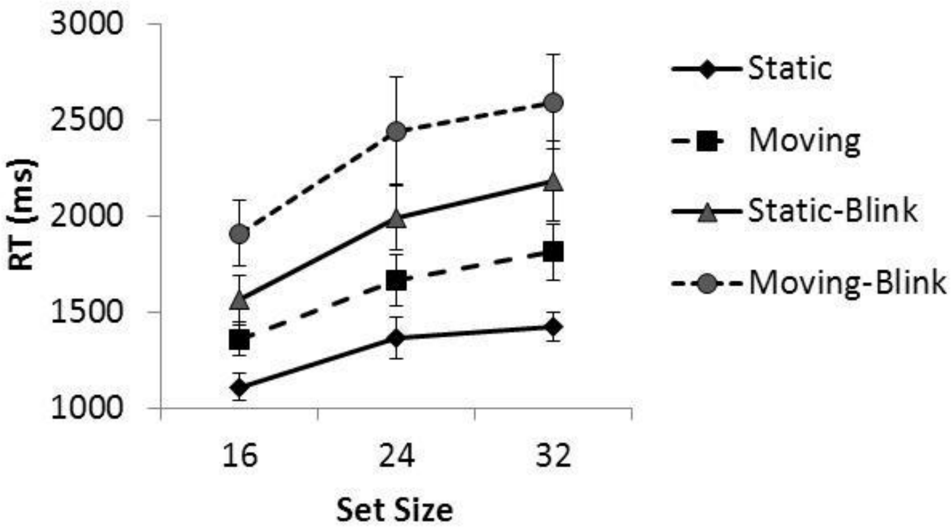
35
30
25
20
15
10
5
0
Miss Errors (%)
Non-blink
Blink
Static
Moving

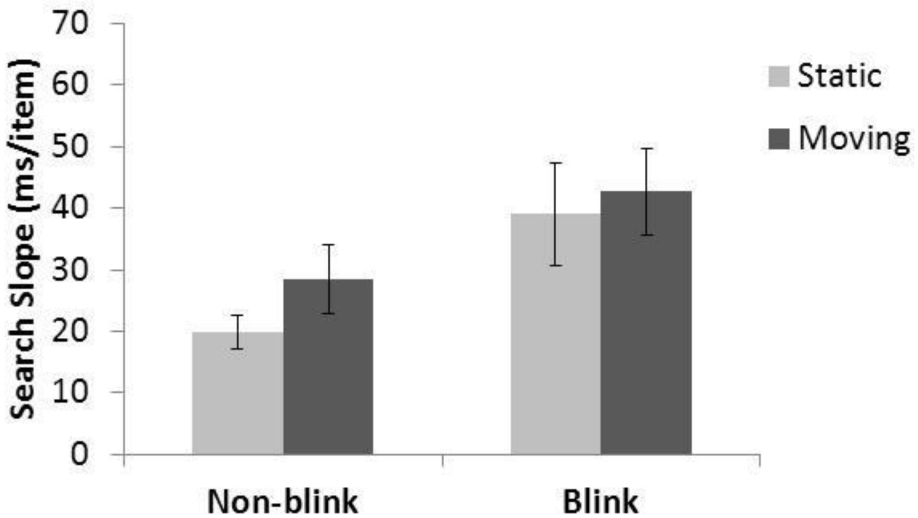
Figure 5

a)



3000
2500
2000
1500
1000
RT (ms)
16
24
32
Set Size
Static
Moving
Static-Blink
Moving-Blink

b)



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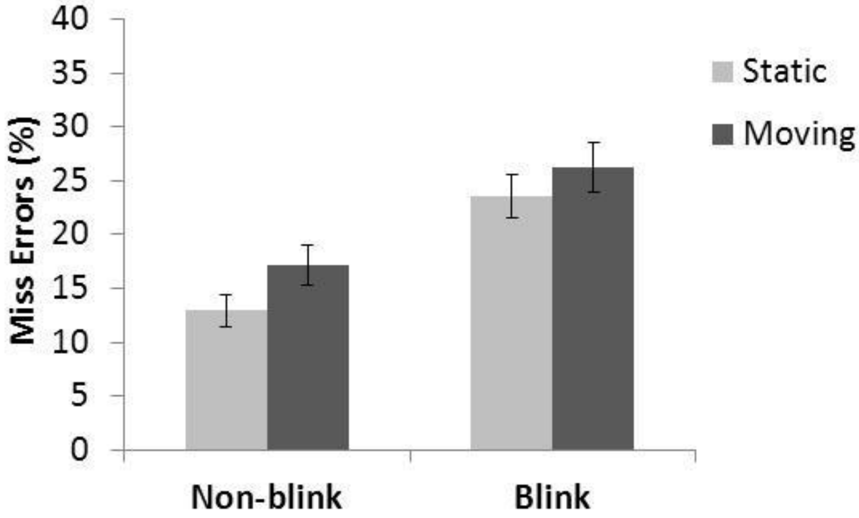
60
50
40
30
20
10
0
Search Slope (ms/item)
Non-blink
Blink
Static
Moving

Figure 6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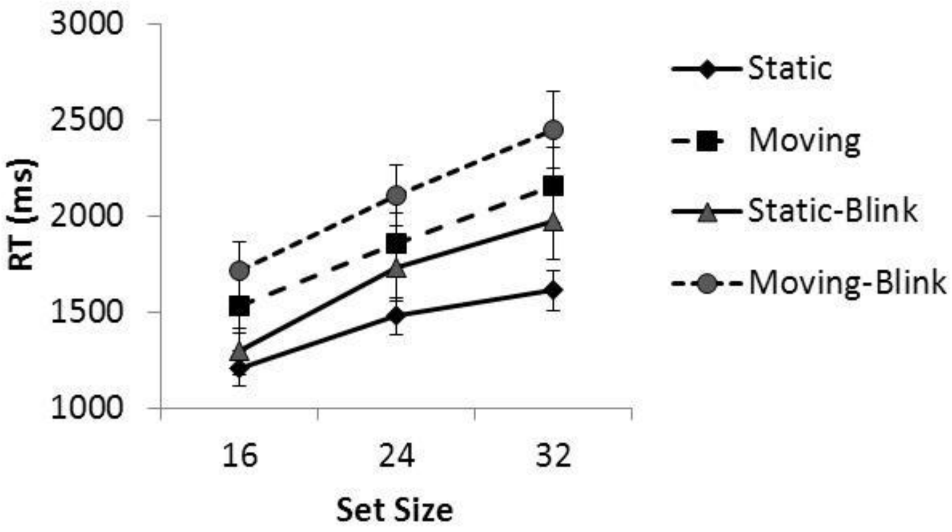
35
30
25
20
15
10
5
0
Miss Errors (%)
Non-blink
Blink
Static
Moving

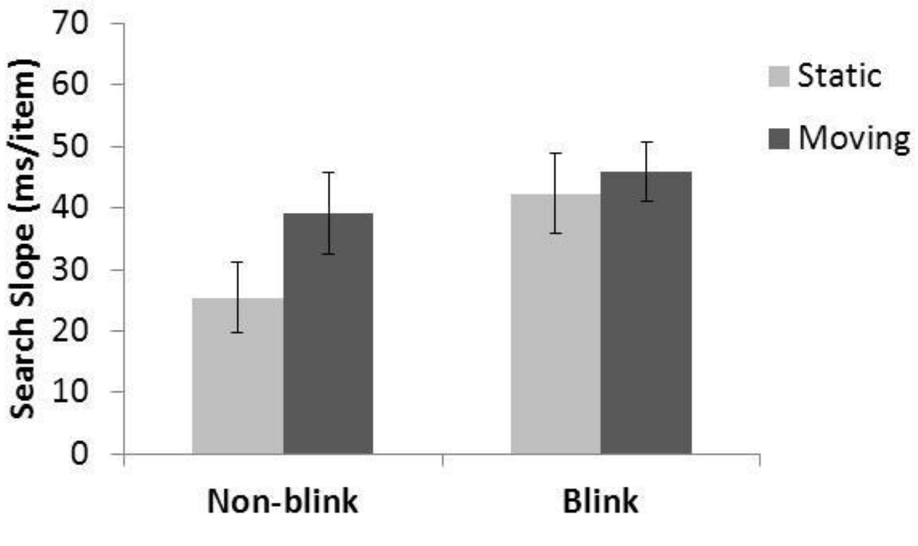
Figure 7

a)



3000
2500
2000
1500
1000
RT (ms)
16
24
32
Set Size
Static
Moving
Static-Blink
Moving-Blink

b)



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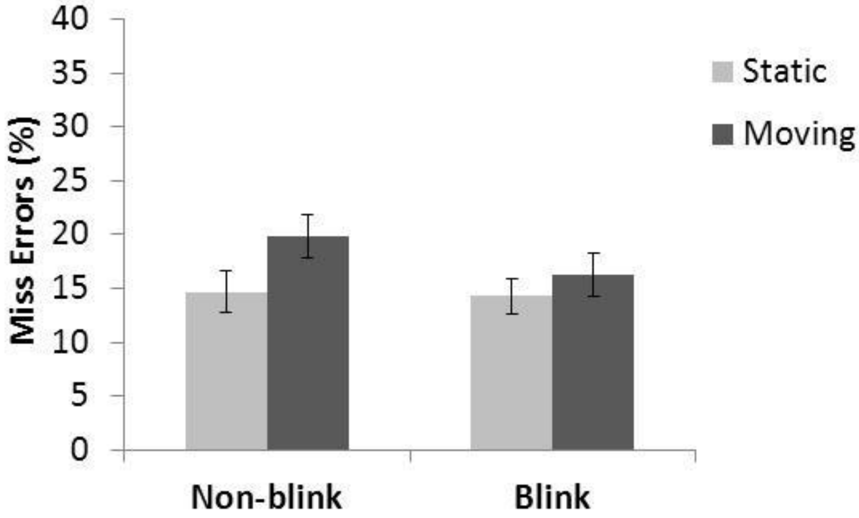
60
50
40
30
20
10
0
Search Slope (ms/item)
Non-blink
Blink
Static
Moving

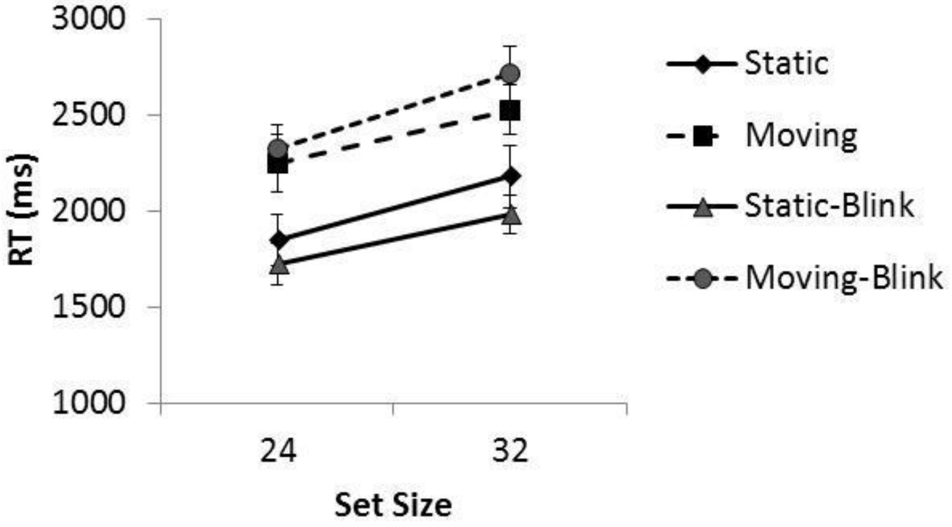
Figure 8



40
35
30
25
20
15
10
5
0
Miss Errors (%)
Static
Moving
Non-blink
Blink

Figure 9

a)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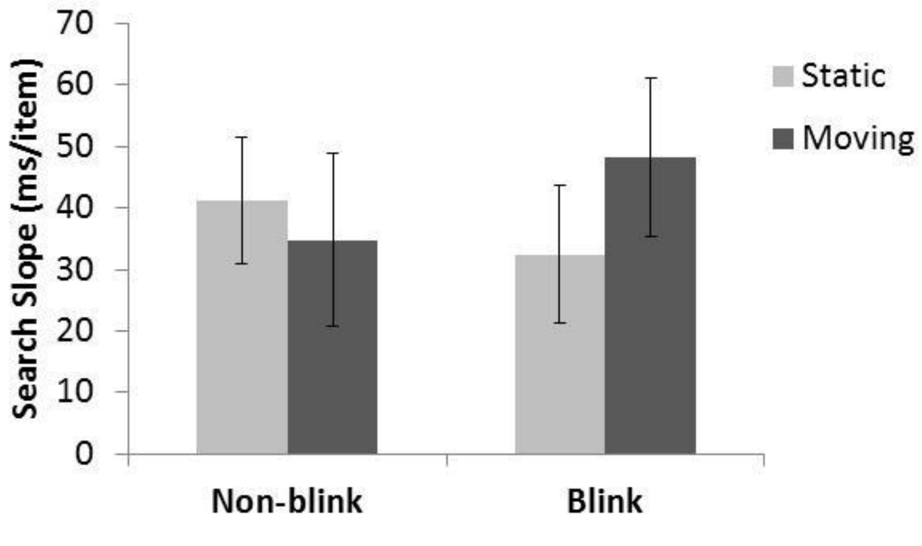
2500
2000
1500
1000
RT (ms)
24
32
Set Size
Static
Moving
Static-Blink
Moving-Blink

b)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60
50
40
30
20
10
0
Search Slope (ms/item)
Non-blink
Blink
Static
Moving

Figure 10

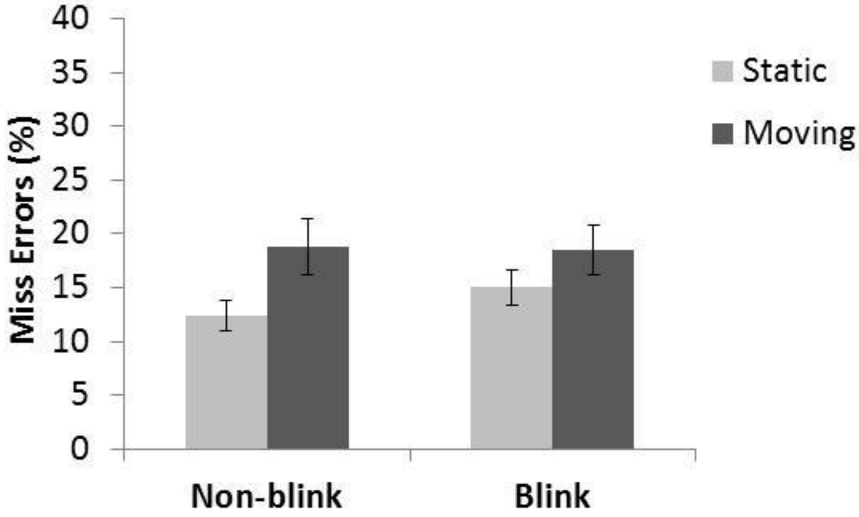
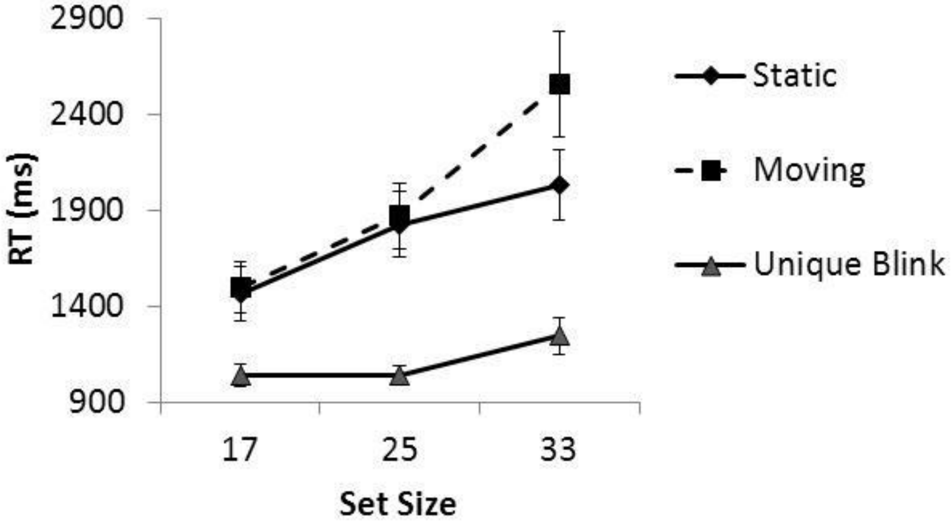
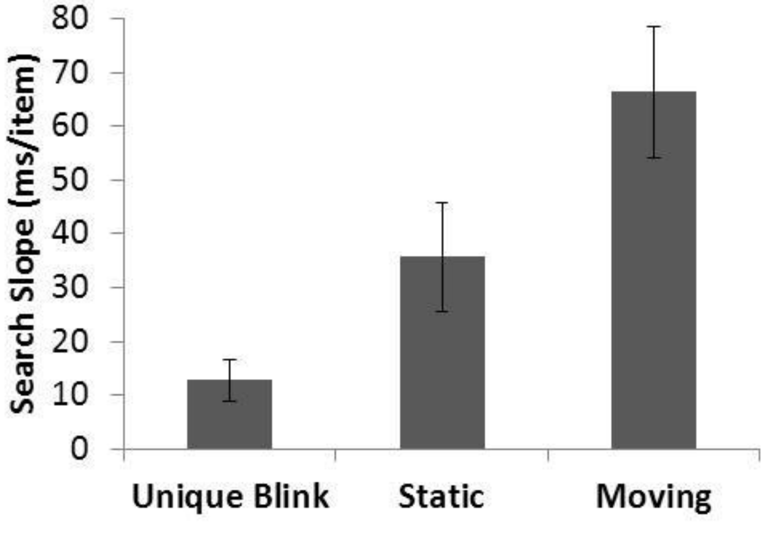

40
35
30
25
20
15
10
5
0
Miss Errors (%)
Static
Moving
Non-blink
Blink

Figure 11

a)


2900
2400
1900
1400
900
RT (ms)
17
25
33
Set Size
Static
Moving
Unique Blink

b)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70
60
50
40
30
20
10
0
Search Slope (ms/item)
Unique Blink
Static
Moving

Figure 12

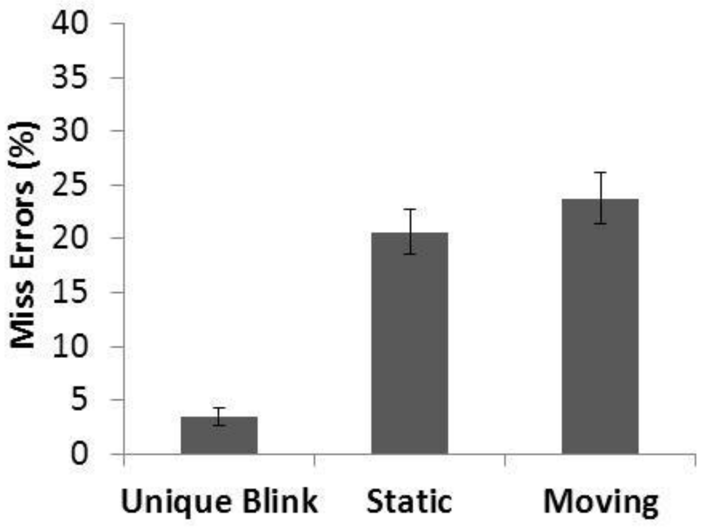
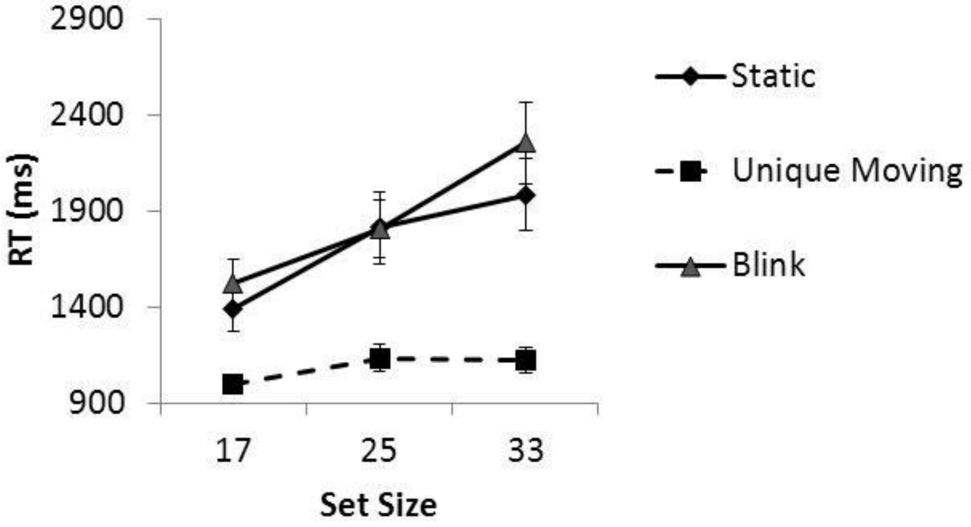


Figure 13

a)


2900
2400
1900
1400
900
RT (ms)
17
25
33
Set Size
Static
Unique Moving
Blink

b)

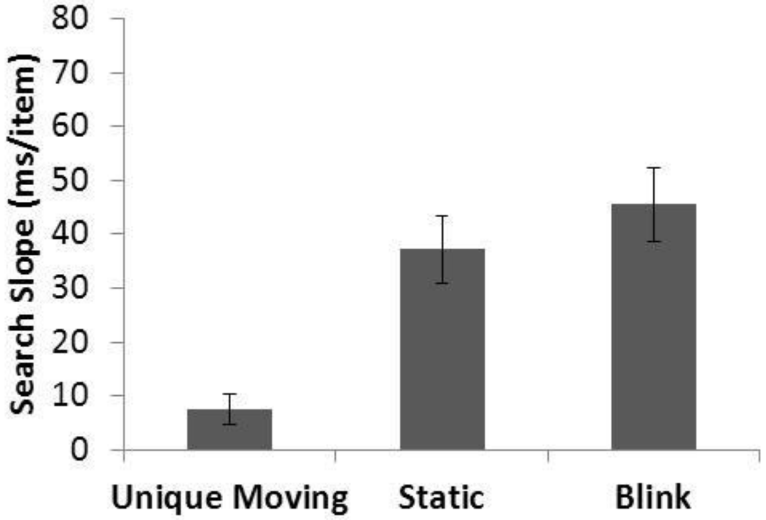

80
70
60
50
40
30
20
10
0
Search Slope (ms/item)
Unique Moving
Static
Blink

Figure 14

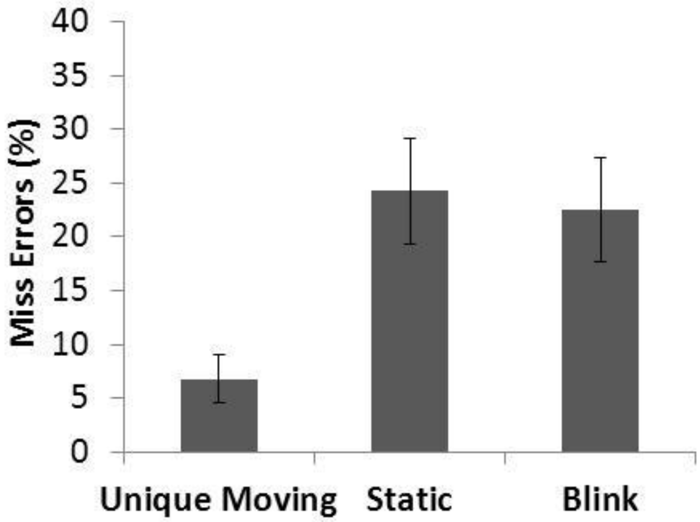
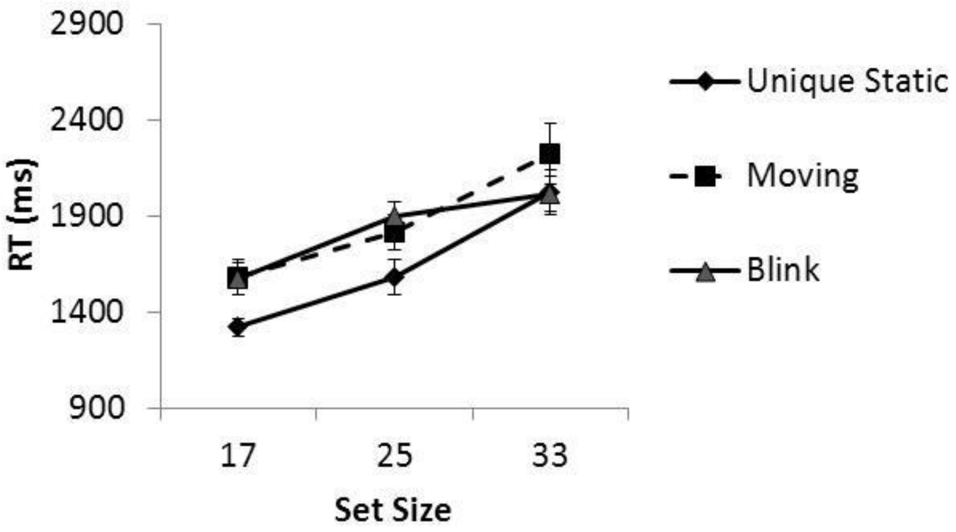
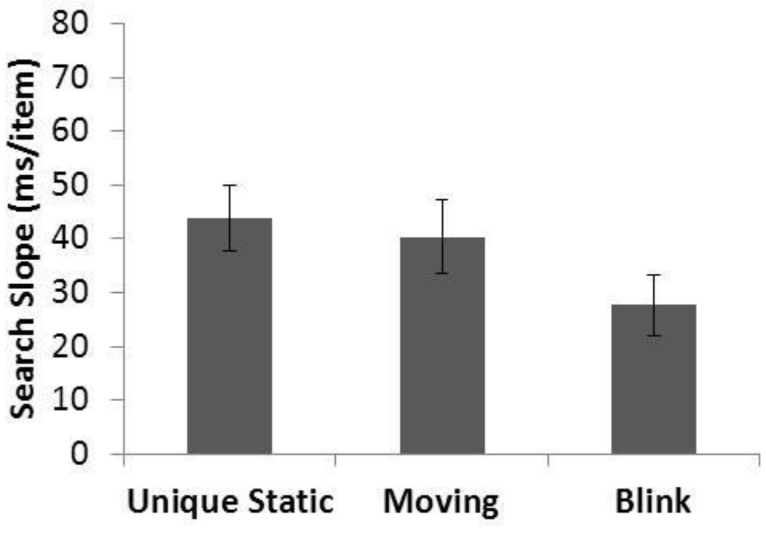


Figure 15

a)


2900
2400
1900
1400
900
RT (ms)
17
25
33
Set Size
Unique Static
Moving
Blink

b)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70
60
50
40
30
20
10
0
Search Slope (ms/item)
Unique Static
Moving
Blink

Figure 16

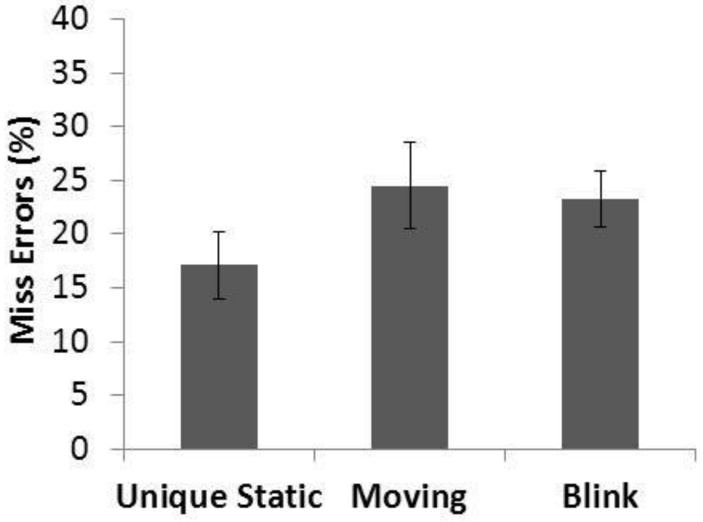
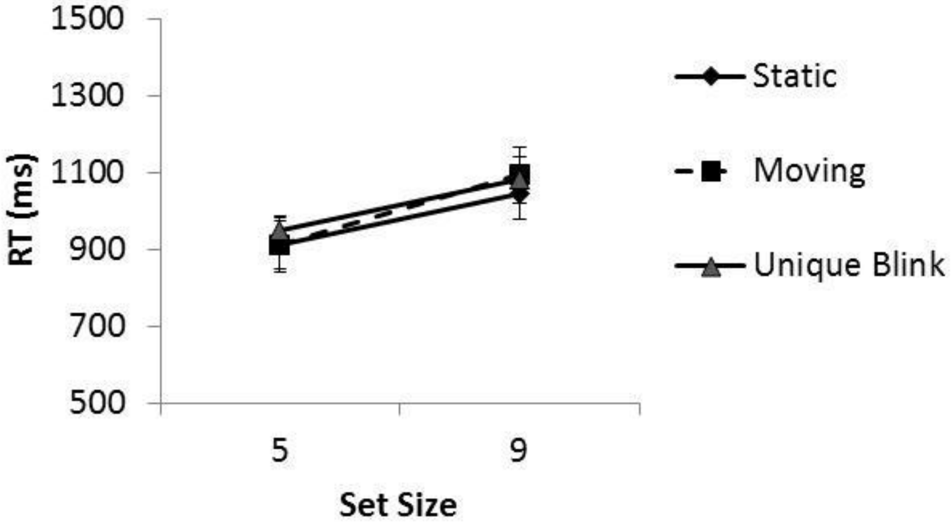
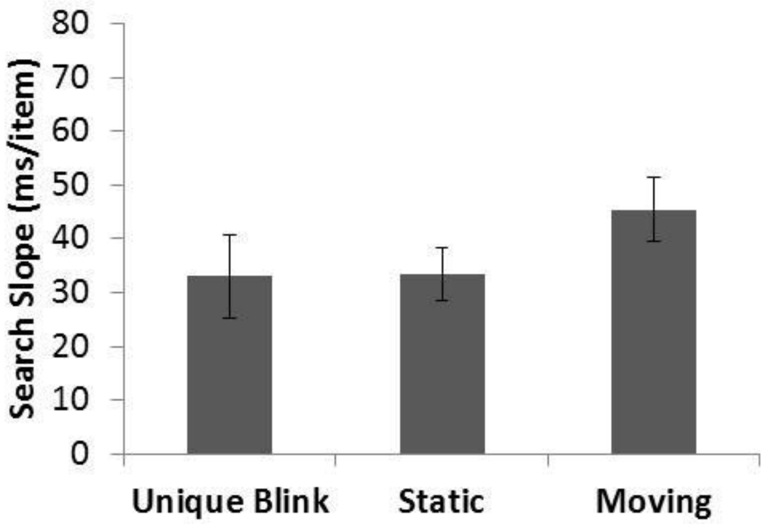


Figure 17

a)


1500
1300
1100
900
700
500
RT (ms)
5
9
Set Size
Static
Moving
Unique Blink

b)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50
40
30
20
10
0
Search Slope (ms/item)
Unique Blink
Static
Moving

Figure 18

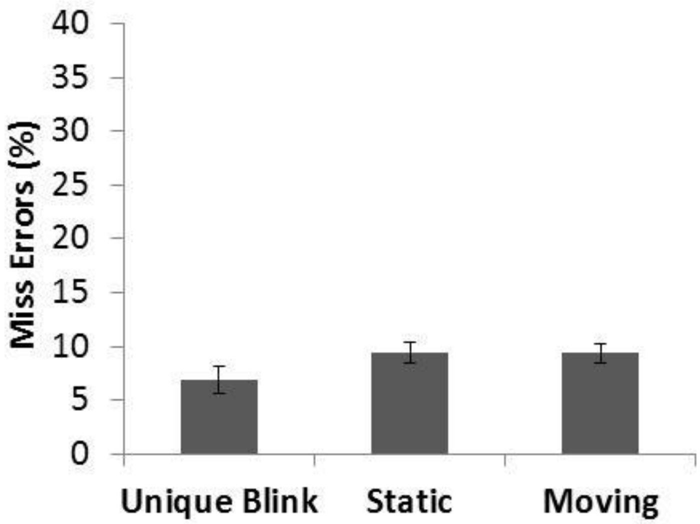

Figure 19