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Rapid, object-based learning in the deployment of transient attention

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Abstract. We show that transient attention summoned by an exogenous cue shows rapid learning of the relationship between the cue and a subsequent target in a discrimination task. In experiment 1, performance was unaffected when a target always appeared in the same position on a large cue, but was degraded when the target could appear anywhere within the extent of the larger cue. Experiment 2 shows that it was not the predictability of where the target appeared within the cue that aided performance, but rather a consistent location mapping of cue and target, since predictably alternating the target location relative to the cue led to worse performance than when the target was presented in the same location relative to the cue from trial to trial. Further analysis of the results of experiment 2 shows that the learning is rapid, evident after one trial, and has a cumulative influence over four consecutive trials. Possible neural correlates of this form of learning are discussed, with a focus on the supplementary eye fields in the prefrontal cortex. The reported experiments show that transient attention is not a simple reflexive mechanism but can show rapid visuospatial learning, in object-based coordinates.

1 Introduction

Research on covert shifts of visual attention has focused on two different kinds of attentional deployment (see Klein et al 1992; Pashler 1997; Yantis 1998 for reviews). Endogenous orienting of attention has been thought to be a top – down, voluntary process because there is no local connection between the site of attention and its cue. Endogenous attention can be summoned, for example, in a display in which an arrow at the center indicates where on an outer circle a target item will appear. Exogenous orienting, on the other hand, has often been assumed to be mediated by reflexive, low-level perceptual processes that automatically capture attention. Thus a stimulus that suddenly appears in the periphery of the visual field can summon exogenous attention. Nakayama and Mackeben (1989) suggested that these two forms of attention have different time courses: endogenous attention rises slowly and can be sustained whereas exogenous attention shows a very rapid onset and cannot be sustained.

Exogenous attention is stimulus-driven and is often assumed to be entirely 'bottom – up', such that it is automatically applied to a suddenly appearing stimulus (Jonides 1981; Yantis and Jonides 1984; Theeuwes 1991). The transient cells (y-cells) of the retina (Enroth-Cugell and Robson 1966; Cleland et al 1973) have been implicated as the neural substrate of this automatic capture of visual attention (Breitmeyer and Ganz 1976; Lennie 1980). Their fast responses and coarse position coding suggest that they could mediate sudden shifts of attention without detailed information about the exact nature and boundaries of the stimulus.

In contrast, Nakayama and Mackeben (1989), argued that, while transient attention was likely to be more automatic than sustained attention in that it was bound to the stimulus, it was an autonomous mechanism, not the same as the transient sensory mechanisms themselves. As evidence they showed that (i) local sensory transients were not needed to summon transient focal attention, and that (ii) repeated local transients could not maintain the deployment of transient attention. Further evidence for the decoupling of transient attention and transient sensory mechanisms comes from experiments where abruptly appearing stimuli are not necessarily attended if they are known to be irrelevant (Yantis and Jonides 1990; Bacon and Egeth 1994). These findings suggest that transient shifts of attention can be modulated and that they can be more or less activated, indicating that transient attention is appropriately adaptive to task demands. Similarly, the results of Folk et al (1992) indicate that exogenous capture of attention can be modulated by the expectancies of the observer. Also, Miller (1988) showed that visual search was facilitated at locations that frequently contained a target on different trials, compared to locations where targets appeared infrequently. Furthermore, this facilitation was not necessarily based on absolute coordinates but also on the relative position of display items. Related to this, Lauwereyns (1998) suggested that it may be problematic to make a strong distinction between exogenous and endogenous orienting. Thus there is evidence that attentional capture can be modulated by the expectancies of the viewer.

Though these studies indicate that transient attention is not machine-like or reflexive, they show only simple modulation of its strength. They do not address whether transient attention has a more differentiated flexibility, for example whether it might exhibit more specific forms of learning. For example, can transient attention change its spatial deployment relative to an unchanging cue depending on where a previous target of interest has appeared in relation to this cue? An interesting series of studies by Lambert and colleagues on what they termed "implicit peripheral cueing" imply that visual orienting, along with eye movements, can be influenced by peripheral cues independent of whether observers are aware of the validity of the cues or not (Lambert and Sumich 1996; Lambert et al 1999, 2000).

Taken together, the findings above suggest that the orienting of attention to peripheral stimuli may be more flexible than previously thought. To more fully characterize the flexibility of transient attention, we ask whether it can be applied to different locations within a briefly presented object. It would seem advantageous in everyday situations for attention to be deployed both quickly *and* to spatially appropriate locations. For example, suppose you are in a room and a person walks in. Your attention is likely to be directed towards the person's face insofar as you need to identify this person as quickly as possible. Would this more spatially differentiated form of attentional deployment be available to transient attentional mechanisms or would this be restricted to sustained attention?

In our experiments, we ask whether we *necessarily* attend to the entire transiently appearing object. In other words, does our visual attention spread over its whole extent? If transient attention were purely stimulus driven, it should extend over the entirety of a suddenly appearing object. It appears reasonable that attention would be spread over the whole extent of a *novel* object. However, when that stimulus ceases to be novel (eg through repeated presentation), it is of obvious advantage to attend to that portion of it that has proved the most relevant to the observer on previous presentations. Can transient attention show flexibility of this sort?

2 Experiment 1: The benefits of a consistent relationship between a cue and a target

We used a cue that was four times the diameter of the target (see figure 1). If attention is spread over the full extent of the cue, we expect performance to be unaffected by where, relative to the cue, the target subsequently appears. If, however, transient attention can be narrowed down to a smaller region on the cue, performance might improve when the target consistently appears in the same location relative to the cue.

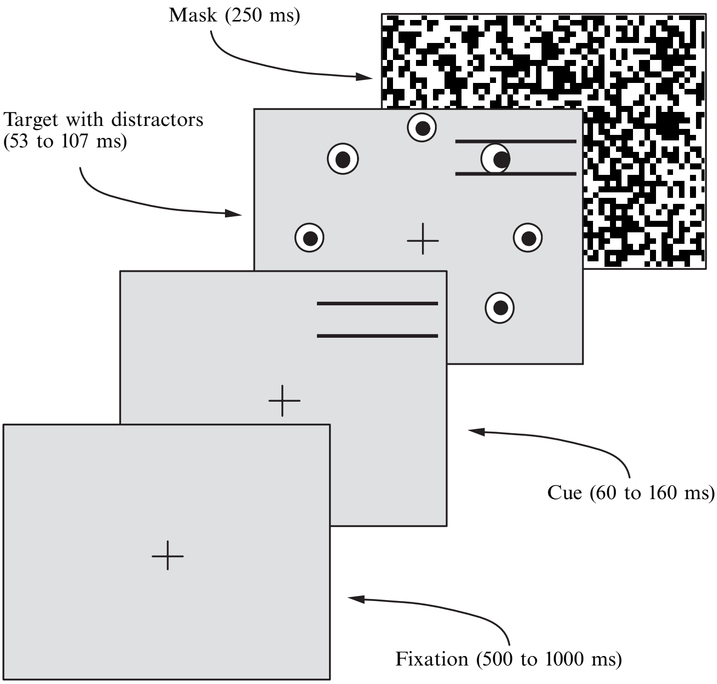

Figure 1. Frame sequence in the experiments: A trial started with the appearance of a fixation point for a variable time interval. Next, the cue, a pair of parallel bars, appeared indicating where the target would appear. The cue appeared for a variable time for the different conditions of the experiments. The target and distractors appeared next, with the cue still visible, followed by a random-dot mask. The figures are not drawn to the scale used in the experiment.

2.1 *Method*

The sequence and timing of events for each trial is depicted in figure 1. To demonstrate that transient attention can be narrowed down to a small portion of the larger cue, it is necessary to show that performance will remain good if the target maintains a fixed position relative to the cue despite large and unpredictable changes in the absolute position of the target from trial to trial. To test whether this is the case we compared the effects of two forms of spatial uncertainty.

In the 'cue-constant' condition (figure 2, left column) the position of the leftmost portion of the cue was 'locked' to the target position, while from trial to trial the whole circular array could vary in horizontal position relative to the fixation point. The amount of horizontal positional uncertainty of this whole array, relative to the fixation point, was fixed for a given block of trials, varying from 0 to 3.5 deg in six steps. The cue and target could appear in any of eight locations on the circle on each trial, while the remaining positions were occupied by distractors.

In the 'space-constant' condition the imaginary circle of the cue and targets was stationary from one trial to the next. Thus the target always appeared at one of eight fixed locations comprising a ring centered on the fixation point (see figure 2, right column). The amount of horizontal uncertainty of the position of the cue was varied from block to block (from 0 to 3.5 deg) in six steps.

Thus the parameter 'horizontal variation' refers to two different things in the two conditions of experiment 1. In the cue-constant condition, it refers to the variation of the search array relative to fixation, and in the space-constant condition it refers to the horizontal variation in the position of the target relative to the cue. Thus in the cue-constant condition the target *always* appeared at the leftmost end of the cue. In the space-constant condition the greater the horizontal variation the

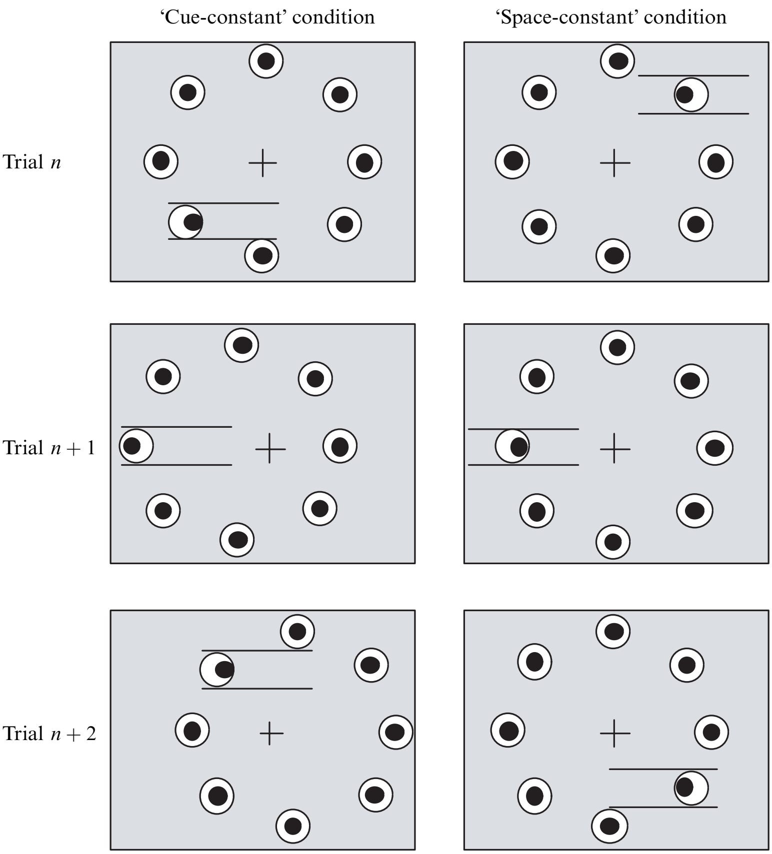

Figure 2. The two different conditions of experiment 1. In the 'cue-constant' condition the target always appeared at the leftmost end of the cue, while the imaginary circle the targets appeared on could move horizontally to a variable degree. In the 'space-constant' condition the imaginary circle stayed in place on the screen, while the position of the target relative to the cue varied. The cue and target could appear in one of eight locations on that circle, while distractors occupied the remaining positions. The figures are not drawn to the scale used in the experiment.

more uncertain the cue – target relationship became, and when the horizontal variation was maximal, the target could appear anywhere on the cue. In either condition, the cue and target could appear anywhere on the imaginary circle, while the remaining spaces were occupied by distractors. Maximum target eccentricity was 6.75 deg.

2.2 *Stimuli and procedure*

The targets were eye-like stimuli, that were looking to the left or to the right (see figure 2). The 'eyes' consisted of a light-gray (40.0 cd m^{-2}) ring surrounding a small disk of the same color. The large ring subtended 1.5 deg, while the disc subtended 0.5 deg. The sideways displacement of the disc on the target was 0.4 deg, whereas the disc was always at the exact center of the larger ring on the distractors. The cue was a pair of green (11.8 cd m^{-2}) horizontal bars 4 times the width of the target. The radius of the circular array was 5 deg. The display items appeared on a black (0.50 cd m^{-2}) background on a CRT screen, driven by an Amiga 1000 computer with a CRT frame rate of 60 Hz. The mask was a field of black (0.50 cd m^{-2}) and light-gray (40.0 cd m^{-2}) random dots, each subtending 6.6 min of arc, and covered the whole screen.

Observers fixated a cross at the center of the screen at a viewing distance of 71 cm. They were instructed to maintain fixation for the whole duration of each trial.

The cue indicated the position of an upcoming target in an array of 8 items. After a cue lead time of 167 ms, the target appeared for 66 ms, while the remaining positions on the circle were occupied by distractors. Observers pressed a key according to whether they saw 'eyes' looking left or right (thus chance performance was 50% correct). We used cue-lead and target times at which the transient component of attention is maximally effective, which are furthermore too brief for the activation of sustained attention (see Nakayama and Mackeben 1989). Trials were run in blocks of 20. All data points in the subsequent graphs represent at least 100 trials.

2.3 *Participants*
Two observers (MM and RO) participated in the experiment. Both had previous experience with the task. Observer RO was unaware of the purpose of the experiment.

2.4 *Results and discussion*
Recall the two conditions of the experiment and the predicted outcomes. If transient, visual attention were to be spread over the full extent of the suddenly appearing cue-object—there should be no effects of the relative position of the target and the cue as long as the target remains within the spatial extent of the cue. If, on the other hand, transient attention can be effectively deployed to a particular portion of a larger cue, then performance should depend heavily on the consistency of the relationship between the cue and the target. So, even if the target remains in the same set of eight positions from trial to trial as in the space-constant position, performance should become progressively degraded as the relative spatial uncertainty increases.

Figure 3 depicts the results from the experiment for the two observers. Note that there is a clear difference between the two conditions. With increasing uncertainty as to the position of the target relative to the cue in the space-constant condition performance becomes worse, going from the high point of 85% when there is no uncertainty, down to almost chance levels (50%) for the maximum uncertainty. Under the cue-constant condition, on the other hand, performance remains high and constant at approximately 85% correct despite the increasing uncertainty as to the absolute horizontal position of the target ring. So horizontal jumps of the array over a range of 3.5 deg from trial to trial have no deleterious effect on performance as long as the cue–target relationship remains fixed. In short, transient attention can be effectively deployed to the left end of a cue despite large shifts of the whole array.

It should be evident that these results are not consistent with a purely bottom–up account of exogenous cueing. Exogenous attention does not automatically spread over

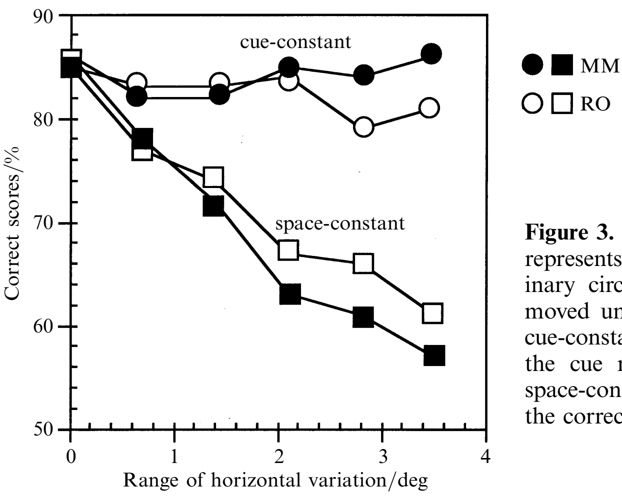

Figure 3. Results of experiment 1. The abscissa represents the spatial extent to which the imaginary circle of the target and the distractors moved unpredictably from trial to trial in the cue-constant condition and the extent to which the cue moved relative to the target in the space-constant condition. The ordinate shows the correct scores for each condition.

the whole extent of an abruptly appearing object, but can be focused on a much smaller portion if a consistent spatial pattern exists between the cue and target. It is also important to note that this result is object-based, rather than retinotopically specific, since the cue and target could appear on any part of the imaginary circle of targets and distractors from one trial to the next.

3 Experiment 2: Rapid learning in the deployment of transient attention

With experiment 2 we address the issue of learning. By what process does the attentional system come to deploy attention to just one portion of a large, suddenly appearing object, as in experiment 1? Whatever the process, the learning must occur fairly rapidly, because in the previous experiment there were large differences in performance between the different blocks of 20 trials. Thus, whenever there was a consistent relation between the cue and the target, it must not have taken long for that relation to be learned. Otherwise the differences in performance as a function of uncertainty in the space-constant condition would not have been seen. Thus we assume that the learning we observed must have occurred over intervals considerably shorter than 20 trials.

We addressed two questions regarding this learning of relations between stimuli with experiment 2. First, how quickly does the learning of the relationship develop? Second, what kind of consistency can be learned? There are at least two possible explanations why performance was not affected by the horizontal variation in the cue-constant condition of experiment 1: (i) the target was in a *predictable* location from trial to trial; (ii) the target always appeared in the *same location* relative to the cue. We ask whether it was the predictability of the location of the target that aided discrimination, or whether it was that the target always appeared in the same location on the cue. Performance was compared under three different conditions (see figure 4): (a) when the target was in a predictable, alternating location with respect to the cue from trial to trial (the 'switch' condition); (b) when the target appeared relatively consistently in the same location from trial to trial (the 'streak' condition), and (c) when the target was neither in a predictable nor in a consistent location from trial to trial (the 'random' condition).

3.1 *Method*

We used a similar cue to the one we used in experiment 1, but now the target could only appear in two locations relative to the cue: at the leftmost or rightmost end of it (see figure 4). In the switch condition the target always appeared in the opposite location to where it appeared on the last trial. Thus, in this condition, the target location was completely predictable from trial to trial. In the random condition the target appeared randomly at the leftmost or rightmost end of the cue on each trial. In the streak condition the target could appear at the same location on the cue for long sets of consecutive trials (streaks). The maximum length of a streak was 8 trials. The streak condition addresses the question whether a temporary consistency in the location mapping of the cue and target is adequate for the efficient deployment of transient attention.

We tested a number of different combinations of cue-lead and target times, all within the range at which the transient component of attention is maximally effective (Nakayama and Mackeben 1989).

3.2 *Procedure*

The experimental procedure was similar to that in experiment 1 except where noted. Observers were seated 57 cm away from the screen. The radius of the circular array was 5 deg. Observers responded by pressing a key whether the eye-like stimuli were looking up, down, to the left, or to the right (thus chance performance was 25%). The imaginary circle moved horizontally in a random direction relative to the fixation point (maximum 3.5 deg), from one trial to the next, keeping the cue versus target

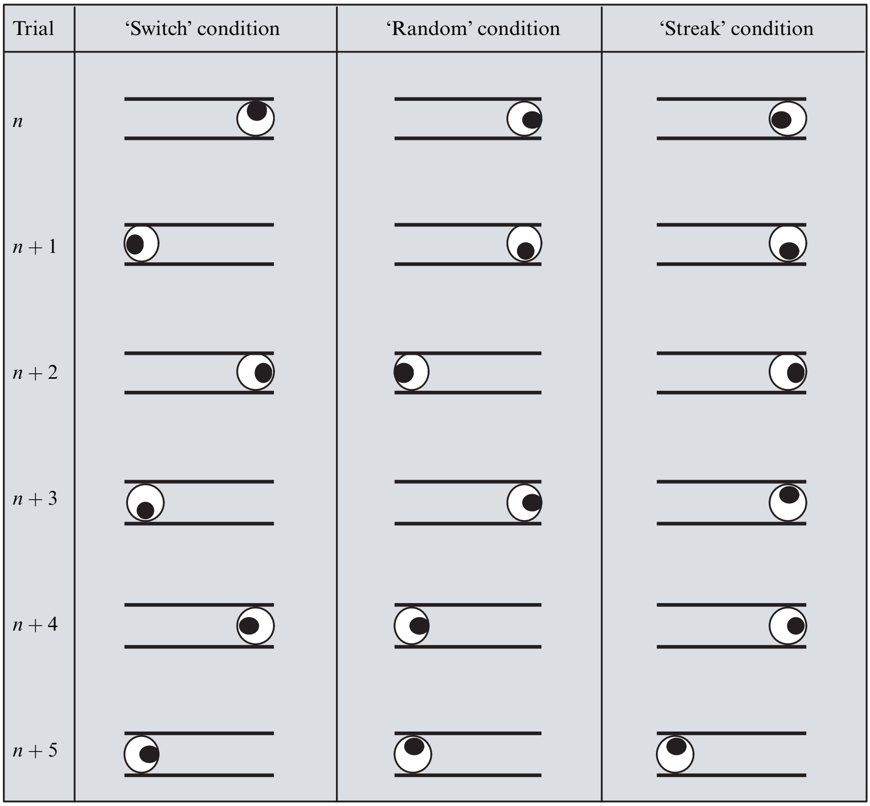

Figure 4. The three conditions of experiment 2. In all conditions the target could only appear at the leftmost or rightmost end of the cue. In the 'switch' condition the target always appeared in the opposite location to where it appeared on the previous trial. In the 'random' condition the target appeared randomly in either location, while in the 'streak' condition the target appeared in the same location for longer streaks (up to eight times in a row). The figures are not drawn to the scale used in the experiment.

configurations the same as described above. All data points in the subsequent graphs represent at least 100 trials. The cue-lead and target times tested were the same within each block of trials (100 trials in each block). We tested a number of different combinations of cue lead and target times (six different combinations for observer AMH and seven for AK), all previously shown to be within the temporal intervals activating transient attention, while target exposure is too brief for the activation of sustained attention (Nakayama and Mackeben 1989).

3.3 *Stimuli*

The 'eyes' consisted of a light-gray (41.0 cd m^{-2}) ring surrounding a smaller disk of the same color. The cue was a pair of green (11.8 cd m^{-2}) horizontal bars of a length equal to 4 times the diameter of the target. The display items appeared on a black (0.50 cd m^{-2}) background. Stimuli were presented on a CRT screen (with a frame rate of 75 Hz), driven by an Apple Macintosh 7500 computer. In this experiment, we used a local mask that replaced the target and distractors. The mask was a set of square patches of random dots (size = 6 min of arc). Each side of the square patch was equal in length to the diameter of the target and distractors.

3.4 *Participants*

Two observers (AK and AMH) participated in the experiment. Both had lengthy experience with the task. AMH was not aware of the purpose of the experiment.

3.5 *Results and discussion*

Figure 5 presents the mean correct score for the different combinations of cue lead and target times under the three different conditions. The results for all the different combinations were similar, so they are combined here. Under *all* combinations of cue lead and target times tested, performance was significantly better under the streak condition than the random and switch conditions (χ^2_2, $p < 0.05$). This was the case for both observers. A clear conclusion from this is that the consistent location mapping between the cue and target accounts for the results of experiment 1, where performance was unaffected by the horizontal variation in the cue-constant condition (recall that under the streak condition the target appears in the same location on the cue for long stretches of contiguous trials). It was not the predictability of the target location relative to the cue that aided performance, since performance in the switch condition in experiment 2, when the target was in a predictable location from trial to trial, was only slightly better than chance (25%).

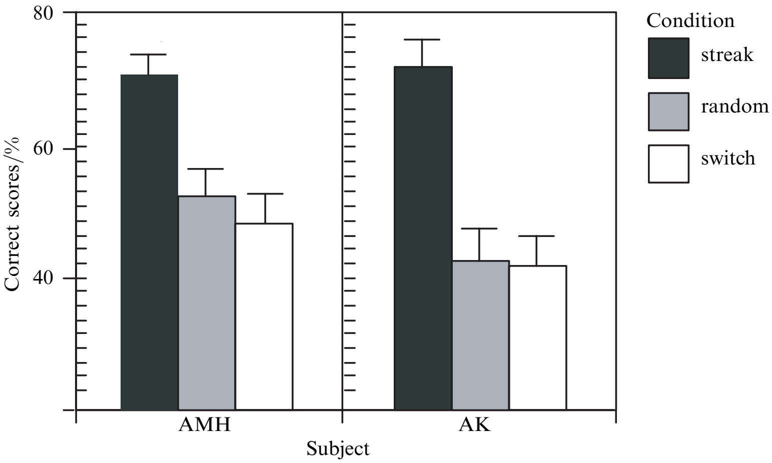

Figure 5. The results of experiment 2 for the two observers. The ordinate represents discrimination performance in terms of percentage correct responses. The results are averaged over the different combinations of cue-lead and target times that were tested. The error bars show the standard errors of proportion.

3.6 *Temporal build-up of the learning of cue – target relations*

The results from experiment 2 provide additional support for our conclusions from experiment 1 that transient, exogenously summoned attention is not necessarily automatic and impervious to experiential influences, since it can learn cue – target relations. Furthermore the results provide information about the time course of the learning of the relations between the cue and target. In figure 6 we have plotted performance under the streak condition as a function of where a particular trial was within a streak. If observers adapt quickly to where on the cue the target appears, we should see improvement in performance within a streak since the target appears in the same location on the consecutive trials within the streak. Figure 6 shows that there is rapid improvement in discrimination performance over a short span within a streak. By the fourth trial, performance seems to have reached a maximum. Note that, on the first trial of a streak, performance is poor, far below the streak average shown in figure 5. The first trial within a streak is where the target appeared in the location opposite to that on the previous trial.

The results of this experiment demonstrate rapid learning of cue – target relationships. They also demonstrate a relationship between the cue and target that transient attention can *not* learn. Even though the target location in the switch condition is

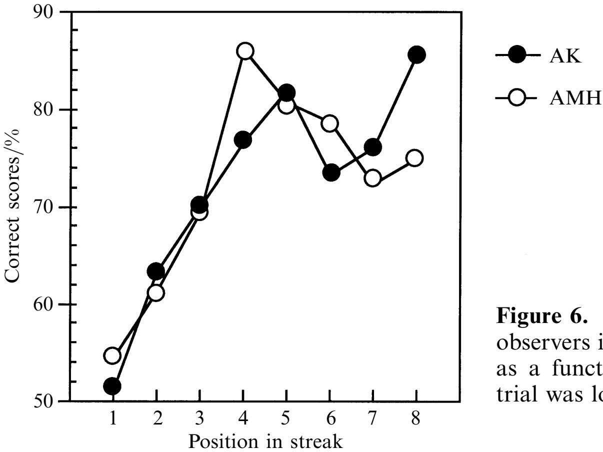

Figure 6. Discrimination performance for two observers in the 'streak' condition in experiment 2 as a function of where in a streak a particular trial was located.

predictable from trial to trial, performance is poor, no better than in the random condition, indicating that this particular cue – target relationship cannot be learned by the transient attentional system. Again, we emphasize that this learning is object-based rather than retinotopic, since the cue and target could appear in different locations from one trial to the next.

4 Experiment 3: Learning in transient attentional mechanisms

In experiment 2 we used a number of different combinations of cue lead and target times. Since our purpose was to study transient, exogenously driven attention, it was important to establish that the presentation times we used were indeed in the range where transient attention operates, and that they were also too brief for the activation of sustained attention. Nakayama and Mackeben (1989) observed that with short cue lead times (100 to 200 ms) and brief target exposure (30 to 100 ms) transient attention aided discrimination performance, while target exposure was too brief for the activation of sustained attention.

It is almost certain that the cue lead times and stimulus durations used in experiments 1 and 2 were in this critical range. Yet it would be useful to dispel any residual doubts that we were indeed studying transient attention, that the process which had learned the critical location within the cue would demonstrate the signature characteristics of transient attention itself (Nakayama and Mackeben 1989). In experiment 3 we tested whether the target exposure times we used in experiments 1 and 2 result in the rise in discrimination performance at shorter cue lead times and decline at longer cue lead times that are the signature mark of the activation of transient attention. We collected data for two observers using different cue lead times with a fixed target duration.

Methods for observer MM were similar to those described in experiment 1, while the methods for observer AK were similar to those described for experiment 2. The target appeared at the leftmost end of the cue on all trials for both observers (see figure 1).

4.1 *Results and discussion*

Figure 7 shows the performance of observers MM and AK for different cue lead times and constant target duration (66 ms). Most important to note is that these curves have the same form and time course as those reported in Nakayama and Mackeben's (1989) original description of transient attention. For observer MM, performance reached a peak at a cue lead time of 167 ms. For AK, the maximum cueing benefit was observed at cue lead times of 100 – 150 ms, which is also consistent with previous results. The data

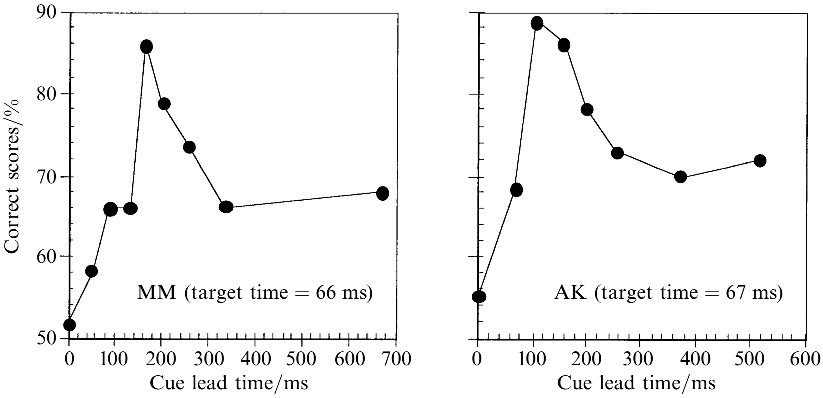

Figure 7. Discrimination performance observed in experiment 3, plotted as a function of cue lead time.

also show the characteristic drop in performance at longer cue lead times. Thus we are confident that the experiments described here reflect performance under transient attention unaffected by sustained attention, since in experiment 1 we examined performance with a target duration of 66 ms and a fixed cue lead time of 167 ms which corresponds to the peak of the transient attention function in figure 7. In experiment 2 the different cue lead times and target durations we used were all within the time window within which transient attention operates.

5 General discussion

We draw three main conclusions from the reported experiments.

(i) Transient attention can be allocated to a small area within a suddenly appearing object. Performance is good when the target always appears at the same location relative to the cue; whereas it is much worse when the target appears anywhere within the cue (experiment 1).

(ii) Consistency of spatial position of the target within the cue is sufficient to establish the phenomenon, target–cue predictability is not. This is shown by the high performance in the streak condition relative to the switch condition (experiment 2).

(iii) Transient attention shows rapid learning of the spatial relationship between the cue and the target (figure 6). The learning is object-based rather than space-based or retinotopic, since it happens independent of where the cue and target are presented in each case.

These points reinforce and extend Nakayama and Mackeben's (1989) earlier view that transient attention is not a reflexive mechanism. Most striking is how rapidly and effectively transient attention can learn to go to a specific position within a larger object. This is in line with other research that the capture of attention by a peripheral stimulus need not be purely bottom–up or reflexive (Folk et al 1992; Bacon and Egeth 1994).

5.1 *Relation of the priming of pop-out to the learned deployment transient attention*

Another phenomenon related to spatial learning and the deployment of attention is the priming of pop-out described by Maljkovic and Nakayama (1994, 1996, 2000). They showed faster identification of targets that were in consistent locations from trial to trial in a visual-search array (Maljkovic and Nakayama 1996, 2000). This priming builds up over several trials and is a form of implicit learning since the observer's performance is not dependent on explicit recall of the previous trials (Maljkovic and Nakayama 2000). The current results indicate that the flexible deployment of transient attention has many similarities to the priming of pop-out, showing a comparable build up over time, a need for spatial consistency, and operation in an object-centered coordinate frame. This broad spectrum of similarities suggests the existence of a powerful learning mechanism useful for the deployment of attention in a wide range of circumstances.

Yet the findings described here characterize the nature of the learning phenomenon with greater specificity, suggesting that it is the deployment of transient attention which is learned in both cases. In the priming of pop-out paradigm, transient attention is deployed more quickly to the odd-colored target and quicker reaction times are the consequence. In this paper, the learned component of transient attention is characterized by a rapidly changing time function, which rises almost immediately after the presentation of the cue and peaks between 100–200 ms (figure 7). This means that, for any suddenly appearing object, transient attention can be rapidly directed to a smaller portion of it—almost immediately upon its presentation.

5.2 *Object-based attention and possible neural correlates*

The learning of cue–target relations we observed was independent of the absolute location of the stimuli we used. Thus, visual attention operated in an object-based fashion since this learning was based on the relative locations of the cue and target (see Duncan 1984; Egly et al 1994; Reuter-Lorenz et al 1996). Abruptly appearing stimuli capture attention as long as they signify the appearance of a new perceptual object (Yantis 1993). The capturing of attention by a peripheral object is thus likely automatic only to a certain degree (Nakayama and Mackeben 1989), and our results in this paper indicate that its capture can be quite focused when a consistent spatial pattern over time is present.

Recently evidence has accumulated regarding the neural correlates of object-centered visual processing. Chen and Wise (1995) recorded from single cells in the supplementary eye fields (SEFs) in the prefrontal cortex and hypothesized that they play a role in eye-movement preparation in object-based coordinates rather than in coordinates based on absolute position. They also suggested that the SEFs are part of a neural system "learning flexible, non-spatial stimulus–response relations" (page 1101). Further evidence for object-centered response properties of neurons in the SEFs comes from single-cell recordings by Olson and Gettner (1995, 1996). They found SEF neurons that were activated most strongly when the animals were preparing saccades to particular locations on a stimulus irrespective of its absolute position. Thus, there is neurophysiological evidence both for the learning of stimulus–response properties in SEF neurons, and that these neurons respond in an object-centered manner. Such neurons could constitute the neurophysiological substrate for the rapid object-centered learning reported here.

5.3 *Possible implications for the control of saccadic eye movements*

We suspect that the adaptation we uncovered with the experiments described here will have an influence on saccadic eye movements—either on their latency or accuracy or both. Our results suggest the possibility that saccades to a target that has a consistent positional relationship to a cue will be more efficient than when that relationship is random. McPeek et al (1999) showed that priming in visual search has a direct facilitatory effect on eye movements to those targets. So, for example, if observers were to make an eye movement to a red target among green distractors, saccade latencies were faster if the target on the previous trial was also red. It is possible that similar facilitation of saccadic eye movements to particular portions of a large cue will be seen, reflecting the adaptive focusing of transient attention that we have demonstrated here. This would accord well with the results of experiments showing the important relationship between shifts of attention and saccadic eye movements (Hoffman and Subramaniam 1995; Kowler et al 1995; Deubel and Schneider 1996).

6 Conclusions

It is important for organisms to orient quickly and purposefully to abruptly changing parts of their visual environment. It is possible that our experiments have uncovered one way in which organisms achieve this goal. The results imply that observers can orient purposefully to previously important parts of stimuli surprisingly fast, within time limits that have often been thought to allow only reflexive responding. Transient, exogenous orienting of visual attention is thus not purely sensory in nature. In this context it may thus be possible to speak of efficient exogenous orienting of attention, which would have been deemed unlikely under many previous accounts of visual attention that emphasized its reflexive nature.

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References

Bacon W F, Egeth H E, 1994 "Overriding stimulus driven attentional capture" *Perception & Psychophysics* **55** 485 – 496

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

Chen L L, Wise S P, 1995 "Neuronal activity in the supplementary eye field during acquisition of conditional oculomotor associations" *Journal of Physiology* **73** 1101 – 1121

Cleland B G, Levick W R, Sanderson K J, 1973 "Properties of sustained and transient ganglion cells in the cat retina" *Journal of Physiology* **228** 649 – 680

Deubel H, Schneider W X, 1996 "Saccade target selection and object recognition—Evidence for a common attentional mechanism" *Vision Research* **36** 441 – 452

Duncan J, 1984 "Selective attention and the organization of visual information" *Journal of Experimental Psychology: General* **113** 501 – 517

Egly R, Driver J, Rafal R D, 1994 "Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects" *Journal of Experimental Psychology: General* **123** 161 – 177

Enroth-Cugell C, Robson J G, 1966 "The contrast sensitivity of retinal ganglion cells of the cat" *Journal of Physiology* **187** 517 – 522

Folk C L, Remington R, Johnston J C, 1992 "Involuntary orienting is contingent on attentional control settings" *Journal of Experimental Psychology: Human Perception and Performance* **18** 1030 – 1044

Hoffman J E, Subramaniam B, 1995 "Saccadic eye movements and visual selective attention" *Perception & Psychophysics* **57** 787 – 795

Jonides J, 1981 "Voluntary versus automatic control over the mind's eye's movement", in *Attention and Performance IX* Eds J B Long, A D Baddeley (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 187 – 203

Klein R, Kingstone A, Pontefract A, 1992 "Orienting of visual attention", in *Eye Movements and Visual Cognition* Ed. K Rayner (New York: Springer) pp 46 – 65

Kowler E, Anderson E, Dosher B, Blaser E, 1995 "The role of attention in the programming of saccades" *Vision Research* **35** 1897 – 1916

Kristjánsson Á, Wang D, Nakayama K, (submitted) "The role of priming in conjunction search"

Lambert A, Naikar N, McLachlan K, Aitken V, 1999 "A new component of visual orienting: Implicit effects of peripheral information and subthreshold cues on covert attention" *Journal of Experimental Psychology: Human Perception and Performance* **25** 321 – 340

Lambert A, Norris A, Naikar N, Aitken V, 2000 "Effects of informative peripheral cues on eye movements: Revisiting William James' 'derived attention'" *Visual Cognition* **7** 545 – 569

Lambert A, Sumich A L, 1996 "Spatial orienting controlled without awareness: A semantically based implicit learning effect" *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology* **49** 490 – 518

Lauwereyns J, 1998 "Exogenous/endogenous control of space-based/object-based attention: Four types of visual selection?" *European Journal of Cognitive Psychology* **10** 41 – 74

Lennie P, 1980 "Parallel visual pathways: A review" *Vision Research* **20** 561 – 594

McPeek R M, Maljkovic V, Nakayama K, 1999 "Saccades require focal attention and are facilitated by a short-term memory system" *Vision Research* **39** 1555 – 1566

Maljkovic V, Nakayama K, 1994 "Priming of pop-out: I. Role of features" *Memory and Cognition* **22** 657 – 672
Maljkovic V, Nakayama K, 1996 "Priming of pop-out: II. Role of position" *Perception & Psychophysics* **58** 977 – 991
Maljkovic V, Nakayama K, 2000 "Priming of pop-out: III. A short term implicit memory system beneficial for rapid target selection" *Visual Cognition* **7** 571 – 595
Miller J, 1988 "Components of the location probability effect in visual search tasks" *Journal of Experimental Psychology: Human Perception and Performance* **14** 453 – 471
Nakayama K, Mackeben M, 1989 "Sustained and transient components of visual attention" *Vision Research* **29** 1631 – 1647
Olson C R, Gettner S N, 1995 "Object-centered direction selectivity in the macaque supplementary eye field" *Science* **269** 985 – 988
Olson C R, Gettner S N, 1996 "Representation of object-centered space in the primate frontal lobe" *Cognitive Brain Research* **5** 147 – 156
Pashler H, 1997 *The Psychology of Attention* (Cambridge, MA: MIT Press)
Reuter-Lorenz P, Drain M, Hardy-Morais C, 1996 "Object centered attentional biases in the intact brain" *Journal of Cognitive Neuroscience* **8** 540 – 550
Theeuwes J, 1991 "Exogenous and endogenous control of attention: The effects of visual onsets and offsets" *Perception & Psychophysics* **49** 83 – 90
Yantis S, 1993 "Stimulus driven attentional capture" *Current Directions in Psychological Science* **2** 156 – 161
Yantis S, 1998 "Control of visual attention", in *Attention* Ed. H Pashler (Hove, East Sussex: Psychology Press) pp 223 – 256
Yantis S, Jonides J, 1984 "Abrupt visual onsets and selective attention: Evidence from visual search" *Journal of Experimental Psychology: Human Perception and Performance* **10** 601 – 621
Yantis S, Jonides J, 1990 "Abrupt visual onsets and selective attention: Voluntary versus automatic allocation" *Journal of Experimental Psychology: Human Perception and Performance* **16** 121 – 134