1. Background
A fundamental issue in visual attention research is the degree to which what we notice in the world is controlled by properties of the visual scene or by our intentions and goals. Models of visual search make assumptions about interactions between stimulus-driven and goal-directed factors (e.g. Treisman and Sato, 1990; Wolfe, 1994, 1997). One approach to the general question involves studying the conditions under which newly onset visual objects do or do not capture attention. Real world examples would be the likelihood that, or speed with which, an observer might notice a rabbit “breaking cover” or a new token appearing on an air-traffic control screen.

Two of the questions vision scientists have posed are:


(2) What kind of attention is it that new objects capture? (e.g. Gellatly & Cole, 2000; Hand & al, 2000; Luck & Thomas, 1999; Yantis, 1998). More specifically, do new objects attract spatial attention or object-based attention (Duncan, 1980; Driver, 1996; Yantis, 1998)?

Answers to these questions have proved far from easy, as indicated by the scope of the above sample of references. This is partly because the questions are not as simple as they appear. However, a further cause of difficulty has been a lack of methodical comparisons within the field. Investigators have, for good reasons, used a variety of tasks to investigate these issues. Whether all the tasks isolate and tap into the same process(es) has rarely been established. In particular, it is not self evident that the same variety of attention is captured by all experiments on attentional capture (Luck & Thomas, 1999). What is more, performance on the different tasks has usually been assessed in terms only of speed or, sometimes, accuracy, but not both. There has been a tendency to assume the two measures are unproblematically equivalent measures of the same underlying process(es). This is not necessarily the case. Santee & Egeth
(1982) showed that, for short display exposures, response accuracy is sensitive to perceptual factors whereas RT is sensitive to response-selection processes. Gellatly & al (1999b, 2000) found that under some circumstances targets that were better detected on an accuracy measure of performance were responded to more slowly in a RT version of the same task. Equivalence of performance measures needs to be demonstrated not assumed (Handy & al, 1996, 2000; Luck & Thomas, 1999).

2. Objectives

The project objectives are to contribute to answering the four questions:
1) By what mechanism do new objects attract attention?
2) What sort of attention do they attract, spatial attention or object-based attention?
3) Do different tasks for studying the attentional effects of new objects tap into the same attentional processes?
4) Do reaction time and detection accuracy always provide equivalent measures of performance on tasks of this kind?

The proposal outlined 4 sets of experiments to address these questions.

3. Methods

All the research involved standard laboratory-experiment techniques, with computer controlled presentation of stimuli and data recording. All experiments employed undergraduate (or comparable) participants. Few ethical problems arise in connection with studies of this kind, but participants were screened for sensitivity to flicker and informed of their right to withdraw at any stage. Data analysis has been and continues to be by ANOVA and associated parametric techniques.

4. Results

Results are reported in terms of the originally proposed sets of experiments. For expository purposes the order of these has been changed from the order in the proposal.

(1) Capture by Luminance Change, Contour Onset or Object Onset
Yantis & Gibson (1994), Yantis & Hillstrom (1994) and Gellatly & Cole (1999a) found that changing the luminance of old objects did not cause them to be treated as new objects, suggesting that only object onsets capture attention. However the conclusion has to be qualified because all these studies employed the onset singleton letter task (OSLT – see Fig 1) in which new object onsets are confounded with onset of new contours constituting the new objects. By contrast, Watson and Humphreys (1995, 1997) found that luminance changes did "rejuvenate" old objects and whereas contour onsets that were not object onsets did not attract attention. However, Watson & Humphreys used a very different task and, because it was not their aim to do so, they did not demonstrate capture of attention by object onsets in their studies.

Such contradictory results raise the issue of comparability across tasks and performance measures. This series of studies sought to cast some light on these matters. Our proposal outlined 4 possible methods for addressing the issue. In practice, it was possible to implement only two of these.

Experiments 1.1 to 1.4 compared performance on a standard version of the Onset Multiple Feature Task (OMFT - 4 old + 4 new objects – Fig 2) with versions in which, simultaneously with new object onset, old objects altered in size by growing either larger or smaller to match the size of the new objects, with their contours therefore changing position. The degree of size change, the measure of performance, and the nature of the squares (filled or outline) varied across experiments. Results from the experiments showed some inconsistencies with one another but overall the weight of evidence was that changing the location of old object contours did not eliminate or reduce the new object (or new target) advantage (e.g. Graph 1).

Experiment 1.5 compared performance on the OSLT (Fig 1) using standard figure eight placeholders versus 90° rotated \( \perp \) placeholders. In the latter condition old as well as new objects were associated with onset of external contours, and amount of luminance change at old and new object locations was approximately matched. There was evidence of attentional capture by the onset singleton in both conditions; but the effect was greatly reduced with the \( \perp \) placeholders (Graph 2). The addition of new contour to old objects reduced the power of the new object to attract attention. This outcome contrasts markedly with the results of the previous 4 experiments. Which result obtains may depend on whether the old objects are perceived as "the same" but with altered contours or as having "changed into new objects".
Section summary: Experiments 1.1 to 1.4 demonstrate that when old objects are perceived as “the same objects” (or as occupying broadly the same locations) then, even though their contours have changed in size and position, the visual system does not treat them as new. This suggests that what is attracted by new objects is object-based attention rather than spatial attention. This follows because spatial attention should be equally attracted by luminance change associated with new object onset or with old object size changes, which was clearly not the case in 1.1 to 1.4. It also seems that object-base attention is only attracted by onset of a new object and not by onset of new contour. However, the Experiment 1.5 result hints that contour onset may attract attention only when it seems to indicate the appearance of a new object rather than transformation of an old object.

(2) Time course of new target effects.
If different tasks index fluctuations of the same kind of attention to objects, it is to be expected that the time course of fluctuation should be comparable across tasks and performance measures. We can ask how “old” an old object has to be before the visual system treats it as “old”. We know of no published papers that address this paper directly, and of only one that does so indirectly (Watson and Humphreys, 1997).

A total of 8 experiments have been conducted under this heading during the period of the grant. Experiment 2.1 examined the effect of varying the SOA between old objects and the new object in the OSLT (Fig 1 but with placeholder duration varying from 33ms to 500ms). RT was the measure of performance. Experiment 2.2 was the same except that it employed the onset singleton feature task (OSFT), a variant of OMFT in which only a single new square is added to a display of old squares (Fig 3). In both experiments, it was found that the single new object enjoyed a marked advantage at all SOAs (Graphs 3 & 4). The size of the effect did not increase with duration of the placeholder display (i.e. with the “age” of old objects). These results suggest that an onset singleton does indeed “capture” attention from older objects rather than the older objects simply losing attention as they age.

Because a singleton new object may be especially able to capture both spatial and object-based attention, Experiments 2.3 and 2.4 examined what happens when there are multiple old and new objects in a search display. Experiment 2.3 employed RT and the Onset Multiple Letter
Task (OMLT). Displays contained 3 old objects, derived from placeholders, and 3 new objects (Fig 4). The age of old objects again varied from 33ms to 500ms. RT was faster to new targets at all old/new SOAs but the difference was not significant until 300ms (Graph 5). In general, RT to old targets became slower with increasing SOA while RT to new targets became faster. Experiment 2.4 gave a similar result using RT and the OMFT, with search displays containing 4 old and 4 new objects (Fig 2). However, the slowing of RT to old targets as SOA increased was much more pronounced and the speeding of RT to new targets rather less pronounced (Graph 6). RT was also longer overall.

The combination of faster RT to new targets and slower RT to old targets as SOA increases could suggest a battle for attention between new and old objects, with the balance of power shifting increasingly towards new objects at longer SOAs. This would make sense if onsetting objects attract attention but, as they grow older, become increasingly at risk of having it stolen from them by subsequently onsetting new objects. Against this interpretation, however, is the finding from Experiments 2.1 and 2.2 that a single new object captures attention at the shortest of SOAs, and that this effect does not greatly increase with SOA.

However, in all these studies there was a possibility of RTs having been contaminated by response inhibition (Gellatly et al, 1999b, 2002). Subjects must inhibit their motor systems in order to prevent responses being erroneously emitted to the onset of the placeholder display. If the switch to onset of the search display (new object onset) occurs very soon after, then RT may reflect not just time to identify the target but also the persisting effect of response inhibition. The speed up in RT to new targets as SOA (placeholder duration) increases might then reflect not an increase in attention but a gradual decline of response inhibition. By contrast, the slowing of responses to old targets would reflect a genuine loss of attention to old objects. The latter could occur either because attention has been “captured” by the new objects or simply because attention “leaks away” from old objects as they “age”.

Experiment 2.5 replicated Experiment 2.4 but with accuracy as the measure of performance. New targets were better detected than old targets at all SOAs, detection of old targets decreased steadily with SOA (i.e. “age”) but detection of new targets did not vary (Graph 7). This contrast with the results of 2.3 and 2.4 implies that, because of response inhibition, RT may be a less reliable measure of performance than detection accuracy. The rapid reduction in the attentional status of almost new (i.e. Old) objects seems to occur automatically since in these
experiments subjects, far from benefiting from inhibition of object representations (or locations), are disadvantaged by it. Also, the process starts with a rapidity that rules out the imposition of selective voluntary inhibition. This conclusion found further support in the results of Experiment 2.6. In this experiment displays of 8 squares were presented one of which turned into a target after a delay of 0, 33, 83, 150, 300 or 500 ms (Fig 5). Relative to the zero delay condition, detection accuracy had dropped at the shortest interval and continued to decline as the objects grew older (Graph 8). It is anticipated that with the addition of one further experiment to replicate Experiment 2.3 with detection accuracy rather than RT as the measure, these experiments will make a single paper.

The experiments just described employed first order, luminance defined objects. A parallel stream of experiments was also conducted using second order objects. These were defined by contrast in the direction of motion of figural and background texture elements. A target was a square containing stationary texture, non-target objects contained upward moving texture (Fig 6), and the background consisted of downward moving texture. Experiment 2.7 replicated Experiment 2.4. Search displays contained 4 old and 4 new objects. RT for new targets was little affected by the SOA between old and new objects. RT to old targets did not become significantly slower than RT to new targets until SOA = 300ms, with a further marked slowing at 500 ms. Very similar results were obtained in Experiment 2.8, which differed from Experiment 2.7 only in that accuracy of target detection was the measure of performance rather than speed. Detection accuracy was significantly worse for old targets than for new targets by SOA = 300 ms, with a further marked decline at 500 ms. The two experiments indicate that second order objects lose attention rather more slowly than do first order objects. Reasons for this are not immediately apparent and a further experiment is to be undertaken. A further paper is expected from these three experiments.

Section summary: The results of 2.1 and 2.2 showed that a single new object captures attention, probably including spatial attention, at any SOA and that the strength of the effect is independent of the “age” of old objects. By contrast the results of Experiments 2.3 to 2.6 indicated that when multiple new objects compete with multiple old objects it is inhibition of attention to the latter that confers an advantage on the former. This may be yet another example of inhibition of return (Posner and Cohen, 1984). But whereas IOR has never previously been found for SOAs below 300 ms, our studies show inhibition starting to operate
within 33 ms of object onset. Comparison of 2.5 with 2.3 and 2.4 suggests that detection accuracy is a better measure of performance than RT for tasks of this sort. Experiments 2.7 and 2.8 show that the time, course of inhibition may differ between first and second order objects.

(3) Spatial cueing and capture of attention

This series of experiments was designed to test what kind of attention it is that new objects initially attract but then rapidly lose. Two experimental techniques were outlined in the grant proposal: cueing large areas within a hemifield, and cueing relatively specific locations. In practice, only the second of these techniques, by far the more widely employed in previous research, was utilised.

The cueing technique introduced by Posner (1980) is thought to summon spatial attention to the location of the cue. We predicted that if new objects attract spatial attention, then cueing spatial attention to the location of a target, new or old, should greatly reduce, or eliminate, the new target advantage. Focusing spatial attention at the target location might be expected to swamp any difference in spatial attention due to the age of the object; as it seemed to do in the studies of Yantis & Jonides (1990). Alternatively, if new objects attract object-based attention then, in keeping with the logic of additive factors (Sternberg, 1969), their advantage might be independent of the effect of spatial attention. In other words, object age and cueing should have additive effects on performance.

In Experiment 3.1, displays of all new or all old luminance defined objects were briefly presented (Figure 7), with detection accuracy as the measure of performance. Each object appeared inside an already present outline box. On every trial one box was cued by being brightened for 100 ms immediately prior to onset of the search display. The location of the cue was unpredictive of target location. A very large new target advantage was found when the locations of cue and target coincided. The further apart these locations were, the smaller the new object advantage became, disappearing entirely when the two were on opposite sides of the circular array (Graph 9). Experiment 3.2 was a partial replication of Experiment 3.1 but included additional control conditions. On 25% of target present trials, the cue validly predicted target location; on 25% cue and target were at opposite locations; on 25% all locations were cued; on 25% no locations were cued. Results were similar to Experiment 3.1 (Graph 10). There was a large new target advantage in the valid cue condition, but only a very small effect in the other 3 conditions. Results
of both experiments demonstrate that far from eliminating or leaving unaffected the new target advantage, valid cueing of target location maximises the effect. This is an unexpected result. Furthermore, in both experiments the new target advantage was either absent or unusually small when the cue was opposite the target or when there was no effective cue. Given the reliability of the advantage in all the set 1 and set 2 studies, this was a perplexing finding.

Experiment 3.3 investigated the possibility that having objects presented in boxes in OMFT displays may have affected the new target advantage. All old or all new search displays were presented either in the standard way (Fig 5) or with the objects appearing in boxes (Fig 7). There was no cueing, and accuracy of detection was the measure. The usual new target advantage was observed for the standard condition but this was greatly reduced when objects appeared in boxes. In particular, the presence of boxes reduced the detection of new targets but had little effect on old targets. Given the widespread use of box cues in studies of visual attention, this is a highly pertinent finding.

Experiments 3.1 - 3.3 yielded important findings using the OMFT. The cueing result was contrary to that reported by Yantis & Jonides (1990), who had used different tasks (OSLT and OMLT), RT rather than accuracy, and endogenous rather than exogenous cueing. Experiment 3.4 was, therefore, conducted to see if the main results of the three preceding studies would generalise to the OMLT. Accuracy was again the measure of performance. Displays of 3 old and 3 new objects were presented on every trial Letters (and figure 8 placeholders) appeared as normal (Fig 4) or in already present boxes (Fig 8). These were the standard and box conditions. In both conditions, there might or might not be a cue. In the standard condition, the cue appeared as a bright box for 100 ms immediately prior to the search display, but no other boxes were present. In the boxed condition the trial sequence commenced with the presentation of 6 boxes. On cued trials the target appeared at the cued location (valid cue) or opposite it (invalid cue). There was a large cueing effect in both the standard and boxed conditions (Graph 11). Valid cueing was of greater benefit for new targets than for old targets. And, as in 3.3, the new target advantage was reduced in the boxed no cue condition. The difference between our results and those of Yantis & Jonides is, therefore, not due to a difference between letter identification and detection of a target defined by a simple feature.

Section summary: We know from the time course studies that, as they age, visual objects accrue inhibition. Boxes are old objects. Inhibition
applies not just to an outline box itself but to a square that comes on inside it. A new square (object) coming on inside a box attracts less attention than it would outside a box because of the inhibition applying to the box, so detection of new targets is decreased. For old objects there is less effect of a box because old objects suffer their own inhibition even when not inside a box. What sort of attention is first attracted to a new object and then so rapidly inhibited? Since cueing spatial attention to the target location does not eliminate the new object advantage, the attention summoned by new objects must be object-based attention. It also turns out that rather than merely adding to object-based attention, spatial attention actually multiplies its effect. (Because eye-movements were not monitored, we might be dealing here with overt rather than covert spatial attention; but the same interpretation applies.)

The 4 experiments in this series have yielded consistent and important results that generalise across tasks. Unfortunately, a ceiling effect obscured some of the finer detail of the results of Experiment 3.4. A further experiment is to be conducted to rectify the matter, and also to control for eye-movements. The 5 experiments in this set will then make a single paper.

(4) How many new objects can benefit from capture?

As the project proceeded it became clear both that there would be insufficient time to pursue all the initially identified lines of enquiry and also that output targets were likely to be achieved without doing so. On the basis of the time course data, it was felt that the question of how many new objects can benefit from capture would prove to be the least fruitful to pursue. This line of enquiry was therefore chosen to be dropped.

Additional studies

Early in the project, a number of studies were conducted with displays of objects that were isoluminant with their background. It was thought these might have advantages over displays with luminance defined shapes. In the event there were problems with control of stimulus saliency and the original luminance defined display types were retained. It is possible that data from these studies may at some future time appear as part of a paper examining the role of stimulus parameters in the new target effect.
Over-view of experimental work completed

The grant application requested funding for 200 hours of experimentation to yield 4 conference papers and 4 journal articles. This was calculated on the basis of 10 subjects for each of 40 half-hour experiments. In practice, there were 12 to 16 subjects per experiment and most experiments took a full hour. In total, 246 hours of experimentation were conducted. Outputs already achieved and planned outputs are listed on Page 9.

Assessment of objectives

The objectives of the project were stated above in terms of four questions. Our data provide at least partial answers to all of these. New objects attract attention by means of a mechanism that responds to “objecthood” (figure/ground segregation) rather than to luminance change or contour onset (Experimental set 1). The attention attracted to new objects is object-based attention rather than spatial attention (Experimental sets 1 and 3). The different tasks used to study this type of attentional effect — or at least those employed in our studies — clearly tap into the same attentional processes (Experimental sets 2 and 3). However, there are circumstances in which detection accuracy is a more veridical measure of performance than is RT, because RTs are sometimes affected by response inhibition (Experimental sets 1 and 2).

In addition, three other important findings were made:
1) When there is more than a single new object, the new object advantage results almost exclusively from loss of attention to old objects rather than from “capture” of attention by new objects. This loss starts within 33 ms of onset (Experimental set 2)
2) The inhibition that accrues to an outline box applies also to new objects that onset inside it (Experimental set 3)
3) Spatial attention does not simply add to the effect of object-based attention but multiplies it (Experimental set 3).

5. Activities

Part of the Experimental set 1 work was reported at the European Conference on Visual Perception 2001 (Cole and Gellatly, 2001). The data of Experiments 3.1 and 3.2 were presented at a meeting of the European Society for Cognitive Psychology (Gellatly and Cole 2001). A further conference paper based on the other experiments of set 3 will be submitted for presentation to the Experimental Psychology Society,
probably in January 2003. A presentation based on Experimental set 2 is to be given at a meeting of the Vision Sciences Society in May 2002 (Gellatly & Cole 2002a). It was intended that a related presentation of other data from the same set should be given to the Applied Vision Association in March 2002 (Gellatly & Cole, 2002b); however, because of conflicting commitments, this has been deferred to the December 2002 meeting of the AVA. In addition, the named investigator has already presented selections of the above results in invited presentations at the Open University, the University of Dundee, Staffordshire University, and Durham University.

6. Outputs
Because this has been a short grant involving a large amount of experimentation, the writing up of results in article form has had to wait until the end of the grant period. Four papers are planned. The first, based on the set 1 experiments, is nearing completion and will be submitted in mid-Spring. A second will be based on Experiments 2.1 to 2.6. The remaining set 2 experiments will constitute a third paper. Fourthly, an article based on all 5 experiments of set 3 will be written up and submitted during summer 2002.

7. Impacts
Three findings from this research have implications for the manner in which important new information is displayed to systems operators:
(1) Where multiple new items of information are presented simultaneously, there will be an extremely rapid loss of object-based attention to them.
(2) Presenting new information in boxes reduces attention to it.
(3) Pre-cueing spatial attention to the location of new information yields a disproportionate increase in total attention paid to it.

8. Future research priorities
Several lines of investigation follow from the research reported here:
(1) The generality of the cueing effect – Does it apply to face recognition? Might it have implications for witness identification?
(2) Why does inhibition of old objects appear to be automatic in our studies but strategic in others (e.g. Watson & Humphreys, 1997)?
(3) How much is inhibition of old objects object-based or space-based?
(4) Under what conditions does response inhibition affect RTs?
(5) What can contour change experiments tell us about what constitutes an object (new object) for the visual system (e.g. Scholl 2001)