Inattentional blindness: the role of perceptual load, effects of stimulus type and position, and development over childhood.

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Abstract

Inattentional blindness refers to a failure to detect visible objects when attention is engaged in a task. Despite the central role for attention implied by its name, there is surprisingly little evidence that inattentional blindness indeed results from inattention. In this thesis I provide such evidence in demonstrating that rates of inattentional blindness critically depend on the extent to which a relevant task exhausts attentional capacity (under high perceptual load) or leaves spare capacity (under low perceptual load) for determining awareness of task-irrelevant stimuli. This was found when load was increased by requiring a more subtle line-length judgment in the traditional inattentional blindness cross-task, or by increasing the number of items in a visual search task. Further experiments generalised the effects of perceptual load on awareness across simple shapes and meaningful objects, and for irrelevant stimuli appearing in the periphery and at fixation. By contrast, upright (but not inverted) faces reached awareness regardless of the level of perceptual load in the relevant task. These findings are consistent with previous behavioural perceptual load studies using reaction time (RT) measures of task-irrelevant processing (Lavie, 1995; Lavie, Ro & Russell, 2003; see Lavie, 2005 for review) and support the conclusion that perceptual load determines conscious awareness. The experiments also found no advantage for awareness at fixation versus awareness at the periphery, highlighting a potential dissociation between awareness measures and distracter effects on RTs (which have previously shown such an advantage, Beck & Lavie, 2005). Finally, this thesis presents a preliminary investigation of the development of awareness as measured by rates of inattentional blindness under different levels of task load in children and in adults. Results

demonstrated a clear pattern of increasing awareness with increasing age, and lend partial support to the notion that the development of attentional capacity underlies this trend in awareness.

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Chapter 1

General Introduction

1.1 Preface

The brain receives a constant stream of information from all the senses. However, despite this enormity of information and despite the rich visual impression we usually enjoy of the world, it is a common experience that clearly visible events are overlooked when attention is paid to an alternative task. When driving, for example, motorists often fail to notice crucial road signs because concentration is focused on navigating through traffic. Similarly, faced with a critical shoot-out situation, a footballer at the penalty spot is unlikely to be aware of action in the stands even millimetres away from the goal. Subjective experience suggests that the act of attending affords a remarkably detailed visual experience. Conversely when attention is absent, it appears that our visual representation of the rest of the world is surprisingly limited.

Research has revealed several important principles affecting this intrinsic relationship between attention and visual awareness. The current thesis examines the role of perceptual load in determining awareness. Experiments also investigate effects of stimulus position and biological salience in determining explicit awareness, as well as the development of awareness over childhood.

I begin this chapter with a review of evidence from the selective attention literature illustrating the debate between early and late selection theories over whether attention can affect perceptual awareness. I then outline the proposed resolution to this debate offered by the perceptual load model, reviewing the evidence which has been accumulated in its support. Finally I turn to examine effects of attention on explicit measures of awareness focusing on the inattentional blindness paradigm. In this section, I review existing findings relating to principles affecting the magnitude of experienced awareness within this paradigm. As I shall discuss at the end of this chapter, the experiments presented in this thesis were designed to combine direct manipulations of perceptual load with the inattentional blindness method. Using this design, I aim to assess a number of different factors influencing rates of experienced awareness, including retinal position (contrasting fixation with periphery), biological salience and age.

1.2 Early selection versus late selection

A central question that has pervaded selective attention research for years, concerns the extent to which task-irrelevant information is perceived. Decades of research have advanced two opposing views which have formed the heart of a long-standing debate. One viewpoint proposes that attention represents an inherently limited capacity system, and that perception is therefore restricted to attended (selected) items only. Under this hypothesis, irrelevant information must necessarily be filtered out (ignored) at an early stage of processing (early selection; e.g. Broadbent, 1958; Treisman, 1969). Conversely, proponents of the opposing late selection view conceive of perception as an effortless automatic process. Thus, all and every stimulus is processed regardless of relevance, and attentional selection operates instead on later post-perceptual processes such as memory or response selection (e.g. Deutsch & Deutsch, 1963; Duncan, 1980). Evidence supporting the early selection view typically derives from the early period of research, whereas evidence for late selection is usually found in more recent studies. A resolution to this debate has proved difficult to obtain, since a substantial amount of work has been amassed over the years lending support to both opposing viewpoints. I shall begin by reviewing evidence favouring early selection followed by evidence supporting late selection.

1.2.1 Evidence for early selection

There is considerable evidence to suggest that focusing attention on one stream of information substantially reduces knowledge regarding the information contained in other, irrelevant streams.

In early studies using the *dichotic listening technique*, participants selectively attended to a stream of words presented to one ear (usually by repeating those words aloud) whilst ignoring a second stream of information presented to the other ear. Experiments found frequent failures to report information from the unattended stream (e.g. Moray, 1959; Cherry, 1953). This provided the first evidence that focusing attention on one selected stream causes unattended information to proceed unnoticed.

Modelled closely on the original auditory dichotic listening technique, the *selective reading paradigm* provided complementary effects of selective attention on visual information processing. Neisser (1969) found that when participants read aloud lines of text printed in a particular colour (whilst ignoring alternating lines of text printed in a different colour), the content of unattended text could not be reported. Such results suggested that processing was restricted to the selected colour-text only. However, dichotic listening and selective reading paradigms typically involved the presentation of relatively complex verbal material that may require carefully focused attention. As such, the generality of conclusions regarding the effects of attention on knowledge of irrelevant information may be limited to these special situations.

To counter these limitations, an analogous non-verbal *selective looking paradigm* was created which afforded the possibility of lengthier stimulus presentations and hence greater real-life relevance. For example, Neisser and Becklen (1975) asked participants to monitor one of two video-taped episodes which were viewed simultaneously, either binocularly by superimposing the two tapes or dichoptically using traditional binocular rivalry. Under all conditions, the majority of participants failed to report unusual yet visually conspicuous events in the unattended tape (e.g. a striking change in the physical activity) during post-stimulus questioning.

Similar failures in visual awareness occurred when attention was defined by colour (rather than activity-type). Becklen and Cervone (1983) found that participants attending to one of two superimposed videotapes of ball-games (distinguishable by the colour of players' shirts) failed to show knowledge of strange and obvious events occurring in the unattended tape (e.g. a woman with a large umbrella walking across the playing space, see Figure 1.1). Such bizarre events proceeded without report despite variation in the delay between the event and the awareness enquiry, and despite instruction to describe the last image seen when tapes were paused with the "umbrella woman" present.

Figure 1.1 A single video-frame from the selective looking study of Becklen and Cervone (1983). Participants monitored one team of ball-players (black or white) and an "umbrella-woman" (pictured here at the centre of the playing area) appeared unexpectedly during the clip.

Failures in visual detection as a result of attention were not dependent upon eye movements. Similar rates of noticing (or indeed, failures to notice) were obtained when observers performed an identical task whilst fixating their gaze on a central location (Littman & Becklen, 1976). Eye movements were monitored during selective looking tasks to confirm gaze stability. Therefore, the mechanism of visual selection responsible for the breakdown in visual experience cannot be attributed to eye movements or their effects (e.g. "smearing" of visual stimuli in the display other than the visually tracked, attended objects).

Another line of evidence also supports the idea of an early selection mechanism. In a simplified version of the selective looking paradigm, Rock, Schauer and Halper (1976) found only chance level recognition of unattended outline figures which were presented during a distracting attention task. In one version of this experiment, participants made aesthetic judgments on a stream of objects crossing the screen (e.g. from left to right) whilst ignoring a second, overlapping stream which was moving in the opposite direction (i.e. from right to left). Rock et al (1976) found that participants were unable to recognise items from the unattended stream in surprise recognition memory tests following the attended tasks.

Similar results were obtained from variations using a static selective looking task. Rock and Gutman (1981) directed participants' attention to one of two superimposed figures (a line drawing or a geometric shape) differentiated along the dimension of colour, either by explicit instruction or by performance of an aesthetic judgment task on one set of figures. In an unexpected recognition test including attended, unattended and novel items, only figures presented in the attended colour were recognised above chance level. This indicated that unattended items were not analysed to a level supporting conscious recollection. Comparable results were obtained by Goldstein and Fink (1981) when the superimposed images covered large (11°-22°) and small (3°) visual extents.

1.2.2 Evidence for late selection

The studies reviewed so far have demonstrated that attentional selection can prevent the processing and subsequent awareness of irrelevant (ignored) information. Such findings support the early selection view. However, subsequent studies using variations of the classic *Stroop paradigm* (Stroop, 1935) have lent much support to the alternative late selection view. Typically in these studies, processing of unattended stimuli (distracters) is measured indirectly via the effects they exert on reaction times (RTs) to attended targets.

In the standard Stroop colour-word task (e.g. Stroop, 1935), participants were presented with a compound stimulus in which a distracting dimension (usually a printed colour name, e.g. BLUE) was congruent or incongruent with a target dimension to which the participant responded (usually ink colour, e.g. red). An example of an incongruent colour-word stimulus would be: **BLUE**. Processing of the irrelevant dimension was then assessed by target RTs as a function of distracter congruency: Typically participants were slower to respond when the printed colour word was incongruent with the target ink colour than when both distracter and target indicated the same, congruent response (e.g. **RED**). This influence on target responding suggested that the ignored dimension (the written colour word) was processed regardless of its irrelevance to the task at hand. This therefore provides a demonstrable case of late selection.

However, targets and distracters in classic Stroop tasks not only occupy the same location, but are in fact conjoined within the same visual object. It may therefore not be surprising that participants could not ignore the distracters in such tasks, since the irrelevant dimension appeared directly at the focus – and even within the object – of their attention. In addition, the automatic nature of reading might be responsible in part for the processing of irrelevant distracters in this particular situation[1] (e.g. Posner & Snyder, 1975).

An alternative method termed the *flanker paradigm* (Eriksen & Eriksen, 1974) found similar evidence of Stroop-like interference effects whilst importantly allowing for the spatial separation of targets and distracters. For example, Eriksen and Eriksen (1974) presented participants with central targets (demanding a choice response) accompanied by distracters (indicating a response that was neutral,

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[1] This notion is supported by the asymmetrical Stroop-effect size found between words on colours (larger effect) versus colours on words (smaller effect).

compatible, or incompatible with the target response) at either side. Although the positional certainty of targets and distracters in this task should theoretically have allowed the deployment of attention towards only relevant locations, target RTs were slower in the presence of incompatible distracters (vs. compatible or neutral distracters). Such response interference indicated that distracter identity was perceived and its associated (inappropriate) response was activated. Effects of such "response competition" are strong and robust, and have been replicated many times. Indeed, they may even be seen when the responses associated with distracters are learned through correlating the repeated co-occurrence of distracters with specific targets. Miller (1987), for example, transformed initially "response-unprimed" stimuli into disruptive distracters by repeatedly pairing their appearance with targets.

Evidence for late selection as indicated by interference effects in Stroop-like tasks can even be found when there is a clear spatial separation between relevant and irrelevant items. For example, Eriksen and Eriksen (1974) continued to find significant distracter effects on RTs in the flanker paradigm, albeit at a reduced level, when the distance between targets and distracters was increased. The persistence of interference effects in the flanker task despite spatial separation has been replicated in many experiments (e.g. Miller, 1987; Flowers & Wilcox, 1982), and was shown most strongly with a considerable distance manipulation (target-to-distracter gap up to 6°) by Murphy and Eriksen (1987).

In an analogous fashion, the spatial separation between targets and distracters was manipulated in classic Stroop tasks by presenting target colour patches and distracter words individually, and at varying distances (e.g. Gatti & Egeth, 1978; Merikle & Gorewich, 1979; Hagenaar & van der Heijden, 1986). In line with findings from the flanker paradigm, studies of this kind typically found that, although increasing target-to-distracter distance can reduce interference effects, spatial separation did not eliminate the influence of the irrelevant dimension on target-responding. Thus, there is evidence that late selection proceeds in spite of considerable spatial separation between targets and distracters in both Stroop and flanker paradigms.

There is evidence that interference effects (demonstrating late selection) occur even when targets are separated from distracters over time. Using a flanker paradigm, Gathercole and Broadbent (1987; also Flowers & Wilcox, 1982) varied both the distance separation and the temporal delay between presentation of targets and distracters. Importantly, they found significant interference effects from distracters on target responding at all intervals of time and space (except when distracters were presented temporally after the targets).

Although interference effects are reduced by increasing distance between targets and distracters, several studies have demonstrated that these effects of spatial separation (i.e. reducing response competition) can be abolished if displays are arranged so that distracters are perceived as falling into the same perceptual group as targets. For example, a distant distracter that is perceptually grouped with a centrally-presented target by common motion (Driver & Baylis, 1989), common colour (Baylis & Driver, 1992) or connectedness (Kramer & Jacobson, 1991) was able to produce significant interference effects, substantially slowing target responding when it was incongruent (vs. congruent). Therefore, although late selection in flanker and Stroop paradigms may be reduced by spatial separation, it is rarely eliminated. Furthermore, effects of perceptual grouping are able to override the modulation of interference by spatial separation.

Evidence from a different line of investigation provides yet another instance of evident irrelevant processing, lending further support to the late selection view. In a succession of studies, Tipper and colleagues identified the phenomenon of *negative priming*, where the time taken to identify a target (probe) is increased if that target appeared as a distracter (prime) on a previous trial. This is evidence that associations (e.g. "inhibit this distracter") formed during previous trials are processed despite their irrelevance to the current task (i.e. late selection), and in fact, can slow relevant-target responding. Indeed, experiments have shown that effects of negative priming are caused by inhibition of responses to the probe, rather than a conflict between different encodings of the probe as both to-be-ignored and to-be-identified (Allport, Tipper & Chmiel, 1985). Further, Tipper and Driver (1988) showed that negative priming occurred even when the ignored primes and later attended probes were presented in entirely different symbolic domains. For example, a categorisation response to a *word* probe was delayed if that category served as an ignored *picture* in a previous prime display. This finding of negative priming across symbolic domains suggested that irrelevant processing generates an abstract, categorical representation rather than a mere structural description (Tipper, 1985).

1.2.3 The debate

This review highlights an important dichotomy in the selective attention literature concerning the locus of attentional selection: early or late? One body of literature (selective looking) provides evidence that information from irrelevant streams is excluded from processing and is subsequently unavailable for later conscious report (demonstrating early selection). Another (response competition) presents evidence that irrelevant distracters are capable of interfering with target responding even when targets and distracters are clearly separable (demonstrating late selection).

It is tempting to attribute this inconsistency to fundamental differences between the methodological paradigms which have lent support to either viewpoint. For example, evidence for early selection derives primarily from studies using direct, explicit measures of awareness which are necessarily collected at a time point *after* stimulus presentation. As such, an absence of awareness as indexed with "offline" measures of this kind may reflect a failure to *remember* a perceived stimulus rather than a genuine failure in awareness (and hence also perception, as argued by early selection proponents). This interpretation of attentional effects seems extremely unlikely however, given the remarkable nature of some of the unreported stimuli (e.g. a woman carrying an umbrella). Many would find it an unconvincing explanation that observers were fully conscious of such stimuli (visible on-screen for ~8 seconds), yet simply forgot to report it in subsequent direct questioning (as in Becklen & Cervone, 1983).

An alternative explanation of the discrepancy between conclusions derived from direct versus indirect measures states that irrelevant information is perceived, but does not reach awareness (or at least, does not afford a reportable representation in memory). Accordingly, direct measures of awareness, which often rely on subjective verbal report, may simply be too insensitive to detect the perception of irrelevant information. With the exception of negative priming, evidence that selection occurs late in the processing stream is obtained from paradigms which measure irrelevant processing by the effects of distracters on target RTs *at the time* of stimulus presentation. By virtue of being indirect and "online", such measures may therefore be more sensitive in revealing the extent of processing outside the focus of attention. In this way, the conflicting conclusions regarding the locus of selection may simply reflect differences in the methodologies employed to examine irrelevant processing.

This apparently neat solution collapses however, when taking into consideration some small discrepancies that exist within the literature supporting each separate viewpoint. For example, even the earliest studies of selective attention using dichotic listening did not offer absolute support for early selection. Some researchers found that participants were consistently able to detect their own name when it was spoken in the irrelevant stream (e.g. Moray, 1959; the "cocktail party effect", Cherry, 1953). This unusual effect indicates that some level of semantic analysis was performed on unattended information before it was "selected out" (i.e. late selection).

Similarly, although the majority of response competition studies advocate late selection, there are a few important exceptions which reported instead instances of early selection. For example, locational certainty of the target in a letter-identification task eliminated negative priming effects (Ruthruff & Miller, 1995). Alternatively, in a spatially separated Stroop task, Kahneman and Chajczyk (1983; and more recently Brown, Gore & Carr, 2002) found that display clutter can lessen the interfering effect of a distracting colour-word on target colour-patch responding. They reported a marked reduction (or "dilution") in the effects of irrelevant distracters on centrally-presented target RTs when a response-neutral word or even a row of "X"s was added to the display. Similarly, the magnitude of interference caused by distracters within flanker tasks was diminished by the presence of an additional distracter in the display (Jenkins, Lavie & Driver, 2003). Further experiments provide illustrations of early selection within the flanker paradigm when attention is effectively cued to targets (Yantis & Johnston, 1990; Eriksen & Hoffman, 1972, 1973). Therefore, inconsistencies concerning the locus of selective attention are present even within the same methodology.

1.2.4 Summary

The research I have reviewed in this section has shown that both early selection and late selection can occur in studies of visual attention. Usually, support for the two different accounts derives from quite distinct methodologies (selective looking vs. response competition), but some discrepancies have been found between studies which use identical tasks. Thus, the debate concerning whether selection for attention occurs early or late in the processing stream remains unanswered despite a considerable amount of evidence compiled in favour of each view.

1.3 Perceptual load theory

In order to successfully account for the conflicting evidence that has accumulated, models of selective attention must necessarily adopt a hybrid approach combining aspects from both viewpoints. The perceptual load model forwarded by Lavie (1995, 2001; Lavie & Tsal, 1994) satisfies this crucial criterion and offers a neat resolution to the historical selection debate. According to this model, selective attention is characterised as a limited capacity system as forwarded by proponents of early selection. However, all stimuli falling within these limits are processed automatically, regardless of relevance as indicated by the late selection view. Therefore, when attentional capacity is available, irrelevant stimuli are inevitably and unavoidably perceived. By contrast, when limits are reached, perception of unattended stimuli is naturally prevented. Critically, the model proposes that the level of perceptual load in the relevant task will determine the locus of attentional selection, and thus the extent to which irrelevant information will be perceived. Conditions of high load will exhaust available capacity, leaving little or no residual processing resources for irrelevant items, hence unattended items are not perceived: early selection occurs. On the other hand, in less capacity-taxing low load situations, the surplus processing capacity will unavoidably extend to irrelevant information, thereby affording the perception of unwanted information: late selection occurs.

An extensive re-examination of the controversial literature on the locus of selective attention (Lavie & Tsal, 1994) provides evidence consistent with the perceptual load model. In this way, previous studies which found evidence of late selection tended to use tasks demanding a relatively low level of perceptual load. For example, the persistence of Stroop interference from distracter colour words despite increases in spatial separation in Gatti and Egeth's (1978) study were found when participants were presented with only one target and one irrelevant distracter. Many more studies giving illustrations of late selection similarly presented just one target and one or two irrelevant items, particularly within Stroop tasks (e.g. Kahneman & Henik, 1981; van der Heijden et al, 1984) but also within the flanker paradigm (e.g. Eriksen & Eriksen, 1974). Under such conditions of low perceptual load, Lavie's (1995) perceptual load theory would predict that remaining spare capacity would necessarily spill over and process the irrelevant items in the display, thus leading to late selection. Conversely, the experimental situations in studies lending support to the early selection view were generally characterised by a higher level of perceptual load. For example, the anomalous findings of early selection within response competition paradigms (e.g. Kahneman & Chajczyk, 1983; Yantis & Johnston, 1990) were seen when the tasks involved greater numbers of stimuli in target displays. Such an increase in stimulus numbers would exhaust attentional capacity according to the perceptual load theory. By the same token, the selective looking paradigms which reported early selection arguably placed significantly greater perceptual demand (load) on participants. The tasks in these studies typically involved participants monitoring a complex, semi-transparent scene of multiple randomly moving targets (e.g. Neisser & Becklen, 1975). Thus, this review shows that selection can operate both early and late within the attentional system, with the locus of selection critically being determined by the task-characteristic of perceptual load.

1.3.1 Evidence for perceptual load theory

Although discrepancies between paradigms and between experiments regarding the locus of attentional selection may be understood in the light of the perceptual load model, none of the previous experiments directly manipulated the effect of perceptual load on target responding. Moreover, some instances of contention, such as the reduction of interference effects from distracters within more cluttered displays (e.g. Kahneman & Chazjwick, 1983; Brown et al, 2002; Jenkins et al, 2003), could be attributed to alternative factors other than the consumption of available capacity for distracter processing by the imposition of perceptual load. For example, adding an additional response-neutral distracter into a flanker display may reduce the salience of the critical response-related distracter, thereby lessening its effect on target responding. Therefore, in a series of studies, Lavie and colleagues varied the level of perceptual load in a relevant task whilst measuring the effects on distracter processing (by response competition effects on target RTs). I shall review these studies following a brief outline of the definition of perceptual load.

Perceptual load is conceptualised as either (i) an increase in the number of relevant items in a display when the same task is performed, or (ii) an increase in the perceptual demands of the relevant task for the same number of items. Attentional capacity is therefore consumed by these items or operations acting in relevant channels with the result that the processing of irrelevant information is prevented. It should be noted that the definition of what constitutes "an item" within any given display may change depending upon the particular task. For example, a string of letters could be considered as one word within a word-judgment task, or it could be regarded as several letters within a letter-search task. As such, it is crucial that comparisons be restricted to different numbers of items within the same task. Similarly, Lavie and De Fockert (2003) have recently outlined boundary conditions for what represents a raise in the perceptual demands of a task. Specifically, they make a clear dissociation between increases in perceptual load and increases in general task difficulty related to processing speed (e.g. via basic stimulus degradation such as reduced size, contrast, duration, acuity or visibility from backward masking).

With these definitions in place, a line of studies were conducted specifically varying the level of perceptual load within a task. Firstly, Lavie (1995; Lavie & Cox, 1997) varied perceptual load within the flanker paradigm using the traditional method of imposing task load (Duncan, 1980) by varying the number of relevant items in an attended set. Thus, participants searched for a target letter (making a choice discrimination) which appeared either alone (low load) or with five additional nontarget letters (high load) in the display (Figure 1.2). The response competition effects induced by simultaneously presented (and deliberately ignored) distracters were measured, and predictions derived from the model were supported. With only one target in the display and a consequently low level of perceptual load, response competition effects were significantly greater for trials including an incompatible flanking distracter compared to either compatible or neutral ones. Conversely, with six relevant items producing a situation of high perceptual load, interference effects from distracters were eliminated.

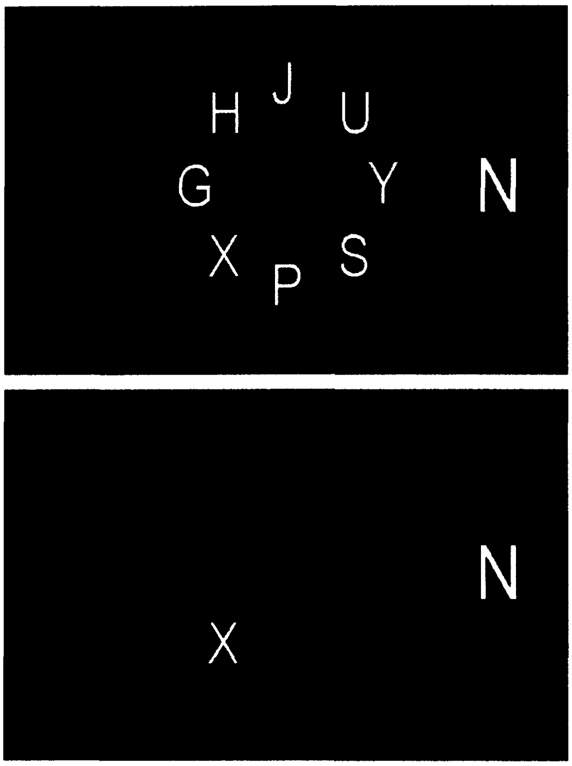

Figure 1.2 Example displays used by Lavie and colleagues. Participants made a choice response to letter targets (either X or N), which appeared either among 8 non-target letters (high load, top box) or alone (low load, bottom box), and with an irrelevant distracter (congruent, incongruent (as in both examples here) or neutral) in the periphery.

In this experimental design of variable relevant set size, the conditions of high load and low load differed not only in the perceptual demands they placed on the system, but also in their physical appearance. As such, it could be that the physical variation was responsible for the effects. To rule out this possibility and to test the second conceptualisation of perceptual load, further experiments varied the perceptual demands in the relevant task whilst maintaining identical displays across conditions. For example, response competition effects were measured whilst participants performed either a single feature search under conditions of low load, or a search for a conjunction of features in the condition of high load. Alternatively, distracter effects were contrasted when participants performed a demanding size and position judgment versus a simple detection of presence. In line with the perceptual load theory, Lavie (1995) found that distracters exerted greater interfering effects when the processing requirements in the task were low (single feature search or simple presence detection) compared to when they were high (feature conjunction search or complex discrimination of size and position).

Several studies from other lines of investigation have lent support to the notion that perceptual load determines the extent to which irrelevant distracters are processed. For example, Lavie and Fox (2000) showed that modulating perceptual load by increasing the set size in a relevant search task changes levels of negative priming as well as interference from distracters on target responding. Negative priming effects were seen when distracter primes were presented within displays of low load, but were eliminated under situations of high perceptual load in the relevant task.

Evidence from imaging studies shows that variations in perceptual load are accompanied by changes in neural activity. For example, event-related potential (ERP) components that are sensitive to the early allocation of attentional resources (Mangun & Hillyard, 1990) are modulated by load. When participants complete a demanding discrimination task, both the P1 and N1 sensory-evoked ERP components are reduced compared to potentials measured during an easier discrimination (Handy & Mangun, 2000). A functional imaging study also lends support to the claim that increasing perceptual load leads to a reduction in the processing of irrelevant information. Rees, Frith and Lavie (1997) measured neural responses (in area V5) associated with an irrelevant distracter motion stimulus whilst participants made linguistic judgments of either low load (is a word printed in UPPER or lower case?) or high load (how many syllables in a word?) in a relevant yet unrelated task. They found that neural activity in V5 was significantly reduced when participants performed the higher load linguistic judgment compared to the low load judgment. Other functional imaging studies have also found that visual cortex activity related to irrelevant stimuli (including checkerboards, meaningful pictures) was significantly reduced, indeed typically eliminated, when the level of perceptual load was increased in the relevant task (Pessoa, McKenna, Gutierrez & Ungerleider, 2002; Pinsk, Doniger & Kastner, 2003; Schwartz, Vuilleumier, Hutton, Maravita, Dolan & Driver, 2004; Yi, Woodman, Widders, Marois & Chun, 2004).

1.3.2 Summary

The research reviewed above shows a convergence of results from both behavioural and imaging experiments indicating that the perceptual load within the relevant task determines the extent of irrelevant distracter processing. A series of studies explicitly varying perceptual load lends support to the model, and perceptual load theory provides a sound framework within which the previously controversial literature on the locus of selective attention can be understood. The modulation of distracter processing by perceptual load can be seen at multiple different levels and therefore does not merely reflect an effect on response times (as stipulated in dissipation accounts).

Nevertheless, although the perceptual load studies clearly demonstrate that high perceptual load in the relevant task restricts the processing of irrelevant distracters, such findings cannot provide information about the effects of perceptual load on conscious awareness of those distracters. The perceptual load model asserts that the elimination of response competition effects by higher loads reflects an overall reduction in distracter perception. This may then imply that there is no conscious perception of irrelevant distracters under high load. These effects are equally consistent however, with alternative interpretations which propose no such role for perceptual load in determining conscious awareness of irrelevant distracters. For example, it could be argued that perceptual load influences unconscious perceptual processes but has no effects on conscious perception. On such an interpretation, irrelevant distracters never enter awareness under either condition of load: Distracter interference effects seen in conditions of low load merely reflect unconscious recognition of target-distracter response associations. Alternatively, it might be that irrelevant distracters always enter awareness regardless of the level of perceptual load. According to this account, the elimination of response competition effects by higher levels of load reflects either the influence of load on post-perceptual processes such as response selection, or simply the dissipation of interference effects during longer response times for higher loads (but see Lavie & De Fockert, 2003; Lavie & Fox, 2000 for counter-evidence). By similar argument, conclusions regarding the effects of perceptual load on conscious awareness cannot be drawn from assessments of neural activity.

One imaging study (Rees et al., 1997) did however include an index of awareness whilst examining the effects of perceptual load on distracter-related neural activity. Rees et al (1997) measured the subjective duration of a motion after effect (MAE) caused by the irrelevant motion in their task. They found that MAE durations were significantly reduced when participants performed the high load task compared with the low load task. As this measurement involved participants providing direct reports of their subjective motion experience, Rees et al's (1997) results provide encouraging preliminary evidence that perceptual load determines awareness. However, without extension to other measures of awareness and for different types of stimuli, these results remain confined to the particular case of motion after effects. In addition, this study only used one manipulation of perceptual load which may have involved an added linguistic load component in the high load condition.

The purpose of this thesis is to examine the role of perceptual load in awareness of task-irrelevant stimuli, using a more general method of assessing awareness. To this end, I adopt the "inattentional blindness" paradigm and next I review previous findings regarding this phenomenon. My review of literature on inattentional blindness will demonstrate that, although some important factors for awareness have been isolated, and although there is some preliminary suggestion that task difficulty influences awareness, a systematic investigation of the effects of perceptual load on awareness has not been conducted within this paradigm as yet.

1.4 Inattentional blindness

Inattentional blindness refers to the failure of observers to report awareness for a visual object appearing unexpectedly in a display while they are attending to a task (Mack & Rock, 1998).

In a typical inattentional blindness procedure established by Mack and Rock (1998), participants perform a task (e.g. judge which is the longer of two arms of a cross stimulus) for a few trials. On the final "critical trial", a task-irrelevant stimulus (the "critical stimulus") is presented additionally in the display (Figure 1.3). Following the usual task response on this critical trial, participants are asked to report whether they were aware of this extra critical stimulus. On a subsequent control trial (which is an exact repetition of the critical trial), participants are asked not to perform the task, but instead are asked simply to pay attention to the display and see whether any extra stimulus appears. A failure to detect the critical stimulus when it is unattended in the critical trial (appearing unexpectedly during performance of a task) but successful detection when it is attended (in the fully-attended control trial) is taken to reflect blindness due to lack of attention towards the stimulus, hence the term "inattentional blindness" (Mack & Rock, 1998).

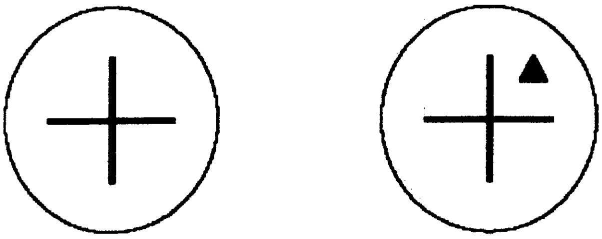

Figure 1.3 Examples of non-critical (left) and critical (right) displays in Mack and Rock's (1998) typical inattentional blindness paradigm. Participants judge which line of a target cross is longer. Awareness for an unexpected task-irrelevant "critical stimulus" (here a filled triangle shape) appearing in the final critical trial is tested immediately after usual task response.

An analogous inattentional blindness effect has been found within studies presenting longer-duration displays comprising of several moving stimuli. For example, the selective looking paradigm has seen a modern-day revival, replicating effects found in the original studies (e.g. Neisser & Becklen, 1979) under different experimental conditions and bringing to light another form of inattentional blindness. In Simons and Chabris' (1999) now-classic study, participants monitor one of two ball games (e.g. by counting ball-passes), with games being distinguishable by players' shirt-colour (black or white). At some time point during the ball-game, a person dressed in a gorilla suit crosses the playing area (Figure 1.4). In much the same way as Mack and Rock's (1998) original inattentional blindness, participants often failed to report awareness of this "gorilla-man" when asked directly at the end of the task. Interestingly, this was found with both transparent (two superimposed tapes, as in Figure 1.1) and opaque (choreographed single-camera clip, as in Figure 1. 4) viewing conditions, emphasising that failures in irrelevant detection were not due to the unusual, slightly degraded physical appearance of the superimposed, semi-transparent films used in original studies of Neisser and colleagues.

Figure 1.4 A single frame from Simons and Chabris' (1999) study. Participants monitor the black or the white team of ball-players for the total number of ball passes. A "gorilla-man" crosses the playing space (here pictured beating his chest) and awareness for this unexpected event is tested after the clip.

A much-simplified computerised analogue of the selective looking method labelled *sustained inattentional blindness,* has also been established. Most and colleagues (2000, 2001) devised a method whereby participants monitor one set of randomly-moving shapes for the number of times they "bounce" off the edges of the viewing display, whilst ignoring a second set of shapes also moving randomly around the display. On a critical trial, an unexpected shape enters the display, crossing the screen with a steady, linear, horizontal trajectory (visible for ~5 seconds, Figure 1.5). Awareness for this critical stimulus is assessed as in Mack and Rock's (1998) method, by direct questioning immediately following termination of the critical trial. Thus, the inattentional blindness phenomenon has been established in both static and sustained moving displays.

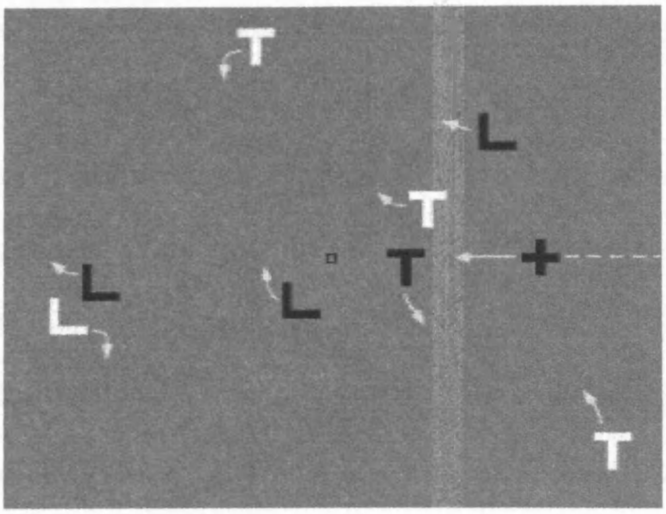

Figure 1.5 A single frame from a typical sustained inattentional blindness paradigm (Most and colleagues). Participants monitor one set of shapes (e.g. attend black whilst ignore white) for the number of times the objects "bounce" off the display-edges. An unexpected shape (here a black cross) crosses the display on critical trials and awareness for this assessed after the task response.

Much research has been devoted to identifying factors which modulate levels of inattentional blindness within static and sustained paradigms, principally varying aspects generally held to be important within attention. I will review the main findings from this research in the following section.

1.4.1 Principles known to modulate inattentional blindness

Several factors demonstrably affect the magnitude of inattentional blindness across participants. These include both low level characteristics of the critical stimulus such as stimulus size, as well as higher level factors including attentional set.

Absolute size

There is evidence reported by Mack and Rock (1998) in the first major exploration of inattentional blindness, that the absolute size of a critical stimulus plays a role in its detection. In one experiment, participants performed the typical line-length judgment on cross targets which could appear in one of four peripheral locations. On the critical trial, a solid black circle was presented at fixation, with either a small (0.6°) or a large (1.1°) diameter. Participants were far more likely to report awareness of the critical stimulus at the larger size (75% aware reports) than the smaller size (43%). Further experiments by Mack and Rock (1998) varied critical stimulus size orthogonally with viewing distance. The results generally lent support to the notion that the *retinal size* of an image rather than its postconstancy aspect (i.e. size following the integration of other sensory information such as distance cues) is critical in determining awareness. However, equivalent rates of awareness for the largest critical stimulus at near and far distances suggest the possibility of a retinal size threshold, beyond which size increases confer no additional advantage in awareness. Because the critical stimuli in these experiments were solid black circles, changes in diameter will have been accompanied by changes in overall luminance and contrast within the stimuli. Despite this potential confound however, the finding that retinal size plays an important role in detection in inattentional blindness paradigms is intuitive, and falls in line with results from experiments where multi-element displays (presented as the critical stimuli) covering large areas reach awareness, even if patterns of grouping within those elements are not detected (Mack & Rock, 1998; Chapter 2).

Spatial separation and critical stimulus position

There is considerable evidence that increasing the spatial separation between a critical stimulus and the focus of attention is likely to decrease rates of awareness reporting. Newby and Rock (1998) systematically varied the distance between the appearance of a critical stimulus and the central junction of a foveally-presented cross-target within a traditional inattentional blindness paradigm (Figure 1.6). They found that rates of awareness decreased with increasing eccentricity of the critical stimulus. Importantly, the same pattern of results was replicated when spatial separation was varied, but retinal eccentricity of the critical stimulus was held constant. This was achieved by presenting both the cross-targets and the critical stimuli at equivalent eccentricities in the periphery. This manipulation confirmed that neither decreased retinal acuity nor differential cortical representations of critical stimuli in the further distance conditions were responsible for this effect. The relationship between spatial separation and detection rates seemed to be linear: It did not matter whether the critical stimulus fell within the imaginary "zone" created by the cross arms (see Figure 1.6) or whether it fell outside this area[2].

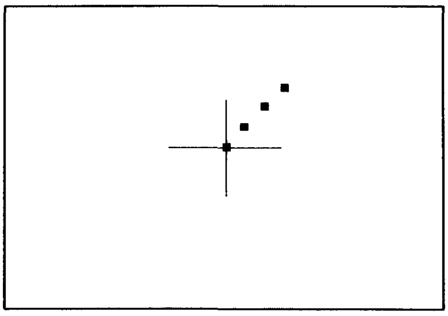

Figure 1.6 Schematic of Newby and Rock's (1998) experimental design (Experiment 1). Participants decide which arm of a cross target is longer, and awareness for a critical stimulus is tested on a critical trial. Critical stimuli appeared at varying distances from the centre of the target cross.

Most, Simons, Scholl and Chabris (2000) found supporting evidence for the role of spatial separation on critical stimulus detection in a variation of the sustained inattentional blindness paradigm. As with Newby and Rock (1998), they found

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[2] This distinction had been suggested by Mack and Rock (1998) following initial studies of the effects of spatial separation.

results consistent with the notion that awareness of a critical stimulus depends upon the spatial gradient of attention originating from the central focus of attention. In Most et al's (2000) study, participants monitored one set of randomly-moving shapes for how many times they crossed a fixated horizontal line which bisected the screen. Critical stimuli entered displays at varying distances from the fixated horizontal line (Figure 1.7). Results across four different spatial separations of critical stimulus and horizontal line showed that participants were more likely to report awareness when critical stimuli were closer to the horizontal line. Although comparisons were not significant between every spatial separation, a linear trend of detection depending upon separation was evident.

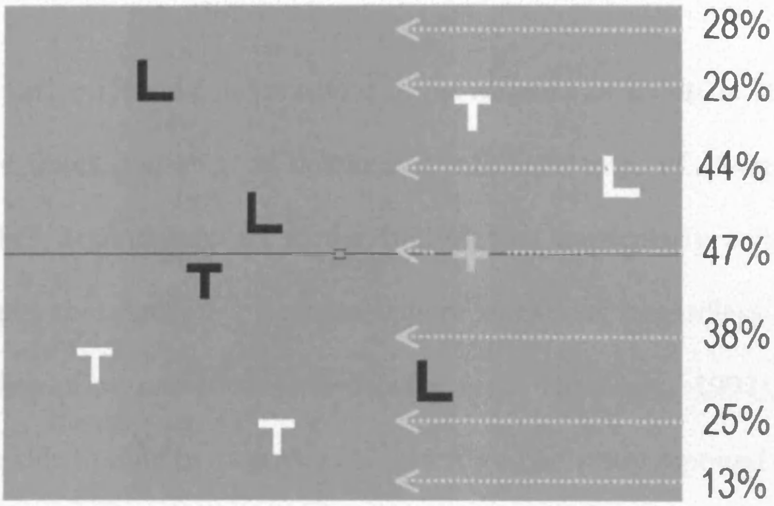

Figure 1.7 A single frame from Most et al's (2002) study. Participants monitored one subset of shapes (e.g. black objects). Awareness for an unexpected light grey cross traversing the screen was measured across varying distances of (horizontal) line-to-critical stimulus separation (each distance indicated by the dotted lines).

One curious related finding concerns the frequency of awareness reports for critical stimuli presented at fixation versus in the periphery. Mack and Rock (1998) reported rates of awareness between 10% and 50% (across experiments) when critical stimuli were presented at fixation while participants performed a demanding peripheral task (judging which line was longer on a target cross presented at one of four possible locations). Surprisingly, the magnitude of awareness was consistently and considerably higher (approximately 75% across experiments) when critical stimuli appeared in the periphery while participants performed an identical task on targets at fixation. These results therefore found greater inattentional blindness (rather than greater awareness) of critical stimuli at fixation (vs. periphery). Explanations alluding to the inhibition of attention at fixation were proposed to account for the unexpected results. I will return to address this surprising finding in Chapter 3.

Salience

There is limited evidence that variations in the salience of a critical stimulus along an irrelevant dimension such as colour can influence rates of awareness reports. This describes a similar effect to the finding that particularly salient singleton distracters are more disruptive than non-salient singletons (regardless of attentional set) in studies of visual attentional capture (e.g. Theeuwes, 1992). Preliminary evidence for this finding in awareness comes from one study reported by Mack and Rock (1998). With their standard cross-task procedure, they found that an equiluminant red critical stimulus (solid circle) located in the periphery was reported significantly more often (75% awareness) than an equiluminant green stimulus of the same size and spatial location (40% awareness). This demonstration offers initial evidence that stimulus salience as defined by the property of colour affects awareness reports.

Further evidence for effects of salience in detection was provided in the sustained inattentional blindness paradigm of Most and colleagues. Most, Scholl, Clifford and Simons (2005) varied the salience of a critical stimulus along a dimension (luminance) that was irrelevant to the participants' attentional task (e.g. shape detection). Participants tracked one selected subset of black shapes (either circles or squares) moving randomly around a computer display, while an unexpected object traversed the screen on critical trials. This critical object could be either black (identical in luminance to the targets and distracters) or white (unique in luminance), but was always identical along the relevant dimension of shape (always a triangle, Figure 1.8). Nevertheless, Most et al (2005) found that more participants noticed the salient and distinctive *white* triangle (68% awareness) than reported awareness of the *black* triangle (38%). Thus, it is possible for the relative salience of a critical stimulus to influence rates of awareness, even if that salience is defined along a dimension irrelevant to the task at hand.

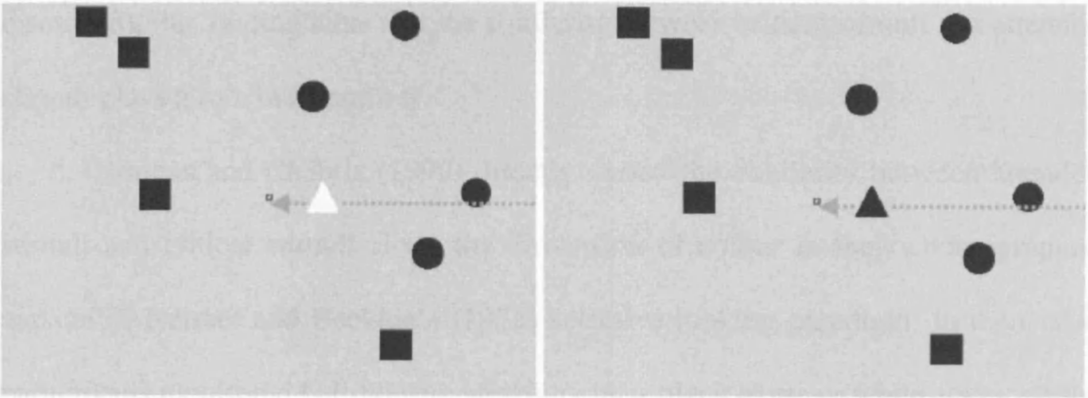

Figure 1.8 Single frames from the two critical trial conditions in Most et al (2005). Participants attend to either circles or squares (note, all black). Awareness of an unexpected triangle (either black or white) crossing the screen was tested immediately following critical trial termination.

Featural similarity and attentional set

So far I have described relatively basic, low-level factors which have been shown to determine awareness in inattentional blindness paradigms. However, there is also evidence that rates of awareness assessed with this method also depend on higher-level factors. These include the similarity between the critical stimulus and ignored non-targets as well as the attentional set of the observer. An incidental report by Rock, Linnet, Grant and Mack (1992) provided the first indication that attentional selection set up by a participants' task could influence the magnitude of awareness for critical stimuli. Rock et al (1992) reported reduced numbers of awareness reports for a dark critical stimulus (coloured black, blue or red) when the task was changed from a line-length judgment on dark cross-targets (black), to a same-different hue judgment on coloured cross-targets (coloured green, orange or purple). Although the colour similarity between critical stimuli and cross-targets was not systematically varied in this study (in fact, the comparison between levels of awareness under the two different task-conditions between experiments was not discussed), this finding hints that the similarity between critical stimuli and attended stimuli plays a role in awareness.

Simons and Chabris (1999) directly varied the similarity between attended stimuli and critical stimuli along the dimension of colour in their choreographed version of Neisser and Becklen's (1975) selective looking paradigm. In their task, participants monitored ball-players wearing either black shirts or white shirts, whilst an unexpected person wearing a black gorilla suit traversed the playing area during the video clip. Despite identical tapes being played to both groups, participants detected the (black) gorilla more frequently when attention was paid to the players in black shirts compared to the players in white shirts. This result suggests that the visual similarity between attended items and critical objects is important in detection. However, the degree of experimental control over stimuli in this experiment may have been compromised by the use of several different people (presumably with individual, distinctive styles of motion; see Hill & Pollick, 2000; Cutting & Kozlowski, 1977, for the recognition of individual identity from biological motion) artificially choreographed in a ball-game. Moreover, this study only varied the visual similarity between critical stimuli and attended targets in the display. As such, these findings cannot tell whether it is *similarity* to attended targets or *dissimilarity* from ignored non-targets which crucially determines detection of critical stimuli.

In a series of studies, Most and colleagues addressed this question amongst others pertaining to attentional set, using their more controlled sustained inattentional blindness paradigm. Firstly, Most, Simons, Scholl, Jimenez, Clifford and Chabris (2001) sought to replicate the effects of visual similarity between critical and attended stimuli. Here, participants attend to either black or white randomly-moving "L"s or "T"s. The luminance of the critical stimulus (a cross, Figure 1.7) was varied so that it could be more or less similar to the attended (and ignored) items, with luminances ranging from white, to light grey, to dark grey, to black. As with findings from Simons and Chabris (1998), Most et al (2001) found that the more similar a critical stimulus was to attended items, the more likely it was to reach awareness. Next, they varied critical stimulus luminance along a continuum with attended items at the centre of the continuum (grey). Ignored items then fell at one end of the continuum (e.g. black) with critical stimuli either being at the same end (i.e. black) or the opposite end (i.e. white) as ignored items. This manipulation could thus reveal whether similarity of critical and attended stimuli is important for detection (as indicated by equal levels of awareness of critical stimuli at either end of the continuum) or whether dissimilarity between critical and ignored stimuli drives the visual similarity effect (indicated by greater noticing of critical stimuli with an opposite luminance to ignored items). Most et al (2001) found clear evidence to support the latter view. Participants ignoring black items (attended grey) detected a white but not a black critical stimulus, with the converse pattern evident for participants ignoring white items (still attend grey). This suggests a role for visual similarity in inattentional blindness, driven by the selective ignoring of irrelevant items.

Finally, Most et al (2005) found evidence that the role of visual similarity in inattentional blindness extends beyond the effects of luminance similarity to the attentional set of the observer, where "attentional set" can refer to any feature dimension(s) that is important for performance of the relevant attended task. For example, awareness of a black circle was modulated when the attended items in a set were defined along the basis of shape (either attend circles or attend squares) but could include both black and white items. Therefore, participants attending to black and white squares typically failed to report the black circle, whereas most of those attending to black and white circles were aware of the identical-shaped critical stimulus. Moreover, the role of shape similarity was reinforced in a replication which gave the critical stimulus a unique feature in the display. Thus, the effect found in the first demonstration of attentional set for shape cannot be attributed to participants simply disregarding the additional critical circle as another ignored item. In a final generalisation of the role of attentional set, Most et al (2005) found that awareness of an additional face stimulus (Caucasian or African-American) was modulated by the race of faces (Caucasian or African-American) to which participants were currently attending. In this way, participants tracking African-American faces (for the number of times they "bounced" off screen edges) whilst ignoring Caucasian faces, were more likely to report awareness of a critical African-America face but less likely to notice a critical Caucasian face (with the opposite pattern found for selective attention to Caucasian faces). Thus, generation of effective attentional sets need not be restricted to simple features. Instead, there is evidence that the attentional set of an observer can be defined by the complex combination of features as exemplified by the case of faces.

Overall, the feature dimension or combination of dimensions to which a participant is selectively attending is a key factor in determining whether additional critical stimuli presented unexpectedly in a display will reach awareness or not. The mechanism critically driving this effect is the selective ignoring of irrelevant items present in a display, rather than the indiscriminate selection of stimuli that are similar to the attended.

Load on attention

A role for general task difficulty, and hence a possible role for perceptual load, in inattentional blindness has been hinted at in two previous studies. An early study using the selective looking paradigm (reported in Neisser, 1979) found greater rates of awareness for an irrelevant stimulus (e.g. a woman walking with an umbrella while participants perform a task concerning ball players) in the third repetition of the same video compared with the first viewing. The increase in awareness with practice may result from a reduction in attentional load from greater practice in the relevant task. Neisser's (1979) report does not however, establish that task performance became any easier with practice, since results regarding task performance were not reported. Moreover, although practice is expected to reduce perceptual load, it is also expected to reduce the load on all other task-processes, including memory. Practice is also expected to speed up task responses, and hence may have reduced the delay between task response (following stimulus presentation) and questioning of awareness. Thus, increased rates of awareness reports with practice may reflect a lower likelihood of forgetting following effects of practice on processes other than perceptual load.

Simons and Chabris (1999) varied task difficulty more directly in their study. In their basketball monitoring task, participants monitored one of the two teams (distinguishable by shirt colour) either by maintaining a silent count of the number of ball-passes made ("easy" condition) or by maintaining two separate silent counts of the number of bounce passes and number of aerial passes made ("hard" condition). Results showed significantly fewer participants reporting awareness of the unexpected "gorilla-man" during the hard task condition compared with the easy task condition. This effect generalised across different viewing conditions of transparent (superimposed) and opaque (one single choreographed) videoclips, and across participants attending to black and white teams. This finding might suggest that awareness of an unexpected event depends on the difficulty of the relevant task and therefore the availability of attention.

However, the particular difficulty manipulation used in this study was likely to involve a greater tendency for eye movements in the hard task condition than the easy task condition, as the discrimination between aerial and bounce passes would benefit from looking up (for aerial throws) and down (for bounces) whereas monitoring all ball-passes can be made without this discrimination. Thus, since eye movements cause blur on the retina (Bridgeman, Hendry & Stark, 1975), the critical stimulus may simply have been less visible in the hard task condition. Moreover, maintaining two separate ball-pass counts in the hard task condition places a greater load on working memory than maintaining just one count (as in the easy task condition). Since encoding into long-term memory is known to be determined by the availability of working memory (Baddeley, 1986), lower awareness in the hard task condition may have been caused by a reduction in the encoding of critical stimuli into memory (where it had to be retained until the awareness questioning following the rest of the video clip and the report of the count). As such, the role of load on attention per se (e.g. without the potential effects of eye movements and working memory load) in determining awareness in this task remains unclear.

Meaningfulness

Another factor influencing rates of inattentional blindness is the meaning conveyed by the critical stimulus. Meaningfulness has been varied either by presenting salient words (e.g. a participant's name) or by presenting biological significance stimuli (e.g. faces, body parts) as critical stimuli on critical trials.

In a variation of their standard cross-task procedure, Mack and Rock (1998) examined the influence of meaning on rates of noticing critical stimuli by comparing awareness for participants' own names against other names or common words. Words were presented unexpectedly at fixation on critical trials whilst participants performed a line-judgment task upon peripheral cross-targets. Mack and Rock (1998) found significantly greater levels of awareness (and correct subsequent identifications) when participants viewed their own name (85% awareness) as compared with another common name (e.g. David, 65% awareness). Both of these conditions yielded higher levels of awareness than neutral common words presented unexpectedly at fixation (e.g. House, 50%). This striking own-name effect was unaffected by name-length and modifications in the procedure such as reduced duration and visual masking.

These results provide an analogous illustration of attentional capture by a participants' own name within dichotic listening (Cherry, 1953; the cocktail party effect) or selective reading (Neisser, 1969) techniques. As with these earlier techniques however, the peculiar attribute of automaticity in reading (e.g. McKoon & Ratcliff, 1992) may restrict the generalisability of these findings. It would therefore be interesting to examine the effects of meaningfulness of critical stimuli for non-verbal meaningful stimuli.

In line with this aim, a few studies have measured awareness for stimuli of greater *biological relevance*. Mack and Rock (1998) reported that participants experienced significantly less blindness on critical trials for a happy face icon (☺) compared to a scrambled face icon or other non-face cartoon schematics, including a tree, a house or a dollar sign (Figure 1.9). Typically, around 85% of participants reported awareness of the unexpected face icon on critical trials whilst performing the usual line-length judgment task. In comparison, a significantly reduced number (around 35%) reported awareness for the control stimuli. By contrast, equivalent levels of awareness were found for the happy face icon and controls on full attention trials. However, Mack and Rock (1998) also found that schematic images of sad faces (☹) reached awareness less often than the control stimuli (e.g. houses, dollar signs) which possibly points to specific effects of emotional expressions in awareness. In addition, Mack and Rock (1998) found lower rates of awareness for neutral faces than other control stimuli (e.g. a schematic house or schematic tree). This unexplained pattern of results raises questions about their previous findings with happy faces and therefore leaves the issue of inattentional blindness to faces unresolved.

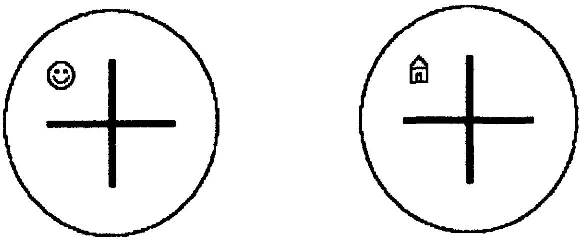

Figure 1.9 Example critical displays from Mack and Rock (1998). Participants judged which was the longer arm of each cross target and on critical trials a smiling face icon (left display) or a schematic control figure (here, a house, right display) was presented in addition in the disaply.

More recently, Downing, Bray, Rogers and Childs (2004) presented schematic images of human figures (e.g. stick figures, silhouettes of bodies or hands, Figure 1.10) whilst participants performed the same line judgment task on cross targets that appeared either at fixation (Experiment 1) or in the periphery (Experiment 2). Awareness for these biologically meaningful stimuli was compared with awareness for control stimuli (including scrambled stick figures, object silhouettes, scrambled silhouettes of bodies/body-parts/objects) across critical trials. The authors found significantly greater detection rates for human bodies (but not body parts) in either schematic form (silhouette or stick figure; around 60% awareness) compared to control stimuli, (around 25%). These initial studies therefore suggest that biologically meaningful stimuli including faces and bodies, receive attentional prioritisation for awareness where other stimuli sharing identical low level visual features would remain undetected.

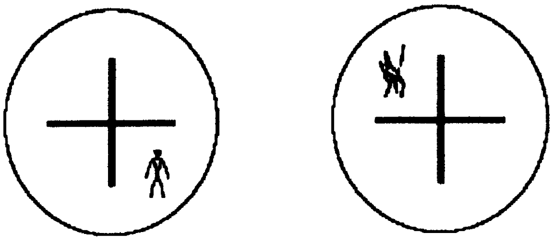

Figure 1.10 Example critical displays from Downing et al (2004). Participants saw an upright schematic stick figure (left display) or a scrambled stick figure (right display) in the critical trial at the same time as the cross target. There were higher rates of awareness reports for the upright vs. the scrambled stick figure.

Thus, the meaning conveyed by a critical stimulus as defined by linguistic familiarity (your own name) or biological pertinence (faces, body parts) seems to be a crucial factor in determining awareness within inattentional blindness paradigms.

1.4.2 Summary

The research described above has shown that there are several important principles in determining the frequency of inattentional blindness. Studies indicate that low-level features of the critical stimulus such as retinal size and spatial separation can influence rates of awareness, as well as similarity between relevant and irrelevant items (i.e. an observer's attentional set) and expectation. However, given the major claim that "blindness" in this paradigm results from "inattention", there has been surprisingly few studies explicitly manipulating the availability of attention. Simons and Chabris (1999) provide one exception, although it is not clear whether the manipulation of task difficulty in their study combines effects of perceptual load with effects of working memory (and therefore coding into long-term memory), or perhaps more critically, whether effects of blurring across saccades could explain the reduced levels of awareness in the irrelevant hard task condition.

1.5 General methodological approach and overview

The purpose of the current thesis was to establish the role of perceptual load in awareness using the inattentional blindness paradigm (Mack & Rock, 1998) as a general measure of awareness (Chapter 2). In addition, Chapter 3 considers whether the position of task-irrelevant critical stimuli on the retina influences rates of awareness, contrasting specifically fixation with periphery. Chapter 4 investigates effects of the biological meaningfulness of critical stimuli, examining particularly the role of perceptual load in awareness for faces. Finally, Chapter 5 begins to address age-related changes in effects of perceptual load on awareness over childhood.

All experiments in this thesis used modifications of Mack and Rock's (1998) typical inattentional blindness paradigm with direct manipulations of perceptual load incorporated into the procedure (except for Experiments 3-5 and 7, Chapter 3). In most of these experiments (with the exception of a few experiments designed specifically to assess RTs and to compare between short and long experimental procedures), participants performed a selective attention task (e.g. visual search or the cross-arm discrimination task) for only a few trials. On the final experimental trial, an unexpected critical stimulus was presented in addition to the usual display. Awareness for the critical stimulus was assessed immediately following the usual target response by direct questioning. The proportion of participants reporting awareness in these critical trials was compared across different experimental conditions. A visual control trial at the end of the experiment confirmed that participants' vision was capable of detecting the stimulus. Different experiments varied the nature (perceptual load) of the task (Chapter 2), the nature (Chapter 4) or position (Chapter 3) of critical stimuli, or the age of participants (Chapter 5).

Study hypotheses

If perceptual load determines conscious awareness as it determines the processing of irrelevant distracters, then increasing perceptual load in the relevant task should reduce the frequency of awareness reports. Recent selective attention research has shown an advantage for distracters at fixation over distracters in the periphery, within the flanker paradigm. On the basis of these findings, I predicted an advantage in awareness for critical stimuli appearing at fixation over critical stimuli appearing in the periphery. Previous evidence also indicates that biologically relevant stimuli (e.g. body parts) suffer less inattentional blindness and indirect measures have shown no modulation of face-processing by perceptual load. Following these findings, I predicted that awareness for upright faces would *not* be influenced by increases in task load, whereas awareness for inverted faces would be reduced to the same extent as neutral stimuli. In line with recent findings from developmental research (using RTs), I predicted that rates of inattentional blindness would reduce with age from young children to older children to adults. In addition, I predicted that the effect of perceptual load on awareness would be greater for younger children than older children or adults suggesting that capacity for awareness develops over childhood.

Chapter 2

The role of perceptual load

2.1 Introduction

The purpose of the present study was to establish the role of perceptual load in awareness of a critical stimulus always presented in the periphery. To that purpose, I have modified the inattentional blindness cross task (Mack & Rock, 1998) to include a manipulation of perceptual load, varying either (i) the number of stimuli for the same task or (ii) the demands of the task for the same number of stimuli. In line with findings of effects of perceptual load on distracter processing, I predicted that increasing the perceptual load in the relevant task would reduce the frequency of awareness reports for an unexpected peripheral critical stimulus.

In previous studies, a failure to detect the critical stimulus when it was unattended in the critical trial (appearing unexpectedly during performance of a task) but successful detection when it was attended (in the fully-attended control trial) was taken to reflect blindness due to inattention hence the term "inattentional blindness" (Mack & Rock, 1998). However, fully-attended control trials differ from experimental trials in several aspects that entail processes other than attention. First, the critical stimulus is expected on the control trials, and participants intentionally look for it (either due to explicit instruction to do so in some studies, or due to the preceding awareness probe raising their expectation of something unusual). Thus, the comparison of control trials with experimental trials confounds effects of attention with effects of expectation and intention (see Braun, 2001). Second, awareness reports are made after a task-response and a surprise awareness question in critical experiment trials, but can be made immediately following the display presentation in control trials. Reduced rates of awareness in critical versus control trials may therefore reflect greater rates of forgetting during the longer delay from display presentation until the awareness question in the critical trials (vs. control trials). In other words, inattentional blindness may be conceptualised as "inattentional amnesia" (e.g. Wolfe, 1999).

Thus, the contrast of awareness between critical trials and control trials in previous experiments cannot inform about the pure role of inattention in the phenomenon of inattentional blindness and may at least in part, reflect effects of expectation, intention, and memory. The present study therefore also served to clarify the role of inattention in "inattentional blindness". To avoid the expectation and memory confound in this study, I did not compare rates of awareness between critical trials and control trials. Instead, rates of awareness were compared between critical trials with different levels of attention available as determined by manipulations of perceptual load in the relevant task. Awareness reports in the control trial were used solely as an exclusion criterion: Participants that could not report the critical stimulus in the fully-attended trial were excluded from analysis (thus ensuring that any failures to report the critical stimulus in the critical trial could not be explained by an inability to see that stimulus). In this way, the current comparisons were not confounded with varying levels of expectation: The additional task-irrelevant stimulus on the critical trial was equally unexpected at both levels of perceptual load. "Inattention" was manipulated through varying perceptual load. Determining the relationship between inattentional blindness and perceptual load in this way will not only establish the role of perceptual load in awareness but will also allow us to confirm that reported "blindness" within the inattentional blindness paradigm is indeed due to inattention.

As described in the general introduction (Chapter 1), increased perceptual load means either that the number of relevant items with different identities is increased (e.g. a visual search task with many items is harder than searching amongst relatively few) or that a more demanding perceptual task is carried out for the same number of items (e.g. detection of a conjunction is harder than simple detection of presence; for review see Lavie, 2005). Accordingly, in the following experiments perceptual load was manipulated both by increasing the number of different letters in a relevant visual search task, and by varying the demands of perceptual judgments for identical stimuli, comparing subtle length discrimination (high load) with simple colour detection (low load).

The effects of perceptual load on explicit reported awareness were explored in six experiments in Chapter 2. In Experiment 1, perceptual load was varied by altering the demands of the conventional inattentional blindness cross-task in identical displays, from a simple colour discrimination task to a subtle line-length discrimination. Experiment 2 examined the effects of varying the set size of a visual search task on awareness, comparing set size one with set size six. Experiment 3 examined the effects of perceptual load on forced-choice recognition of the critical stimulus shape as well as explicit awareness using the load manipulations established in Experiments 1 and 2. In Experiment 4, I examined the effects of perceptual load on RTs and accuracy as well as explicit awareness using longer blocks of randomly intermixed low load and high load trials with the critical questioning of awareness at the end of the block. Perceptual load was varied by altering the difficulty of the line-length judgment of the cross-task used in Experiment 1, with an obvious difference in line-length for low load versus a much smaller difference in line length for the high load. Experiment 5 examined the possibility that longer RTs to tasks of high perceptual load, and thus longer delays until the awareness questioning, were responsible for the decreased awareness in high load by the greater opportunity for forgetting during this delay. In Experiment 5, one long block of randomly intermixed low load and high load trials (from Experiment 2) was presented with the critical trials appearing at the end of the block. RTs between low load and high load trials were equated by forcing a one-second delay between stimulus presentation and response entry.

2.2 Experiment 1

In Experiment 1 the conventional inattentional blindness cross-task procedure (Mack & Rock, 1998) was modified to incorporate a manipulation of perceptual load. Participants in each condition of load were given identical series of central cross-targets with two arms of clearly different colour (blue and green) and slightly different length. Participants in the low load group performed a simple colour discrimination task (indicating which cross-arm was blue) that is typically thought to impose low attentional load (e.g. Treisman & Gelade, 1980). Participants performing the high-load task were required to make subtle line-length discriminations (indicating which cross arm was longer). This task should demand considerably more attentional resources than the low load (e.g. Bonnel, Possamamai & Schmitt, 1987; Lavie, 1995), and has led to a reduction in distracters effects on RTs in previous load studies (for review see Lavie, 2000; 2005). An additional task-irrelevant outline black square (the critical stimulus) appeared in critical displays, and awareness for this stimulus was tested immediately following the task response via direct questioning.

Method

Participants Fifty-four visitors to the Science Museum, London participated in the experiment. All reported normal or corrected-to-normal vision and were aged between 18 and 45 years.

Apparatus and stimuli The experiment was presented using E-Prime version 1.1 (Psychology Software Tools Inc) on a PC connected to a 17" monitor (1024 x 768 screen resolution; 75% contrast). Viewing distance was fixed at 60 cm with a chin-rest. Stimulus displays were bitmap images created in Microsoft Paint and the background remained white throughout. Fixation was indicated by a black dot (0.15°). Target displays consisted of a cross at the centre of the screen, with a shorter arm subtending 3.35° and a longer arm subtending 3.9°. One cross-arm was green (RGB values: 0, 234, 41) and the other was blue (RGB values: 0, 191, 255), with a black intersection between the two arms. On the sixth, critical trial, a black outline square shape (sides subtending 0.3°) was presented in addition to the cross target (see Figure 2.1). This critical stimulus appeared in one of four peripheral locations (counterbalanced between participants) all equidistant from fixation (the centre of the cross) at 3.2° eccentricity, and positioned exactly half-way between two neighbouring cross-arms. A mesh pattern consisting of straight black lines of different orientations against the white background was used as a visual mask.

Procedure Each trial began with a small fixation dot (1500 ms) followed by a brief blank screen (96 ms), a cross-target display (110 ms), and finally, a visual mask (496 ms). A blank screen was then displayed while participants provided their appropriate verbal responses. All trials were initiated by pressing the space bar. Participants in the high load group were asked to judge which arm of the cross was longer, whilst participants in the low load group were asked to decide which arm was blue (horizontal or vertical). Participants were instructed to fixate centrally throughout and to guess if they were unsure. Responses were entered by the experimenter.

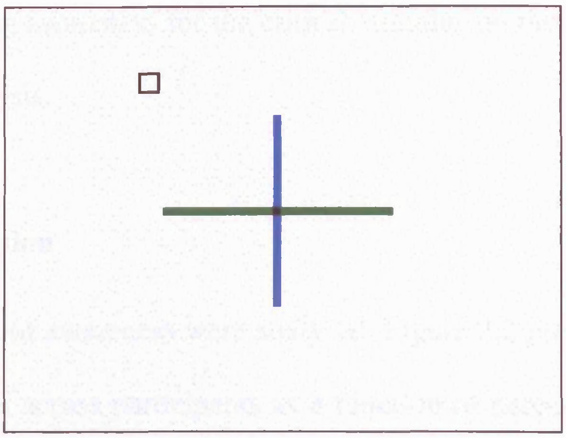

Figure 2.1 An example of a critical display in Experiment 1. Participants in the low load group responded to colour ("which cross-arm is blue?") whereas participants in the high load group responded to line-length ("which cross-arm is longer?").

Each participant completed six experimental trials: five non-critical trials followed by one critical trial. The horizontal cross-arm was longer on half the trials, (the vertical longer on the other half) with order being counterbalanced across participants. Independent of the line-length counterbalancing, the horizontal cross-arm was blue on half of the trials and green on the other half, with the vertical arm taking the opposite colour. Therefore, displays in both conditions of loads consisted of half "horizontal" correct and half "vertical" correct responses. On the sixth trial, the critical stimulus was presented and the cross-task response was made and entered by the experimenter as normal. Immediately following response entry, participants were asked whether they noticed anything else appearing on the screen that had not been there before. Participants responded verbally giving details of the object if possible. The critical trial was then repeated in a final control trial. Before this trial, participants were instructed to ignore the cross-target and instead, look for anything extra that appeared in the display. Awareness for the critical stimulus was measured immediately after trial-termination by direct verbal report as before. Only participants reporting awareness for the critical stimulus on these control trials were included in the analysis.

Results and Discussion

Participants' reports of awareness were analysed. Figure 2.2 presents the percentage of awareness reports across participants as a function of perceptual load (low load vs. high load). The number of errors made across trials in the two conditions of load indicates that the manipulation of perceptual load established in this experiment was effective. On average, participants in the high load group made more errors in experimental trials (M = 17% corresponding to 1.02 trials incorrect on average) than participants in the low load group (M = 5% corresponding to 0.3 trials incorrect on average).

Participants who failed to report the critical stimulus in the final control trial were excluded from the analysis (1), as were those who scored less than four trials correct (6). Note that nearly all of the participants discarded due to low accuracy were in the high load group (5 of 6) whereas only one participant from the low load group was excluded for failing to perform the task. Also discarded were participants who gave ambiguous or uninterpretable responses to the awareness question (5) or participants who did not understand the question about awareness following the critical trial (2).

Remaining participants were equally divided between the two groups: low load (20) and high load (20). All of the participants who reported awareness of the critical stimulus (i.e. made a "Yes" response to the critical question) were also able to describe correctly its location and at least two of its major features (shape, size or colour). Exclusion criteria from this experiment were applied to all experiments reported in the thesis.

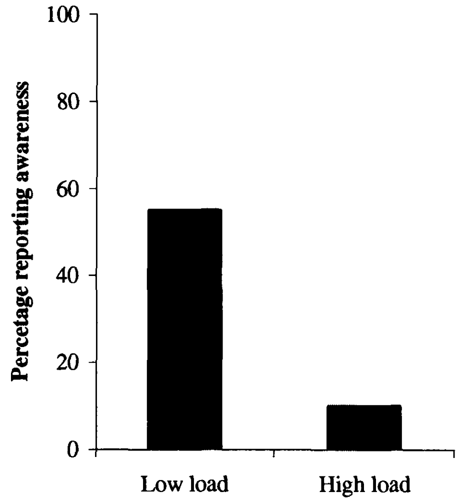

Figure 2.2 Percentage of participants reporting awareness for the critical stimulus as a function of perceptual load (low load vs. high load), N = 40.

The results showed a clear effect of perceptual load on awareness reports. As can be seen in Figure 2.2, fewer participants reported awareness of the critical stimulus under conditions of high perceptual load (2 of 20) than low perceptual load (11 of 20), χ^2 (1, N = 40) = 9.23, p = .002 (two-tailed as in all other experiments reported in this thesis). Thus, the level of perceptual load in a relevant task determined awareness for an additional task-irrelevant object: Increasing the perceptual demands from simple colour discrimination (low load) to more subtle length discrimination (high load) led to greater experienced inattentional blindness.

It is noted that a relatively low level of awareness was seen in Experiment 1, even under conditions of low perceptual load (only 55% awareness). This could be explained by the marked difference in colour and size between the attended stimuli (blue and green, subtending over 3°) and the critical stimulus (black, subtending 0.3°), reducing the salient task-relevance of critical stimuli (see Most et al, 2001, 2005). Thus, since previous studies (e.g. Rock, Linnett, Grant & Rock, 1992; Most et al, 2001; Most et al, 2005) have established a role for similarity or task-relevance (e.g. luminance, shape) in determining rates of inattentional blindness, it may not be surprising that relatively few participants noticed a critical stimulus so dissimilar to the attended target.

This hypothesis can be tested by comparing the present results with overall levels of awareness in the following experiment. In Experiment 2, all stimuli (relevant targets and critical stimuli) were coloured black, and all were of similar size. On the basis of this previous research, this change was expected to elevate the overall level of awareness reported. Critically however, it was predicted that the overall level of awareness should not alter the impact of perceptual load on inattentional blindness. Specifically, high perceptual load was expected to reduce awareness even for a critical stimulus of the same colour and size as the attended stimulus.

In conclusion, Experiment 1 demonstrates that increasing the perceptual load of the relevant task in a standard inattentional blindness paradigm significantly decreased rates of awareness reports of an unexpected critical stimulus. Because displays were identical across conditions of load, Experiment 1 shows that the demands placed on the perceptual system were responsible for this effect, rather than any physical differences between displays.

2.3 Experiment 2

Experiment 2 sought to generalise the effects of perceptual load on inattentional blindness across a manipulation of perceptual load which varied the number of different identity items in the relevant task. Thus, the typical inattentional blindness cross-task was replaced by a visual search task in the current experiment. Participants were asked to search a circular array for a target letter amongst either five non-target letters (high load) or five place-holders (low load). A critical stimulus identical to that used in Experiment 1 was presented on the sixth trial in addition to the usual letter-target display and awareness was assessed immediately following entry of task responses. Critical stimuli were presented in the periphery (at 3.3° eccentricity) clearly separated from the letter circle (which had a radius of 1.6°) in order to avoid any effects of crowding or cluttering of the critical stimulus from target letters or place-holders.

Numerous studies have demonstrated that the level of search load in such tasks determines the extent of distracter effects (e.g. Lavie 1995; Lavie & Cox, 1997; Lavie & Fox, 2000). However, in all of these previous experiments, distracter processing was inferred indirectly by measuring effects on target RTs. It will be interesting to discover here, whether the level of perceptual load in a search task can also dictate explicit awareness for an unexpected task-irrelevant stimulus measured with an inattentional blindness procedure.

Method

Participants Forty-six experimentally-naïve Science Museum visitors participated in the experiment. All reported normal or corrected-to-normal vision and were aged between 18 and 45 years.

Stimuli and Apparatus Fixation was indicated by a small black cross (0.2°). Target displays comprised black letters on a white background measuring 0.36° horizontally and 0.4° vertically at the fixed viewing distance of 60 cm. The target letter (either X or N) appeared once in each of six possible locations falling on an imaginary circle with a radius of 1.6°. The remaining five locations of the circular stimulus array were filled either by small black dot place-holders (low load) or by five non-target letters (U, F, S, P and J) the same size as target letters (high load), see Figure 2.3. Non-target letters appeared randomly but with equal probability in each of the five empty spaces, and appeared 1.8° apart from centre to centre. On the sixth trial, a critical stimulus identical to that in Experiment 1, was presented 3.2° to the left or right of fixation in addition to the letter-target display. The critical stimulus was equally likely for each target position. The visual mask was the same as in Experiment 1. Apparatus was as for Experiment 1.

Procedure The letter displays were presented for 200 ms. Participants were asked to identify whether an "X" or an "N" appeared in each letter display. In the high load group, participants searched for this target amongst five other non-target letters, whereas in low load group, the letter appeared alone amongst five black dots. As before, six trials were presented. The correct target identification response was "X" for half the trials, and "N" for the other half. All possible permutations of target identity and target position order were presented in a design fully counterbalanced across participants. Critical stimuli appeared on the left or right of the letter-circle with equal probability within each group. As before, a final control trial followed the critical trial. All other aspects of the procedure were as in Experiment 1.

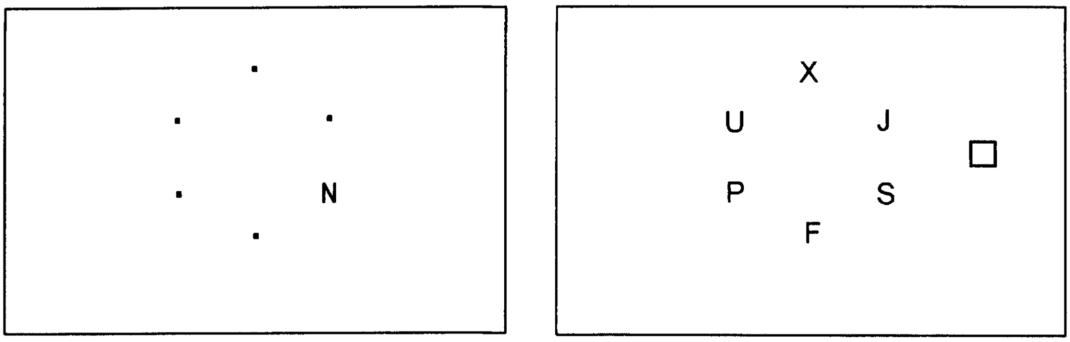

Figure 2.3 Example of a low load non-critical (left) and a high load critical (right) trial in Experiment 2. In both conditions of load, participants searched for a target letter and made the appropriate choice response (X or N).

Results and Discussion

Figure 2.4 presents the percentage of awareness reports across participants as a function of perceptual load in the relevant task (low load vs. high load). Error rates between the two conditions of load confirmed that the set size manipulation of perceptual load in Experiment 2 was effective. There were more errors on average during performance of a high load task (M = 19% corresponding to 0.17 trials incorrect on average) than during performance of a low load task (M = 0%).

Data were excluded from participants who scored less than four trials correct in the attended task (6). Note again that all of these participants who were excluded due to low accuracy (either during the non-critical or critical trials) were performing the high load task. Also discarded were those who failed to report awareness in final control trials (1), those who gave uninterpretable responses to the awareness question (1), and those who failed to understand the awareness question in the critical trial (2). Remaining participants were divided equally between low load (18) and high load (18) groups. Criteria for confirming awareness reports were as for Experiment 1.

The results showed that the perceptual load of a visual search task played a crucial role in determining explicit awareness for task-irrelevant stimuli. Again, high perceptual load significantly reduced the level of awareness reports. Even though most of the participants reported awareness of the critical stimulus under conditions of low perceptual load in this experiment (16 of 18), high perceptual load significantly reduced the rate of awareness reports (to 9 of 18), χ^2 (1, N = 36) = 6.42, p = .011 (see Figure 2.4).

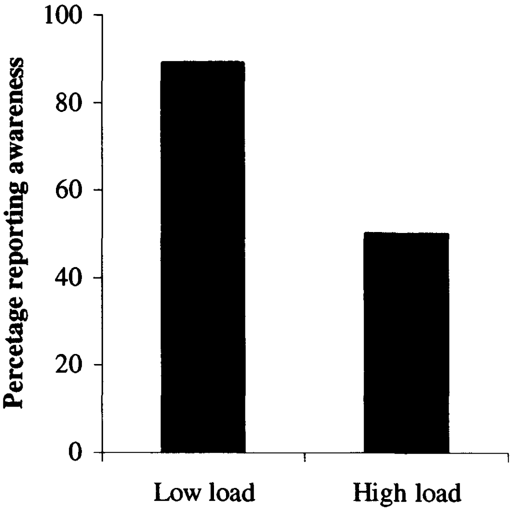

Figure 2.4 Percentage of participants reporting awareness for the critical stimulus as a function of perceptual load (low load vs. high load), N = 36.

Experiment 2 thus generalises the findings of Experiment 1 across different levels of visual similarity (in colour and size) between the critical stimulus and attended targets and hence different overall levels of awareness, as well as across different manipulations of perceptual load.

Awareness reports in both high load and low load were pooled in a combined analysis of the effect of distance (between letter target and critical stimulus) on inattentional blindness. No significant differences were revealed although there is a slight trend towards greater blindness at the furthest distance. Percentage awareness reports were 83%, 58% and 67% for the nearest (1.6°), middle (3.2°) and furthest (4.8°) distances respectively. This is in line with findings that inattentional blindness increases with distance from attention (Newby & Rock, 1998).

In conclusion, Experiment 2 has shown that awareness rates in inattentional blindness paradigms are significantly reduced when perceptual load is increased by adding more relevant items to stimulus displays. The effects of load on inattentional blindness are therefore not confined to experimental conditions using the standard cross-task procedure. Instead, Experiment 2 generalises results across the well-established visual search set size manipulation of perceptual load.

2.4 Experiment 3

Experiments 1 and 2 have established that imposing perceptual load in the relevant task reduces the magnitude of awareness as indexed by explicit verbal report. Experiment 3 asks to what extent perceptual load modulates performance in a forced-choice test of critical stimulus shape which could potentially provide a more sensitive measure of awareness.

Two groups of participants were run with this measure: Group 1 were presented with the cross-task procedure of Experiment 1 (low load vs. high load), and Group 2 were presented with the set size variation of perceptual load described in Experiment 2 (low load vs. high load). Following the usual awareness measures, participants in Experiment 3 were asked to identify which, out of four possible black outline shapes (the outline square critical stimulus, and three alternative outline foils: a star, an upward-pointing arrow, or a ring shape, see Appendix) had appeared in the critical display.

Method

Participants Eighty-eight visitors to the Science Museum, London participated in this experiment. All were between 18 and 45 years of age and all reported normal or corrected-to-normal vision.

Stimuli and Apparatus Stimuli and apparatus were as in Experiments 1 and 2 with the addition of the four black outline shapes (square, star, upward-pointing arrow and ring) comprising the forced-choice test (see Appendix).

Procedure Procedures were identical to Experiments 1 and 2 with the exception of the additional forced-choice recognition measure. Immediately following the awareness measurement procedure used in Experiment 1, participants were asked to choose which of four shapes had appeared on the screen in addition to the usual display (regardless of their awareness response). The four possible choices were presented on paper by the experimenter.

Results and Discussion

Figure 2.5 presents the percentage of awareness reports across participants as a function of perceptual load (low load vs. high load) for Groups 1 and 2. Figure 2.6 presents the percentage of correct responses across participants in the forced-choice test as a function of perceptual load (low load vs. high load) for Groups 1 and 2. Excluded from the analyses were participants who could not perform the main task adequately (seven in total; five in high load, two in low load), participants who did not understand the instructions (3), one participant who failed the visual control trial, and one participant who gave an uninterpretable response.

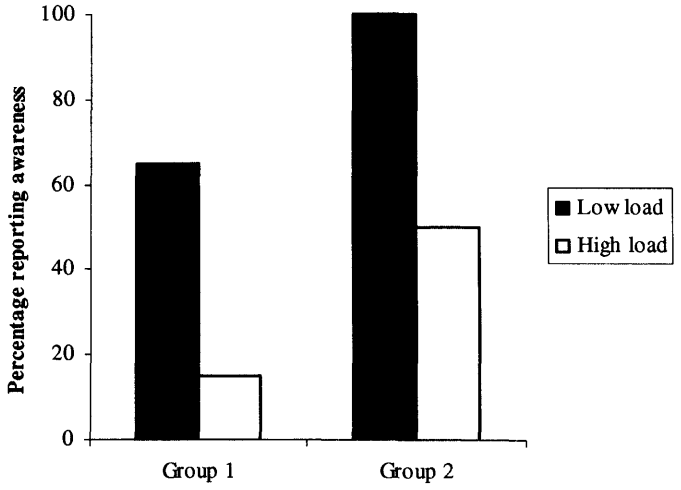

Figure 2.5 Percentage of participants reporting awareness for the critical stimulus as a function of load (low load vs. high load) for Group 1 (N = 40) and Group 2 (N = 36).

Group 1: Cross-task load manipulation

Awareness Results from Group 1 in Experiment 3 replicate the effect of perceptual load on awareness established in Experiment 1. Significantly fewer participants reported awareness for the critical stimulus when asked directly under conditions of high perceptual load (3 of 20) compared with low perceptual load (13 of 20), χ^2 (1, N = 40) = 10.42, p = .001. Similar overall levels of awareness were seen in the present replication, as well as an equivalent modulation by perceptual load.

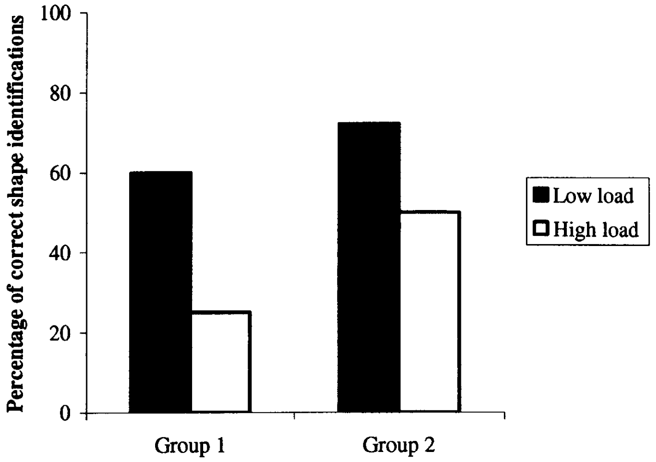

Figure 2.6 Percentage of participants correctly identifying the critical stimulus shape in the forced-choice recognition test as a function of load (low load vs. high load) in Group 1 (N = 40) and Group 2 (N = 36). Yes and No awareness responses are pooled together.

Forced-choice recognition The present experiment showed further that increasing perceptual load in the relevant task determined awareness as measured by a forced-choice recognition test. In accordance with the verbal awareness reports, significantly fewer participants were able to identify the correct shape under conditions of high perceptual load (5 of 20) compared with conditions of low perceptual load (12 of 20), χ^2 (1, N = 40) = 5.01, p = .02. In addition, collapsing across conditions of load, it appears that most participants reporting awareness for the critical stimulus were able to correctly identify its shape (81%), whereas those failing to report awareness could not identify it at level greater than chance (25%). This confirmed the validity of participants' initial awareness reports.

Group 2: Visual search load manipulation

Awareness Results in Group 2 replicated the effects of perceptual load on explicit awareness reports described in Experiment 2. Significantly greater numbers of participants report awareness for a critical stimulus when performing a task of low perceptual load (18 of 18) compared to a task of high perceptual load (9 of 18), χ^2 (1, N = 36) = 12.0, p = 0.001.

Forced-choice recognition In addition, the current manipulation showed that imposing perceptual load caused a corresponding decrease in performance on an immediate memory test of shape recognition. Significantly fewer participants were able to correctly identify the critical stimulus shape under conditions of high perceptual load (7 of 18) than conditions of low perceptual load (13 of 18), χ^2 (1, N = 36) = 4.06, p = .04. Further, as with Group 1, performance in the forced-choice shape recognition test depended upon the direct verbal report of awareness: Collapsed across conditions of load, 70% of participants reporting awareness of a critical stimulus were successfully able to identify it in the shape recognition test, whereas only 11% of those who failed to report awareness of the critical stimulus performed at level lower than chance in the later recognition test.

Despite different overall levels of awareness between Groups 1 and 2, correct performance on the forced-choice recognition test as a function of explicit awareness report (Yes vs. No) were equivalent. This suggests that similar mechanisms for awareness were operating under the two different manipulations to produce two different absolute levels of awareness.

These results demonstrate the impact of perceptual load on recognition tests within an inattentional blindness paradigm. In addition, the pattern of results supports the validity of participants' positive awareness reports and suggests that failure to report awareness for an unexpected object in these experiments was not due to reluctance or uncertainty.

Awareness reports were pooled across Experiments 2 and 3 (Group 2), and across both load conditions (high load and low load) in a combined analysis of the effect of distance (between letter target and critical stimulus) on inattentional blindness. No significant differences were revealed although there is a slight trend towards greater blindness at the furthest distance. Percentage awareness reports were 73%, 74% and 70% for the nearest (1.6°), middle (3.2°) and furthest (4.8°) distances respectively. Although the trend did not reach significance, the direction of the trend is in line with the finding that inattentional blindness increases with greater distance from the attended task (Newby & Rock, 1998).

Results in the current experiment appear to differ from results reported by Rock et al (1992) regarding shape identification following awareness reports. Rock et al (1992) presented a filled shape (e.g. rectangle or triangle) in one of three colours (e.g. red or blue) as a critical stimulus in a standard inattentional blindness cross-task procedure. Following the questioning of awareness, participants were asked to say which shape of six possible choices (all coloured black) had appeared, and where on the screen it had been presented. Results showed that although participants reporting awareness of a critical stimulus were able to identify its location (~95% correct across experiments), they were unable to identify its shape above chance level (~18% correct across experiments). This contrasts with the significantly above chance level performance seen after positive awareness responses in the present experiment (81% and 70% for Groups 1 and 2 respectively). However, because the foils used in the present study were very dissimilar to the critical stimulus, whereas foils used in Rock et al's (1992) study (e.g. square, diamond) were very similar to the critical stimulus shapes (e.g. rectangle), their recognition task may have been less sensitive to reveal recognition. In addition, the set of shapes used in the forced-choice test were all black whereas critical stimuli were presented in colour. This change in visual presentation may have been sufficient to to disrupt a particularly weak memory trace, thereby apparently lowering performance on the test.

In conclusion, Experiment 3 has shown that perceptual load modulates performance in an immediate forced-choice recognition test as well as an explicit detection test measured through direct questioning. Performance in the shape recognition test was shown to correspond to participants' explicit awareness reports.

2.5 Experiment 4

The small number of trials presented to participants in previous experiments precluded the assessment of effects of perceptual load on target RTs. Although it is well-established that the visual search set size manipulation of perceptual load used in Experiments 2 and 3 (Group 2) produces slower target RTs and higher error rates in high load as compared with low load (e.g. Lavie, 1995; Lavie & Cox, 1997; Maylor & Lavie, 1998), the effects of the cross-task load manipulation on RTs and errors are yet to be measured. The accuracy data from Experiment 1 indicated greater error rates under conditions of high perceptual load than low perceptual load. However, in order to obtain reliable measures of RTs and error rates, Experiment 4 presented long blocks of low load and high load trials (randomly intermixed except for the final and penultimate trials for which the level of load was counterbalanced to produce equal numbers of penultimate and final trials with the same, as with different, levels of load) using the cross-task of Experiment 1. In addition, awareness for the same critical stimulus as Experiments 1-3 was assessed in the final trial, which was of low load for one group of participants and high load for a second group of participants. Importantly, as low load and high load trials were randomly intermixed within blocks, participants could not anticipate the level of load in any given trial. Thus, any effects of perceptual load on awareness in this experiment (at the end of the block) cannot be attributed to differences in strategy or in expectation of task difficulty between pure blocks of low load and high load trials.

Randomly intermixing trials of different loads requires the same task to be performed throughout, in order to avoid effects of task switching. Therefore all participants were asked to judge which cross-arm was longer (horizontal or vertical) for each cross target throughout the block. Targets on the high load trials were identical to those used in Experiment 1 (a subtle line length difference). In low load trials, the long arm was the same as in high load trials, but the shorter arm was reduced to a much larger extent (the length difference was thus greater producing a less perceptually demanding length discrimination in low load). This manipulation of perceptual load should produce significantly slower RTs in high load (vs. low load) trials, as well as significantly fewer reports of awareness when critical stimuli appear on high load (vs. low load) trials. The level and order of load across critical and penultimate (to critical) trials was counterbalanced in this experiment: Critical trials in the low load group were preceded by a low load trial for half the participants and a high load trial for the other half (the same counterbalancing for critical trials of high perceptual load).

Method

Participants Fifty-seven respondents to an advertisement for psychology experiments participated in this experiment. All reported normal or corrected-to-normal vision and were aged between 18 and 35 years.

Stimuli Stimuli were as for Experiment 1 with the exception of low load cross targets. On low load trials, the longer arm of the blue-green cross target subtended 3.9° while the shorter arm subtended 1.25°, producing a clear difference in line length (see Figure 2.7).

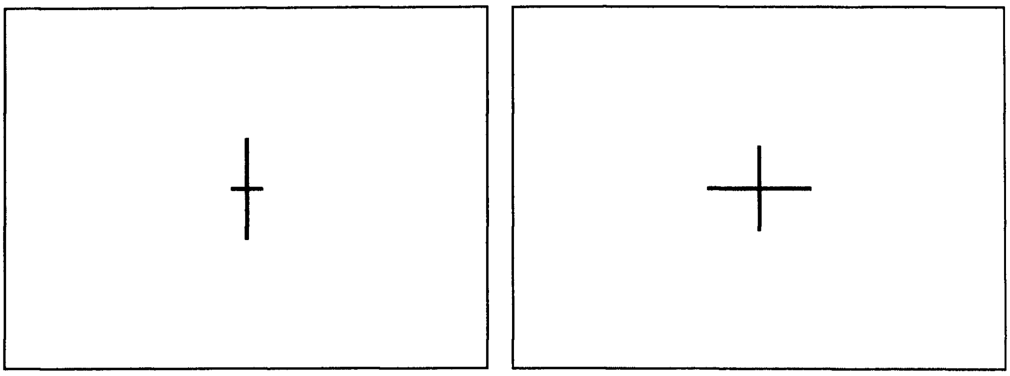

Figure 2.7 Example low load (left) and high load (right) non-critical displays in Experiment 4. For all displays, participants judged which cross-arm was longer. The line-length difference was smaller in high load than low load displays.

Procedure and Design The procedure was similar to Experiment 1 except that now, all participants were asked to judge which arm was longer on a series of coloured cross targets. Targets could be either high load or low load and were randomly intermixed within each block. Participants responded by pressing "H" for horizontal longer or "U" for vertical longer as fast but as accurately as possible. A practice block of 32 trials preceded two blocks of 72 trials, with the critical stimulus (size and locations as in Experiment 1) appearing on an additional trial at the end of the final block. In critical trials, a low load target was presented to one group of participants and a high load target was presented to a second group. Arm length and arm colour of critical targets were fully counterbalanced across participants, as was critical stimulus position (top left, top right, bottom left, bottom right). Awareness of the critical stimulus was tested by presenting the critical question on the computer screen immediately following the entry of target responses. Participants entered their awareness responses pressing "Y" for Yes or "N" for No. Following response entry, participants were asked to guess which shape out of four alternatives (see Appendix) had appeared in the critical display and then to guess which location it had appeared (top left, top right, bottom left or bottom right), regardless of their initial awareness response. These additional measures enabled the verification of the validity of participants' awareness reports within the current automated procedure. As in previous experiments, a final control trial was then presented in which participants simply had to look for anything extra in the repeated critical display. Responses to this control trial were verified in the same way as responses to the critical question (i.e. the "Yes" or "No" awareness probe).

Results and Discussion

Data were excluded from participants who failed the visual control trial (8), participants were familiar with the inattentional blindness phenomenon (2), and participants who could identify neither shape nor location correctly following a "Yes" awareness response (4). Also discarded was one participant who failed to score above 55% correct in the high load trials, and ten participants who failed to give a correct target response (horizontal/vertical) on the critical trial. Note that, as before, almost all of those making errors on critical trial were performing the high load task (8 of 10) whereas only two incorrect responses were given on critical trials of low load. This provides preliminary support that the manipulation of perceptual load was effective. There were 16 remaining participants in each load group, and every participant who reported a "Yes" awareness response could identify either shape or location correctly (and usually both).

RTs and errors Incorrect trials and trials with RTs longer than 1500 ms were excluded from the RT analysis. Results supported the hypotheses and confirmed that the load manipulation was successful. Averaging across participants and across non-critical trials, results confirmed that RTs on high load trials (685 ms) were significantly slower than RTs on low load trials (563 ms), t (31) = 7.4, p = .0001. Importantly, RTs in critical trials were also significantly slower for participants viewing high load targets (687 ms) than low load targets (512 ms), t (30) = 2.1, p = .04. In addition, participants made significantly more errors on high load trials (19%) than low load trials (6%), pooling across participants and across non-critical trials, t (31) = 7.3, p = .0001. Notice that this parallels effects of load on errors seen in Experiment 1. This confirms the efficacy of the perceptual load manipulation of line length for centrally-presented cross targets with arms of blue and green.

Awareness Figure 2.8 presents the percentage of reported awareness across participants as a function of perceptual load (low load vs. high load). Importantly, results revealed a significant effect of perceptual load on rates of awareness reports in the current experiment as illustrated in Figure 2.8. Significantly fewer participants reported awareness of a critical stimulus under conditions of high perceptual load (6 of 16) than conditions of low perceptual load (13 of 16) on critical trials, χ^2 (1, $\underline{N}$ = 32) = 6.35, p = .012. Participants reporting awareness were often able to correctly identify the critical stimulus shape from the four possible alternatives (9 of 13 correct in low load; 4 of 6 correct in high load), and nearly all correctly identified the location of the critical stimulus (12 of 13 in low load; 5 of 6 in high load). By contrast, participants who did not report awareness of the critical stimulus were typically unable to identify the shape or location in the high load group (7 of 10 incorrect shape guessed; 10 of 10 incorrect location guessed). Similarly, participants not reporting awareness were typically unable to identify the location in the low load group (3 of 3 incorrect), although two of the three unaware participants guessed the correct shape. Thus, awareness reports showed good correspondence with the forced-choice discrimination results with the possible exception of better shape-guessing than detection in the low load group. However, as the number of unaware participants in the low load group was so small (3 of 16), this result may not be reliable.

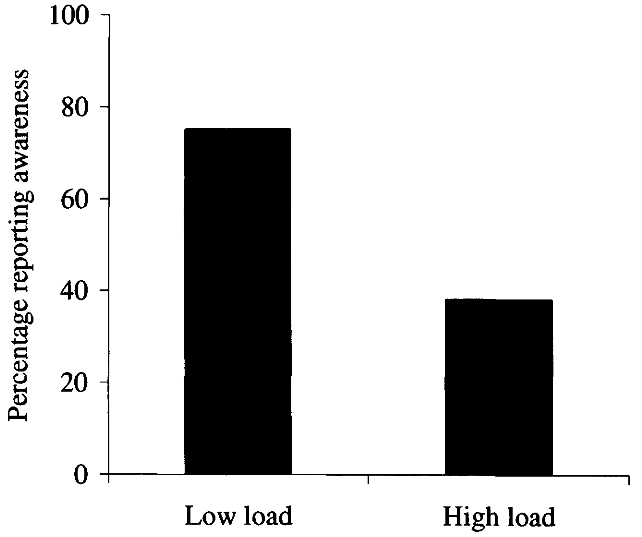

Figure 2.8 Percentage of participants reporting awareness for the critical stimulus as a function of perceptual load (low load vs. high load), N = 32

Carry-over effects from the level of load in penultimate trials on awareness reports or RTs in (final) critical trials only showed small and non-significant numerical trends in the direction of larger load effects in critical trials preceded by the same level of load than preceded by a different level of load. A 2 x 2 between-participants ANOVA on the RTs with the factors of critical trial load (high vs. low) and level of load across critical and penultimate trials (same vs. different) showed no significant interaction ($F < 1$): Effects of perceptual load (high load trial RTs minus low load trial RTs) on the critical trial RTs were similar across penultimate trials of the same level of load (193 ms) and of different levels of load (158 ms). The effects of load on awareness were also similar irrespective of the level of load on the preceding trials (although they showed a small trend for larger effects when critical and penultimate trials were of the same level of load). Rates of awareness decreased from 7 of 8 in the low load group to 2 of 8 in the high load group when the critical trials were preceded by the same level of load, and from 6 of 8 in low load to 4 of 8 in high load when preceded by a different level of load.

Overall then, Experiment 4 established that a perceptual load variation of the inattentional blindness cross-task produced longer target RTs and more errors in high load trials compared with low load trials. In addition, increasing perceptual load significantly reduced rates of awareness reports despite an increase in the number of trials and despite the intermixing of trials of different levels of load within blocks. These findings therefore clearly demonstrate that the effects of perceptual load on awareness cannot be attributed to effects of expectation of task-difficulty or effects of strategy which might be established during performance of low load versus high load tasks in the block designs of Experiments 1-3.

2.6 Experiment 5

As illustrated above, target RTs in Experiment 4 were slower in tasks of high perceptual load compared with tasks of low perceptual load, replicating the typical effects of perceptual load on RTs. Although the measure of awareness used in this experiment (i.e. via Yes/No reports) was not based on RTs, it might have been influenced by slowing of task responses under high perceptual load. Such slowing of responses would introduce a longer delay from presentation of the critical display until questioning about awareness (as this always followed task responses) in conditions of high load compared with low load. This in turn could increase the likelihood of blindness due to forgetting during the longer delay (in other words, greater likelihood of "inattentional amnesia", Wolfe, 1999, in high load than low load trials).

This criticism might also apply to Experiments 1-3. Although participants were not requested to make speeded task responses, it remains possible that the load manipulation in these experiments produced slower task RTs in high load (vs. low load) and hence, a longer delay between critical stimulus presentation and awareness questioning during high load (vs. low load) tasks. Indeed, a test on 16 participants (all students at University College London) with a 48-trial block of each condition of visual search load used in Experiment 2, and without instruction to make speeded responses, confirmed that RTs were longer in the high load (615 ms) than low load condition (512 ms) in this manipulation, $t(15) = 7.03$, $p = .0001$.

It was therefore important to rule out an alternative account for effects of perceptual load in terms of greater inattentional amnesia (rather than greater inattentional blindness) due to the longer delay with slower task responses in high load compared with low load. This was the purpose of Experiment 5. In this experiment, the design used in Experiment 2 was modified in an attempt to equate the delay between critical display presentation (plus the target response) and questioning of awareness across tasks of low load and high load. To this end, a one-second delay was introduced from presentation of the stimulus and mask until the task response could be made. The aim of this delay was to forced participants to withhold their prepared responses on each trial until the set marker appeared, thereby equating RTs on low load and high load trials.

In addition, similar to Experiment 4, one long block of randomly intermixed low load and high load trials was run, with awareness being tested on one final critical trial at the end of the block. In this way, reliable measures of RT could be collected in Experiment 4. In addition, this could establish effects of visual search load on awareness that cannot be explained by differences in strategy or expectation of task-difficulty between low load and high load trials. As there were no carry-over effects of load order found between critical and penultimate trials in Experiment 4, trial load order was fully randomised in this experiment. If perceptual load determines awareness independent of effects on RTs, then there should be fewer reports of awareness under high load compared with low load despite equivalent RTs.

Method

Participants Thirty-nine undergraduate students from University College London were paid to participate in this experiment. All reported normal or corrected-to-normal vision and were aged between 18 and 25 years.

Stimuli and Apparatus These were identical to Experiment 2.

Procedure and Design The procedure was similar to Experiment 2. Participants again searched for a target letter (X or N). However, targets could appear either in low load displays (target with five place-holders) or high load displays (target with five other distracter letters) which were randomly intermixed within each block. Participants were instructed to enter their responses as fast as they could via key-presses but only upon the presentation of a question mark, and not before. The question mark display appeared 1000 ms after termination of the mask. A practice block of 24 trials preceded a single experimental block of 102 trials with the critical stimulus (the same as in Experiment 2) displayed on the final trial. The last trial was either of low load (for one group of participants) or high load (for another group of participants). Target identity and target position were fully counterbalanced across participants in critical displays, as was critical stimulus location (left or right of fixation). The procedure for measuring awareness was as for Experiment 4. A final control trial was included as in Experiment 4.

Results and Discussion

Figure 2.9 presents the percentage of reported awareness as a function of perceptual load (low load vs. high load) in Experiment 5. Data were discarded from participants failing to notice the critical stimulus on the control trial (2). In addition one participant was discarded because they could identify neither shape nor location correctly after giving a “Yes” awareness response to the critical trial. Remaining participants were equally divided between each load group: low load (18) and high load (18).

RTs and errors The results confirmed that RTs in both the low load (335 ms) and high load (334 ms) trials were successfully equated in Experiment 5, although there were more errors in high load trials (5%) than low load trials (2%), t (35) = 4.09, p = .0001, in line with an effective manipulation of load.

Awareness Despite equal reaction times (as well as greater practice during a longer block and performance of high and low load trials in one randomly intermixed block), high perceptual load significantly reduced the rate of awareness reports in Experiment 5 (Figure 2.9). Fifteen out of 18 participants reported awareness of the critical stimulus in low load compared with 8 out of 18 in high load, χ^2 (1, $\underline{N}$ = 36) = 5.90, p = .015. As with Experiment 4, the forced-choice shape and location judgments showed good correspondence with the awareness reports. Participants reporting awareness of critical stimuli were generally able to correctly identify its shape (13 of 15 in low load; 7 of 8 in high load) and location (15 of 15 in low load; 8 of 8 in high load) whereas unaware participants could not identify shape (3 of 3 incorrect guesses in low load; 9 of 10 incorrect in high load) or location (2 of 3 incorrect guesses in low load; 10 of 10 incorrect guesses in high load) correctly.

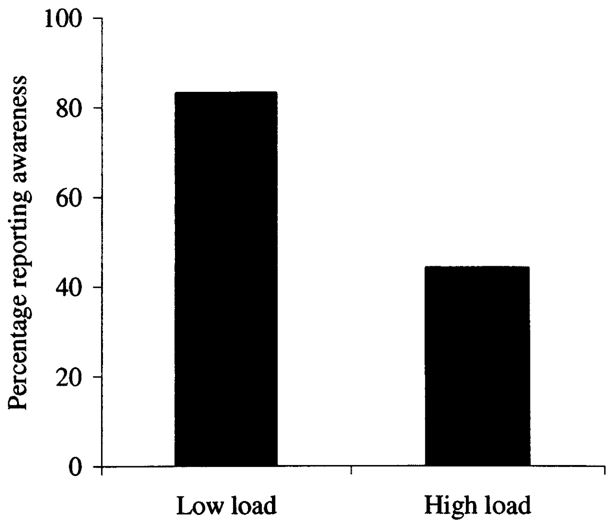

Figure 2.9 Percentage of participants reporting awareness for the critical stimulus as a function of perceptual load (low load vs. high load), N = 36.

2.7 Chapter discussion

The results from Chapter 2 show that the level of perceptual load in a current task determines whether a task-irrelevant stimulus will enter visual awareness. When load is increased in the relevant task (either through a greater number of items among which the target has to be found in search tasks as in Experiments 2, 3 and 5, or through the cross-task requiring a more subtle perceptual discrimination as in Experiments 1, 3 and 4) more participants fail to notice the presence of an additional task-irrelevant stimulus appearing on a final trial, exhibiting inattentional blindness. In addition, perceptual load was also shown to modulate recognition in an immediate forced-choice shape recognition test across different manipulations of perceptual load (Experiment 3)

The results converged across load manipulations that did not vary the appearance of the display (Experiments 1 and 3) and load manipulations that did not vary the task (but instead either increased the number of items in the display, Experiments 2, 3 and 5; or varied the difficulty of a discrimination judgment, Experiment 4). Together these rule out alternative accounts of the findings in terms of any confound each manipulation alone may have carried. For example, although displays may have appeared more cluttered in high load than the low load in the set size load manipulation (Experiments 2, 3 and 5), clearly this is not the case for the cross-task load experiments (Experiments 1, 3 and 4). Similarly, although some load manipulations compared awareness during performance of two different tasks, others manipulations involved identical tasks in both load conditions (Experiments 2-5).

In addition, effects of perceptual load on awareness were found in both the cross task and the visual search task when the level of load was varied randomly from trial to trial within a block (Experiments 4 and 5) and when the load and order across critical and penultimate trials was fully counterbalanced (Experiment 4). Thus, results cannot be explained by differences in the strategies set-up during blocks of high versus low load, or by participants expecting and preparing for a certain level task difficulty in the critical trial.

Finally, effects of perceptual load on awareness were also found when reaction times in high load and low load were equated (Experiment 5). This rules out an alternative explanation of results alluding to the effects of the longer delay between stimulus presentation and awareness questioning caused by the slower target-responses in higher loads. Such an experiment therefore discredits the theory that inattentional blindness is due to participants forgetting the critical stimulus, as forwarded by Wolfe (1999; "inattentional amnesia").

Importantly, the modulation of inattentional blindness across different levels of load found in this study cannot be explained by the variation of intentions or expectations across conditions. In the present experiments, the critical stimulus was equally task-irrelevant and equally unexpected across all conditions of perceptual load. These results therefore offer compelling evidence that the availability of attention for the processing of a task-irrelevant stimulus, as varied by perceptual load, determines whether that stimulus reaches conscious awareness.

As such, the present results provide the strongest behavioural evidence so far that perceptual load plays a critical role in determining conscious awareness. Perceptual load theory has proposed that a consideration of the role of task-relevant perceptual load in determining task-irrelevant processing can resolve the early versus late selection debate regarding the influence of attention on perception. In this theory, task-irrelevant stimuli are perceived only in situations of low perceptual load when the relevant task leaves spare capacity for their processing, but not in situations of high perceptual load that consume all available capacity. Previous research has convincingly demonstrated that the level of perceptual load in the relevant task determines the degree of distracter interference (on RTs), as well as neural activity in visual cortex related to their perception. With one exception however (in the case of subjective duration of the MAE; Rees et al., 1997), previous research did not explicitly address the effects of perceptual load on conscious perception. The present findings support the prediction that perceptual load determines conscious perception of task-irrelevant stimuli as directly measured by participants' awareness reports. This further strengthens the resolution offered by the perceptual load model to the early versus late selection debate regarding the perception of ignored stimuli.

In addition, the present findings make a significant contribution to the understanding of the phenomenon of inattentional blindness. Although attention is held to play a key role in this phenomenon, as stipulated in the term "inattentional blindness", surprisingly little previous research has systematically investigated the pure effects of attentional availability and correspondingly "inattention" on awareness. For example, two studies explored the effects of spatial separation between the critical stimulus and the target stimulus (Newby & Rock, 1998, see also Most et al, 2000). Two other studies explored the effects of stimulus type with the assumption that biologically meaningful stimuli (e.g. body silhouettes, happy faces) capture attention and hence suffer less inattentional blindness (Downing et al, 2004; Mack & Rock, 1998). As there were no direct manipulations of attention in these studies however, causal inferences about the role of attention in awareness cannot be drawn from these results.

Perhaps the most intensive effort to relate inattentional blindness to attention was made by Most and colleagues. In a series of studies, greater rates of awareness were found for critical stimuli that were more visually similar to attended targets along task-relevant dimensions (e.g. in luminance or shape, Most et al, 2001; 2005). These results appear to provide an awareness analogue of "contingent attentional capture" (whereby greater attentional capture effects are found (on search RTs) for "singleton" items that share a feature with the target, e.g. Folk, Remington & Johnston, 1992). However, effects of similarity between critical stimuli and targets on awareness may also be explained as direct effects of priming (driven by expectations of particular target features) on detection thresholds for the critical stimuli. Because critical stimuli that are more similar to the target are more likely to activate the target template (than critical stimuli that are dissimilar to targets) they would also be more readily detected. Such effects of priming on detection thresholds may not necessarily entail greater allocation of attention to the critical stimuli; rather, for the same level of activation and attention (or inattention), primed critical stimuli might be detected more often than unprimed critical stimuli due to lower detection thresholds for primed stimuli.

Finally, as I discussed earlier in the general introduction (Chapter 1), although Simons and Chabris (1999) have shown greater inattentional blindness during performance of a harder counting task, the potential increase in eye movements (reducing critical stimulus visibility) and working memory load (reducing encoding of critical stimuli into long-term memory) with the harder task (vs. the easier task), preclude a clear conclusion on the pure role of attentional load in awareness.

Thus, experiments in Chapter 2 are the first to directly and systematically vary the level of demand that task-relevant processing places specifically on attention (as distinct from expectation, working memory, and eye movements), and hence the level of inattention for task-irrelevant stimuli. The demonstration that reports of awareness or "blindness" critically depend on the extent to which the relevant task exhausts attentional capacity (under high perceptual load) and so leaves little or no capacity for irrelevant processing, produces strong and unequivocal evidence for the critical role of attention in inattentional blindness.

Chapter 3

Effects of critical stimulus position: fixation versus periphery

3.1 Introduction

While performing everyday tasks, we are frequently faced with visual events that appear unexpectedly in our field of view and distract us from our current goal. Computer users for example, will be familiar with the surprising appearance of irrelevant pop-up advertisements while they search the Internet or browse a web page. Such pop-ups may emerge from a corner of the screen, or they can dominate our view by occurring directly at the centre of the display. If a surprising visual stimulus enters awareness and captures attention away from a current goal, task performance may decline (for review, see Yantis, 2000). Thus, a central question in the investigation of attention and awareness remains, whether we are able to exclude surprising, irrelevant stimuli from entering our awareness or not. Since the presentation of surprising information at fixation (i.e. where we are looking) seems intuitively more noticeable than information presented elsewhere, this chapter examines the effects of retinal position of an unexpected stimulus on levels of awareness, contrasting in particular, fixation and periphery. In addition, as has been shown in the experiments reported in Chapter 2, varying the perceptual load of an attended task (either by increasing perceptual demands or increasing the number of relevant display items) influences the rate of awareness reports. Therefore, a second question I ask in this chapter is whether effects of perceptual load on awareness differ depending on whether critical stimuli appear at fixation or in the periphery.

Previous research

The visual system is highly specialised for handling information that falls at fixation. The fovea possesses several marked physiological and functional advantages for processing, including greater cortical representation (e.g. Connolly & van Essen, 1984; Daniel & Whitteridge, 1961; Hubel & Wiesel, 1974), greater contrast sensitivity, and greater visual acuity and resolution (e.g. Fiorentini & Berardi, 1991) than elsewhere in the visual field. In addition, a close behavioural association has been established linking attention to fixated regions (e.g. Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher & Blaser, 1995). For example, although it is possible to dissociate attention from fixation (e.g. Posner, 1980; Posner, Nissen & Ogden, 1978), one is naturally guided by the other under normal circumstances: Eye movements are followed by the redirection of attention towards common locations (e.g. Chelazzi, Biscaldi, Corbetta, Peru, Tassinari & Berlucchi, 1995) and shifts in fixation typically accompany shifts of attention (e.g. Crovitz & Davies, 1962).

Examination of retinal physiology has revealed however, a uniquely high density of rod photoreceptors in the periphery (peak density at ~18° Osterberg, 1935), compared with the high density of cones (and absence of rods) in the foveal region (Curcio, Sloan, Kalina & Hendrickson, 1990). This photoreceptor topography produces advantages in peripheral vision in certain visual tasks including motion and brightness detection (e.g. van de Grind, Koenderink & van Doorn, 1987; Wright, 1987). Harris and Fahle 1996, for example, found a relative improvement in detection of stimulus onsets compared with discrimination tasks as stimulus eccentricity increased. There is thus the alternative possibility of superior awareness detection in the periphery following its specialised visual function.

Visual search studies confirmed an advantage for search items in or around the fovea versus in the periphery (Wolfe, O'Neill & Bennett, 1998; Carrasco, Evert, Chang & Katz, 1995). By contrast, initial evidence of task-irrelevant processing suggested that fixation distracters are ignored to a greater extent than peripheral distracters (e.g. Goolkasian, 1981, 1999), although these findings may be attributed to various confounds as discussed below.

Goolkasian (1981) used a spatially separated Stroop task where a distracter (e.g. a colour name) appeared at fixation whilst a target (e.g. a colour patch) was presented either at fixation (lying directly beneath the distracter) or at one of three peripheral eccentricities (7°, 15° or 25° from fixation). With this arrangement, Goolkasian (1981) found that target RTs were modulated by the fixation distracter at all target eccentricities except for the furthest distance (25°). Furthermore, the amount of distracter interference was positively correlated with the target-to-distracter distance: As with peripheral distracters (e.g. Kahneman & Henik, 1981), increasing the target-to-distracter separation diminished the disruption caused by fixation distracters. However, as there was no peripheral distracter condition to directly compare with effects of fixation distracters in this study, the question of relative processing priority cannot be considered.

In a later study, Goolkasian (1999) examined the effect of target-to-distracter separation and directly compared the processing of fixation versus peripheral distracters within a flanker task (Eriksen & Eriksen, 1974). She found that increasing the target-to-distracter distance reduced compatibility effects to a greater extent when distracters appeared at fixation than when they appeared in the periphery. At first glance, these results appear to suggest that the fixation distracters were easier to ignore under some conditions.

However, this effect may be attributed to variation in the task demands between target tasks presented at fixation (in the presence of peripheral distracters) and target tasks presented at one of two possible locations in the periphery (in the presence of fixation distracters). For example, the peripheral-target task implicated greater spatial uncertainty than the fixation-target task. Several studies have established that spatial uncertainty impairs performance in attention tasks (e.g. increasing orientation discrimination thresholds, Lindblom & Westheimer, 1992; Morgan, Ward & Castet, 1998; or increasing attention capture effects from distracters, Yantis & Jonides, 1990; Theeuwes, 1991). Therefore, the spatially uncertain peripheral-target condition used by Goolkasian (1999) should have imposed greater task demands than the spatially certain fixation-target condition. Indeed, adding a dimension of spatial uncertainty to a task has been used as a method of consuming attentional capacity in some studies (e.g. Mouloua & Parasuraman, 1995).

In addition, performing tasks on peripheral targets may also be more demanding than performing the same task at fixation due to the reduced acuity and resolution of peripheral vision, as well as the unnatural dissociation of attention from fixation (see earlier discussion). For all of these reasons, Goolkasian's (1999) peripheral-target task may have been more demanding – therefore reducing the availability of attention for irrelevant processing (i.e. fixation distracters) to a greater extent – than the comparably less demanding fixation-target task (with peripheral distracters). Therefore, clear conclusions cannot be drawn from the studies outlined so far regarding the comparative processing of centrally-presented versus peripherally-presented irrelevant distractors.

A recent study which eliminates these confounds and directly contrasts the processing of fixation distracters with peripheral distracters within a flanker task, has found that fixation distracters exert consistently greater response competition effects than equivalent distracters in the periphery. Beck and Lavie (2005) presented distracters either at fixation or in one of two peripheral positions while participants performed a letter-search task in the parafovea, located at an eccentricity exactly half way between fixation and peripheral distracter positions. In one experiment, peripheral distracters were only presented in one peripheral location, thus equating spatial certainty between fixation and peripheral distracters. Beck and Lavie (2005) found that irrelevant distracters at fixation caused significantly greater response competition effects than peripheral distracters. This pattern of findings was replicated even when peripheral distracters were magnified to produce a more similar cortical representation between fixation and peripheral distracters, and when fixation was indicated by a fixation ring which cued the letter-target positions rather than a fixation dot cuing the centre of the display where the fixation distracter appeared (e.g. Paquet & Lortie, 1990). Further variations also replicated the findings when the position of the target letter circle moved between trials so that it was centred on fixation and peripheral distracters with equal probability. This arrangement therefore eliminated the perceptual bias towards grouping the fixation distracters (but not with peripheral distracters) with the letter circle when the circle surrounded it. Therefore, as might be predicted based on the physiological and functional advantages of the fovea, fixated distracters were harder to ignore than peripheral distracters. Moreover, a manipulation of perceptual load in this study (increasing the relevant set size of the search task from one to six) demonstrated that fixation distracters, although more disruptive overall, were modulated by load to the same extent as peripheral distracters. This consistent effect of perceptual load on distracter processing across variable retinal locations suggests that, despite a bias in attracting preferential processing to fixation, fixated distracters are subject to the same capacity limits as other irrelevant stimuli.

Therefore, this new study by Beck and Lavie (2005) presents the first evidence that information at fixation interferes with relevant-task responding to a greater extent than information in the periphery. However, their study used indirect measures of target RTs and error rates to assess the processing of distracters. As such, it cannot provide information about whether irrelevant fixation stimuli gain a corresponding, preferential access to awareness compared to peripheral stimuli. The purpose of this chapter was firstly to contrast awareness for fixation stimuli with awareness for equivalent peripheral stimuli. This comparison will determine whether the central processing bias reflected by fixation versus peripheral distracter effects is evident when awareness for irrelevant stimuli is tested directly. Secondly, to compare with results using indirect measures, I aim to ascertain the extent to which perceptual load modulates awareness of irrelevant stimuli at the distinct retinal locations of fixation and periphery. An additional goal enabled by this second objective is to generalise the effects of perceptual load on awareness, established in Chapter 2, to critical stimuli appearing directly where participants are fixating.

One set of studies investigating exactly the issue of awareness at fixation versus periphery, found the surprising result of greater inattentional blindness for fixation stimuli compared with peripheral stimuli. Mack and Rock (1998) reported levels of awareness between 10% and 50% across experiments for critical stimuli presented at fixation while participants performed a demanding peripheral task (judging which line was longer on a target cross presented at one of four possible locations). Surprisingly, the magnitude of awareness was consistently and considerably higher (approximately 75% across experiments) for critical stimuli appearing in the periphery while participants performed the cross task at fixation. These results therefore found greater inattentional blindness rather than greater awareness of critical stimuli at fixation. Explanations alluding to the inhibition of attention at fixation were proposed to account for the unexpected results.

However, as with Goolkasian's (1999) study, the task demands between the fixation-task and peripheral-task conditions were not equivalent in this particular design of Mack and Rock's (1998) and thus could provide an alternative account for their results. The greater spatial uncertainty of peripheral cross-targets (in the fixation critical stimulus condition) together with reduced acuity and resolution of peripheral vision suggest that the peripheral-target task was comparatively more demanding than the fixation-target task. Since task demands – and therefore availability of attention – have been shown to be a critical determinant of awareness in inattentional blindness paradigms (Chapter 2), this imbalance between conditions is likely to be the cause of Mack and Rock's (1998) findings. This hypothesis is addressed specifically in Experiment 12 of this chapter.

The current experiments

Experiments in this chapter compared awareness for critical stimuli appearing at fixation versus those appearing in the periphery. Experiments 6 and 7 used a variation of the standard cross-task to ask whether awareness for fixation stimuli could be modulated by load to the same extent as peripheral stimuli. Experiment 7 also examined whether rates of awareness for fixation versus peripheral stimuli was influenced by a spatial distribution of attention including fixation. Experiment 8 investigated the effects of attention across space on fixation versus peripheral awareness, by using a task which afforded more equivalent attentional deployment at fixation versus periphery. In addition, Experiment 8 examined whether a fixation advantage in awareness could be revealed by increasing the absolute size of critical stimuli. Experiment 9 compared interference effects from fixation versus peripheral distracters with awareness of fixation versus peripheral critical stimuli. Longer blocks of trials were presented so RTs could be measured in addition to awareness. Furthermore, as response competition effects involve incongruent letters, Experiment 9 compared awareness at fixation versus periphery for either a neutral outline rectangle or an incongruent letter as the critical stimulus on the critical trial. Experiment 10 examined the possibility that initial cuing by the central fixation point had concealed a fixation disadvantage in awareness by positively biasing awareness at the central cued location. Experiment 10 also examined whether the perceptual grouping of fixation critical stimuli with target letter-circles (centred about fixation) had caused artificially inflated levels of awareness for fixation (vs. peripheral) critical stimuli. Experiment 11 assessed the impact of spatial uncertainty on awareness for a peripheral stimulus, and established another method of varying perceptual load using the standard inattentional blindness cross-task. To anticipate the results, Experiments 6 to 11, somewhat surprisingly, did not reveal a fixation advantage in awareness. In Experiment 12, I examined whether a fixation advantage would be found for stimuli with the same physical size at fixation and periphery (i.e. peripheral critical stimuli were not magnified as they were in Experiments 6-11).

3.2 Experiment 6

In Experiment 6 levels of awareness were compared for stimuli appearing at fixation versus in the periphery as a function of perceptual load. A series of seven cross-targets was presented to each participant, and they were asked to judge which was the longer arm of each cross-target. Each target could appear in one of two peripheral positions, whereas the critical stimulus appeared either at fixation or in the periphery for two different groups of participants (see Figure 3.1). Perceptual load was varied by changing the difficulty of the perceptual discrimination of line-length. In the low load group, there was a very obvious difference in length between the two cross-arms, as in Experiment 4 (Chapter 2). Conversely, in the high load group the two arms were of very similar length, making them harder to discriminate. On the basis of Beck and Lavie's (2005) results, if awareness is determined by similar factors to those determining distracter interference effects on RTs then there should be greater awareness for critical stimuli appearing at fixation than in the periphery. Rates of awareness should also show similar susceptibility to effects of perceptual load at both retinal positions.

Method

Participants Sixty-nine visitors to the Science Museum, London participated in the experiment. All reported normal or corrected-to-normal vision and were between 18-47 years old.

Apparatus and stimuli Apparatus was as for Experiment 1 (Chapter 2) except that the screen resolution was 640 x 480 in the present experiment. Viewing distance was again 60 cm. At that viewing distance, a fixation square subtending

1.4° was presented at the screen's centre. The size of the fixation square was chosen in order to eliminate the possibility of the initial fixation cue forward-masking critical stimuli that subsequently appeared at fixation (e.g. Breitmeyer, 1984).

Target displays consisted of a black cross target, appearing in either one of two peripheral locations (upper-left or lower-right visual field, see Figure 3.1; counterbalanced across trials) with the centres of each cross-target lying on an imaginary diagonal line, 3.35° away from fixation. The longer arm of each cross-target subtended 3.9° while the shorter arm subtended 0.7° in the low load condition, or 3.31° in the high load condition. In critical trials, a black outline square appeared in addition to the cross-target either at fixation (sides subtending 0.15°) or in one of two peripheral locations (0.3°; counterbalanced between participants). Peripheral critical stimuli were presented at a distance of 3.35° from the centre of the cross and 3.35° from fixation (measuring from the square's centre) so that all possible stimuli (peripheral cross-targets and fixation vs. peripheral critical stimuli) lay equidistant from one another (see Figure 3.1). Thus, when cross-targets appeared in the lower-right position, peripheral critical stimuli were presented only in the lower visual field and vice versa for upper visual field stimuli.

The size of the peripheral critical stimulus was calculated by scaling the fixation critical stimulus according to the cortical magnification equation (nasal visual field[3].) of Rovamo and Virsu (1979) and Virsu and Rovamo (1979). The size of peripheral critical stimuli was therefore increased by a factor of 2.04 according to the equation: $M = 1 + 0.33\ E + 0.00007\ E^3$, where E refers to eccentricity in

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[3] Separate equations are given for nasal and temporal visual fields, with marginally different values for the first eccentricity coefficient (nasal = 0.33, temporal = 0.29). Since we are specifically investigating a possible fixation advantage, the nasal visual field formula was used in all experiments reported here as it produces the most generous scaling advantage to the periphery. It should be noted however, that the difference between the magnification factors produced by the two formulae is negligible in the present experiments.

degrees of visual angle (3.35°) and M refers to the magnification factor. The visual mask from Experiment 1 (Chapter 2) was used. A white background was maintained throughout.

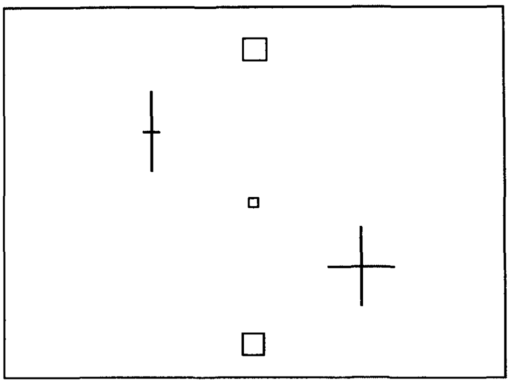

Figure 3.1 A diagrammatic representation of all possible target stimulus (low load in top left position; high load in bottom right position) and critical stimulus (fixation at the centre; peripheral above and below centre) positions in Experiment 6.

Procedure Each trial began with an outline fixation square (1400 ms), followed by a blank white interval (57 ms), the fixation cue again (97 ms) and then another blank interval (43 ms)[4]. The cross-target was then presented (110 ms), followed by the visual mask (496 ms). As in Experiment 1 (Chapter 2), the experiment then asked "which arm was longer"? Responses were entered by the experimenter: "0" for "horizontal", "2" for "vertical longer? (horizontal or vertical)". All trials were initiated by the experimenter pressing the space bar. Participants were instructed to fixate centrally throughout and to guess if they were unsure.

Each participant completed seven experimental trials: six non-critical trials and one critical trial. Within both non-critical and critical trials, the horizontal

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[4] This temporal presentation produced a flickering appearance, which was designed to refocus participants' attention towards fixation immediately preceding each trial.

cross-arm was longer on half the trials (the vertical longer on the other half) with order counterbalanced across participants. Target position was also counterbalanced across participants with targets appearing in the upper visual field position on half the trials and in the lower position on the other half of trials. Targets in critical displays were identical across the two conditions of critical stimulus position (fixation and periphery). Target crosses were presented in the same position on the sixth and seventh (critical) trials for one group of participants (e.g. upper position followed by upper position) and in different positions for another group of participants (e.g. upper position followed by lower position). The position of peripheral critical stimuli (left or right) was counterbalanced across participants.

Procedures for determining awareness were as for Experiment 1 (Chapter 2).

Results and Discussion

Figure 3.2 presents the percentage of awareness reports across participants as a function of critical stimulus position (fixation vs. periphery) and perceptual load (low load vs. high load). All participants performed the task adequately, with four or more correct line-length judgments entered. Excluded were participants who failed the final control trial (2), participants who provided unclear responses to the awareness probe (2), and one participant who did not understand the awareness questioning. Remaining participants were divided equally between the four experimental groups: fixation critical stimulus, low load (16); fixation critical stimulus, high load (16); peripheral critical stimulus, low load (16); and peripheral critical stimulus high load (16). All of the participants who reported awareness of the critical stimulus (i.e. made a "Yes" response to the critical question) were able to describe correctly its location and at least two of its major features (shape, size or colour).

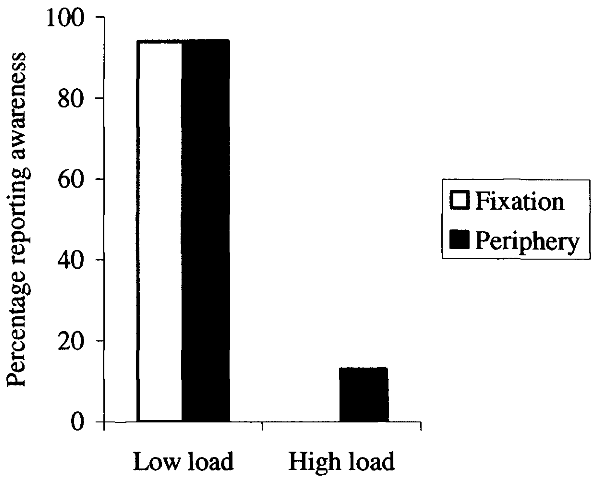

Figure 3.2 Percentage of participants reporting awareness as a function of critical stimulus position (fixation vs. periphery) and perceptual load (low load vs. high load), N = 64.

The results showed that, unlike the fixation advantage prediction, rates of awareness were the same for fixation (15 of 16) and peripheral critical stimuli (15 of 16) under conditions of low perceptual load. In accordance with the hypothesis and previous findings (Chapter 2), imposing high perceptual load significantly reduced awareness both for fixation critical stimuli (to 0 of 16), χ^2 (1, $\underline{N}$ = 32) = 28.24, p = .0001, and peripheral critical stimuli (to 2 of 16), χ^2 (1, $\underline{N}$ = 32) = 21.20, p = .0001. The results also clearly show that that the effect of perceptual load on awareness is the same for both critical stimulus positions, that is, there was no interaction between load and critical stimulus position, χ^2 (1, $\underline{N}$ = 64) = .25.

Pooling across conditions of perceptual load and critical stimulus position, a trial-by-trial analysis of the data confirms that there was no effect of target-location repetition across the sixth (final non-critical) and seventh (critical) trials. There were equivalent levels of inattentional blindness when targets were repeated in the same location (19 of 32; e.g. upper followed by upper location), as when the targets alternated across different locations (17 of 32; e.g. upper followed by lower location).

Therefore, the level of perceptual load in the relevant task determines awareness within Mack and Rock's (1998) original cross-task procedure when load is manipulated by the difficulty of a line length discrimination. Experiment 6 in this chapter also generalised the findings of Chapter 2 to show that perceptual load modulates awareness for critical stimuli appearing directly where participants are fixating to the same extent as critical stimuli presented in the periphery. This is in accordance with Beck and Lavie's (2005) findings that perceptual load modulates interference effects equally when distracters are presented in the periphery and at fixation.

However, Experiment 6 found no evidence of an advantage in awareness for fixation stimuli over peripheral stimuli. This stands in contrast to Beck and Lavie's (2005) demonstration of greater distracter interference effects on RTs for distracters appearing at fixation versus distracters appearing in the periphery. This contrast may reflect a real difference between explicit awareness and processes reflected in RT interference effects (e.g. unconscious perception or responses selection) highlighting an interesting dissociation between the two types of measure. Alternatively, the contrast may result from methodological differences between the two experimental procedures. These possibilities will be addressed and discussed in greater detail in later experiments.

3.3 Experiment 7

It could be argued that presenting the cross-targets at one of two peripheral locations in each trial (as in Experiment 6) caused attentional cuing towards the periphery (e.g. Jonides, 1981) and a concordant disengagement of attention from fixation. In order to produce a more even spatial distribution of attention in the current experiment, targets were presented with equal likelihood at fixation (33%) and peripheral positions (33% in upper-left; 33% in lower-right). The critical stimuli and the manipulations of perceptual load used were identical to those in Experiment 6.

Method

Participants Ninety-one participants were recruited from the Psychology Department Café, University College London and from the Science Museum, London. All were between 17-54 years and all reported normal or corrected-to-normal vision.

Stimuli Stimuli were identical to those in Experiment 6 with the addition of non-critical target displays with the cross appearing at the centre.

Procedure All aspects of the procedure were identical to Experiment 6 except that targets appeared randomly but with equal probability (i.e. twice each) at each of three possible locations (centre, upper-left visual field and lower-right visual field) on non-critical trials. One constraint to this randomisation was that there were equivalent numbers of participants viewing target crosses in the same position (e.g. upper position followed by upper position) and target crosses in different positions (e.g. upper position followed by lower position) on the sixth and seventh (critical) trials as in Experiment 6. Critical trials were identical to the previous experiment (i.e. the target never appeared at the central position in critical trials).

Results and Discussion

Figure 3.3 shows the percentage of reported awareness across participants as a function of critical stimulus position (fixation vs. periphery) and perceptual load (low load vs. high load). Excluded from this analysis were: participants who failed the final control trial (5), participants who gave unclear responses to the awareness probe (4), or participants who failed to score at least four non-critical trials correct (2). Remaining participants were divided equally (20 per group) between the four experimental groups.

As with Experiment 6, there was no difference between rates of reported awareness for fixation (19 of 20) versus peripheral (18 of 20) critical stimuli, under situations of low perceptual load. In line with previous experiment, increasing perceptual load from low load to high load reduced rates of awareness for stimuli appearing both at fixation (to 1 of 20), χ^2 (1, N = 40) = 32.4, p = .0001, and in the periphery (to 4 of 20), χ^2 (1, N = 40) = 19.78, p = .0001. Again, as is clearly visible from the figure, there was no difference in the effect of perceptual load on awareness between the different critical stimulus positions, χ^2 (1, N = 80) = 1.9, p = .17, in the load by position interaction.

As with Experiment 6, similar numbers of participants reported awareness when targets were presented in the same peripheral location on critical and final non-critical trials (54%) as when the target shifted to different locations across these two trials (left periphery to right periphery, or vice versa = 52%; fixation to periphery = 48%), χ^2 (1, N = 80) = .09, p = .66.

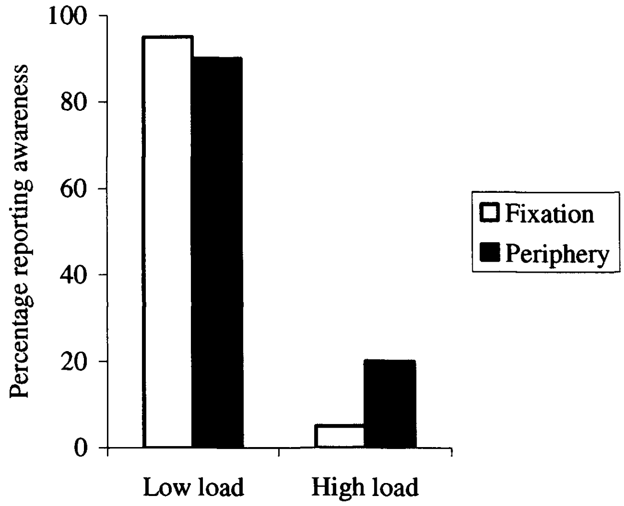

Figure 3.3 Percentage of participants reporting awareness as a function of critical stimulus position (fixation vs. periphery) and perceptual load (low load vs. high load), N = 80.

Overall, Experiment 7 replicates the findings of Experiment 6, with similar levels of awareness for fixation and peripheral stimuli and an equivalent modulation by load in these conditions when targets are presented both at fixation and peripheral locations. Notice, however, that as cross-targets appeared at fixation on only one third of the six trials and never on critical trials, this design may still have biased attention towards the periphery. This issue is addressed in following experiments.

The fact that the target always appeared in the periphery on the critical trial may have disadvantaged awareness at fixation. The following experiments therefore ask whether a fixation advantage would be found when targets are positioned in a retinal position equidistant between fixation and periphery (i.e. not favouring either fixation or periphery).

3.4 Experiment 8

It is possible that the load manipulation used in Experiments 6 and 7 was particularly strong such that it concealed effects of retinal position. Thus awareness was near-ceiling under low perceptual load (indeed, in most low load conditions, all or all but one participant reported awareness) and approaching-floor levels under high perceptual load (in most high load conditions only one participant successfully reported awareness). As such, it is possible that any difference between awareness at fixation versus periphery was obscured by ceiling and floor effects in overall awareness. Consequently, the attended task in subsequent experiments was changed to the visual search task used in Chapter 2 which was seen to produce an intermediate level of awareness (around 50%) with a set size of six in previous versions of this experiment. In the present experiment, participants searched for either an “X” or a “Z” amongst five other non-target letters (J, P, F, S and U) arranged in a circular display. Perceptual load was thus no longer varied in this, or following, experiments. As mentioned before, this display arrangement also avoids the possible influence of differential attentional deployment across space with specifically greater attention to peripheral than fixation positions, afforded by the cross-target task designs of Experiments 6 and 7.

In addition, the fixation critical stimuli used in Experiments 6 and 7 may have simply been too small (0.15° at fixation; 0.3° in periphery) to show an advantage for fixation. Goolkasian (1994) demonstrated that an advantage of fixation over peripheral stimuli in letter discrimination tasks may only be revealed when fixation stimuli are 0.74° or larger. Accordingly, a significantly larger black outline square shape (0.74°) was presented as the fixation critical stimulus in Experiment 8 (peripheral critical stimuli were scaled accordingly from this new larger size).

Method

Participants Thirty-six new undergraduate students (18-20 years) participated in this experiment as part of a laboratory practical class. All reported normal or corrected-to-normal vision.

Apparatus and stimuli Apparatus was as in previous experiments with the exception of the chin-rests and computer monitors. In the present experiment, a viewing distance of 60 cm was maintained by participants holding a taut length of string (attached to the computer monitor) to their chin throughout the experiment. 15” monitors (1024 x 768 screen resolutions; 75% contrast) were used to present the experiments.

Targets appeared among the same set of non-target letters: J, P, S, F and U. Target displays were as in the high load condition for Experiment 2 (Chapter 2) except that the targets were now either “X” or “Z”, and the radius of the letter-circle was 1.65°. A black outline square shape was presented on the sixth, critical trial in addition to the target-letter display. At an eccentricity of 3.3° (measuring from the square’s centre), the sides of peripheral critical stimuli were magnified from 0.74° at fixation to 1.50°, with the magnification factor of 2.04 (derived again from Rovamo & Virsu, 1979). Critical stimuli were positioned either at fixation, or on the horizontal meridian, to the left or right of fixation (counterbalanced between participants). The visual mask was the same as previous experiments.

Procedure Each trial began with a small fixation dot (1000 ms) followed by a short blank interval (100 ms), the letter-target display (200 ms) and finally, the visual mask (496 ms). A blank screen then appeared (3000 ms) whilst participants provided their target response, pressing "X" or "Z" as appropriate on the computer keyboard. No feedback was given. Following termination of this three-second window, or after participants' key-press response (whichever was sooner), a further blank interval was presented (1500 ms) and then the next trial began automatically.

Each participant completed six experimental trials, preceded by four practice trials. The correct target identification response was "X" for half the trials, and "Z" for the other half. All possible permutations of target-identity/target-position order were presented in a design fully counterbalanced across participants, with the constraint that targets in (peripheral group) critical trials were presented only on the side of the critical stimulus (i.e. in the left-most or right-most circle positions). This constraint produced equal distances between targets and critical stimuli across all conditions. The procedure for measuring awareness was via questions presented on the computer as for Experiment 4 (Chapter 2). This procedure included forced-choice identification tests of shape and location following the initial awareness report.

Results and Discussion

Figure 3.4 presents the percentage of reported awareness across participants as a function of critical stimulus position (fixation vs. periphery). Four participants failed the final control trial and were discarded. The remaining participants were equally distributed (16 per group) between the two experimental conditions: fixation versus peripheral critical stimulus.

The results showed no modulation of awareness by retinal position of the critical stimulus within the current visual search paradigm. Similar rates of awareness were reported when participants were presented with critical stimuli at fixation (9 of 16) and in the periphery (7 of 16), χ^2 (1, N = 32) = .50, p = .72. Criteria for assessing awareness reports were as for Experiment 4 (Chapter 2). Thus, all participants giving "Yes" awareness reports could identify correctly either shape or location of the critical stimulus (and usually both were correct). Importantly for the current experiment, this confirms that the pattern of awareness results is not a consequence of random guessing by the participants on the awareness probe (which may also produce the current ~50% Yes, ~50% No response results).

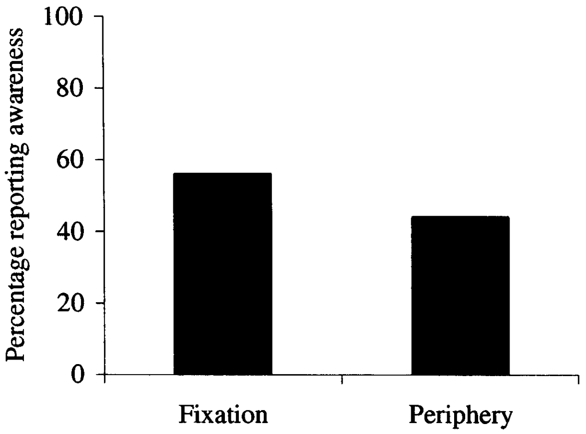

Figure 3.4 Percentage of participants reporting awareness as a function of critical stimulus position (fixation vs. periphery), N = 32.

A higher overall level of awareness was seen in Experiment 8 (50%) compared with the high load conditions of the previous experiments in this chapter. This is likely to be due to the increased absolute size of the critical stimulus (e.g.

Mack & Rock, 1998) as well as the lesser task demands of the (spatially certain) visual search task. The current results provide a replication of the degree of awareness (around 50%) found during performance of a visual search task with a set size six in Experiments 2, 3 (Group 2) and 5 of Chapter 2.

In conclusion, Experiment 8 found no advantage for fixation in awareness, even when a larger stimulus is used (a size which affords superior fixation performance in tests of visual acuity; Goolksian, 1981), when the targets in the test trial do not cue to the periphery, and when the level of load produces an intermediate level of awareness free of the limitations of ceiling and floor effects.

3.5 Experiment 9

Results reported here about direct visual awareness (inattentional blindness) of fixation versus peripheral events have so far not agreed with results from indirect measures of distracter processing (RTs; Beck & Lavie, 2005). The purpose of Experiment 9 was to directly contrast inattentional blindness with distracter interference effects at fixation versus periphery within the same task. Methodological differences between previous experiments in this chapter and Beck and Lavie's (2005) paradigm preclude meaningful conclusions to be drawn regarding the relationship between these two types of measures. However, the present direct comparison now has the ability to reveal any true differences between the mental processes determining awareness and those producing RTs related to distracter processing.

Therefore, in Experiment 9 I ran two separate groups of participants on long blocks of trials that could also include a distracter. This allowed the assessment of response competition effects (RTs) from distracters (at fixation versus periphery), as well as awareness of critical stimuli (at fixation versus periphery) in a final critical trial. Group 1 was presented with a distracter on each trial (either compatible or incompatible) which was equally likely to appear at fixation (50%) or periphery (50%). Group 2 was run without any distracters present in displays, but with an additional outline rectangle (similar to the previous, typically simpler critical stimuli) on a last, additional trial.

In addition, since the specialisations of the foveal region include heightened visual acuity and increased spatial resolution (e.g. Fiorentini & Berardi, 1991), it is possible that a fixation advantage (over peripheral locations) in processing for awareness may be revealed only when stimuli require a spatial resolution that demands such specialization. Indeed, the fixation bias has been demonstrated with distracter letters as ignored items (Beck & Lavie, 2005). In addition, the distracters used in this previous study were relevant to the task (i.e. letters). It was therefore desirable to establish levels of awareness for critical stimuli at fixation and periphery that were equally meaningful to those used by Beck and Lavie (2005; i.e. distracter letters). Thus, I ran one final group of participants (Group 3) using the same procedure as Group 2 except that a target-incompatible letter was presented as a critical stimulus on the final trial.

If the processing priority for attention at fixation revealed by indirect measures assessing distracter effects on target RTs and error rates (Beck & Lavie, 2005) has an equivalent counterpart in awareness, there should be greater RT costs *and* greater awareness of distracters appearing at fixation versus periphery evident in Experiment 9. Alternatively, if RT measures reflect processes that are distinct from explicit awareness revealed with participants reports, there will be a dissociation between results from RTs and awareness reports regarding the role of fixation versus periphery.

Method

Participants One-hundred-and-twenty-two students, aged 18-30 years, were paid to participate in this experiment. All reported normal or corrected-to-normal vision and all were naïve to the experimental hypotheses.

Apparatus and stimuli Stimuli were matched as far as possible to those used in Beck and Lavie, Experiment 5 (2005). Target displays were as for the high load of Experiment 2 (Chapter 2) apart from the stimulus sizes and the addition of distracters. Participants therefore searched for an X or N target among the non-target letters: J, P, S, U and F. Target and non-target letters measured 0.73° x 1.12° at the 60 cm viewing distance, and were arranged around a circle with a radius of 2°. Targets appeared randomly but with equal probability in each of the six possible positions. For the first group of participants (Group 1), an additional task-irrelevant distracter was presented in each display either at fixation or in the periphery (3.5° to the left or right of fixation, producing a cortical magnification factor of 2.16). Measuring from the centre of each letter, this produced a target-to-distracter distance of 2°. In order to equate predictability and location certainty between fixation and peripheral distracters, each participant viewed distracters at fixation and only one peripheral location: right or left (see Beck & Lavie, 2005, Experiment 5). Distracter letters were either congruent (distracter X with a target X) or incongruent (distracter N with a target X). Distracters measured 0.52° x 0.78° at fixation and 1.12° x 1.68° in the periphery, scaled with the cortical magnification factor. With these sizes, the ratio of distracter size to target size is equal for fixation and peripheral distracters (2:3 and 3:2 respectively), producing equivalent relative size similarities between distracters and targets in both distracter-position conditions. For the second and third (awareness) groups of participants, distracters were excluded from all except the final, critical trial. On this trial, either an outline rectangle (Group 2) or an incompatible distracter (Group 3) was presented in addition to the usual target display either at fixation or in the periphery (counterbalanced across participants). All critical stimuli had identical dimensions and identical locations as the distracters shown to participants in Group 1. All stimuli were coloured in light grey upon a black background, except for critical stimuli which were a slightly darker grey. This modification was expected to decrease the overall likelihood of detection (Mack & Rock, 1998), which was important in combating the anticipated effects of practice (i.e. to increase the baseline of awareness to a ceiling level) afforded by the longer blocks of trials used in this design. As the present experiments were to serve both as a replication of RTs effects and as awareness tests, the visual mask (from previous experiments reported here) was incorporated in the design. Apparatus was as for Experiment 6.

Procedure The procedure was similar to Beck and Lavie, (2005) Experiment 5. A fixation dot (1000 ms) signalled the beginning of each trial, followed by the target display (200 ms) and finally, a visual mask (500 ms). A blank, black screen (2000 ms) was then presented whilst participants entered their responses on the computer's numerical keypad: "0" for "X" or "2" for "N". Participants were instructed to maintain fixation throughout and to respond as fast and as accurately as possible to the target displays. Group 1 was also asked to ignore distracters as far as possible. Error beeps were given as feedback for an incorrect response or if participants failed to make a response within two seconds.

Distracters were presented at fixation on a random half of the trials and at a peripheral location (either left or right, counterbalanced across participants) on the other half of the trials for Group 1. For Groups 2 and 3, critical stimuli were presented at fixation for half the participants and in the periphery (either left or right, counterbalanced across participants) for half of the participants. For Group 1, target identity (X or N), target position (six), distracter compatibility (congruent vs. incongruent) and distracter location (fixation vs. periphery) were fully counterbalanced producing 48 possible permutations of target. For Groups 2 and 3, target identity (X or N) and target location (six) were fully counterbalanced in the current experimental design to produce 12 possible (non-critical) target displays. All trials were randomly intermixed within each block. Three experimental blocks of 96 trials were presented, following one 12-trial practice block and two demonstration trials shown with the instructions. For Groups 2 and 3, an extra critical trial was presented at the end of the third experimental block of 96 trials; half appearing at fixation and half in the periphery. Target identity in critical trials was counterbalanced across participants: Half the participants saw a target "X" on the critical trials, and half saw a target "N" in both fixation and peripheral critical stimulus conditions. In Group 2, participants saw an outline rectangle shape as the critical stimulus. In Group 3, half the participants saw an "N" and half saw an "X" for the critical stimulus (always incompatible with the target). Targets (for both Groups 2 and 3) only appeared in the left-most or right-most circle positions in critical trials, fully counterbalanced with peripheral critical stimulus position (left or right) across participants, giving two target-to-critical stimulus distances (near and far). The procedure for measuring awareness in Groups 2 and 3 was as for

Experiment 4 (Chapter 2), except that the four-alternative forced choice shape judgment for Group 3 included the critical stimulus (X or N) and K, T or O.

Results and Discussion

Group 1: Distracters at fixation and periphery

Mean target RTs and accuracy rates were analysed as a function of compatibility (congruent vs. incongruent) and distracter location (fixation vs. periphery). For the RT analysis, incorrect responses were excluded from the analysis as were those RTs over 1500 ms. Demonstration and practice trials were also excluded from the analysis. Two participants were excluded as they performed the task with less than 60% accuracy overall, and two were excluded because they performed at less than 50% accuracy in one of the conditions. All 16 remaining participants performed the task adequately accurately, with more than 70% correct overall.

RTs A three-way mixed model ANOVA with the within-participants factors of distracter position (fixation vs. periphery) and distracter compatibility (compatible vs. incompatible) and the between-participants factor of peripheral distracter side (left vs. right) was conducted. This revealed a main effect of distracter compatibility, F (1,14) = 96.25, *MSE* = 49353.40, p = .0001, which interacted with distracter side, F (1,14) = 8.72, *MSE* = 4471.43, p = .01. This shows that target RTs were slower in the presence of incongruent distracters (761 ms) as compared with congruent distracters (706 ms), and that this effect of compatibility was larger for participants viewing left-side distracters (compatibility effect of 50 ms) than right-side peripheral distracters (compatibility effect of 20 ms), see Table 3.1. This result might be due to participants' tendency to scan displays from left to right during reading. The ANOVA also revealed a main effect of distracter position, F (1,14) = 17.01, *MSE* = 27303.12, p = .001: Target RTs were slower in the presence of distracters at fixation (754 ms) than distracters in the periphery (713 ms) in line with Beck and Lavie's (2005). This finding suggests a greater filtering cost (Kahneman, Treisman & Burkell, 1983) for fixation versus periphery. Distracter position was also found to interact with distracter side, F (1,14) = 4.49, *MSE* = 7198.46, p = .053, showing greater effects of distracter position (fixation minus peripheral distracter RTs) for participants presented with left-side (61 ms) than right-side peripheral distracters (22 ms). Importantly however, although there were some effects of distracter side, there was a significant two-way interaction of distracter position and distracter compatibility, F (1,14) = 8.11, *MSE* = 6901.66, p = .013, showing greater compatibility effects at fixation (76 ms) than periphery (34 ms), which did not interact with peripheral distracter side, F (1,14) = .06, MSE = 47.32, p = .82. Therefore results from this experiment replicate the main findings in Beck and Lavie (2005).

Importantly, this could not be explained by peripheral distracters being further away from some targets: An additional analysis was run which excluded those trials in which the peripheral distracter was further away from the target than the fixation distracters. Replicating the main findings, this further analysis revealed that response compatibility effects were significantly greater for fixation distracters (121 ms) than peripheral distracters (38 ms), F (1,31) = 6.89, *MSE* = 55695, p = .01. This is consistent with previous research which suggests that the effect of target-to-distracter distance on response compatibility effects is very small when targets vary in location from trial to trial (e.g. Goolkasian & Bojko, 2001), as in the present experiment.

Table 3.1 Mean RTs (in milliseconds) and error rates across participants (N = 16) as a function of distracter compatibility and position.

	Distracter Compatibility					
	Incongruent (I)		Congruent (C)		I-C	
Distracter position	**RT**	% Error	**RT**	% Error	**RT**	% Error
Fixation	**792**	15	**716**	10	**76**	5
	(22)	(3)	**(23)**	(2)	**(11)**	(2)
Periphery (overall)	**730**	15	**696**	8	**34**	7
	(22)	(2)	**(22)**	(2)	**(9)**	(2)
Left periphery only	**718**	10	**668**	7	**50**	4
	(8)	(3)	**(9)**	(3)	**(10)**	(3)
Right periphery only	**742**	20	**722**	11	**20**	5
	(10)	(3)	**(10)**	(3)	**(4)**	(3)

Note: Standard errors of the mean are given in parentheses beneath the RTs.

Errors Error rates ranged from 28% to 2% across participants, giving an average of 12% overall. There were no significant differences between error rates for participants viewing distracters on the left (9%) versus distracters on the right (14%), t (7) = 1.67, p = .12, so results were pooled to form one "peripheral distracter" condition, as with the RT analyses. A similar two-way ANOVA with the factors of distracter compatibility (congruent vs. incongruent) and distracter location (fixation vs. periphery) was run on the error rates. This ANOVA revealed a significant main effect of distracter congruency, F (1, 15) = 15.5, *MSE* = .055, p = .001; with a higher error rate in the presence of incongruent (15%) versus congruent (9%) distracters. However, there was no significant main effect of position, F (1,15)

= 1.04, *MSE* = .003, p = .323: Error rates were equivalent when distracters were presented at fixation (13%) or in the periphery (11%). The interaction between distracter position and distracter congruency also did not reach significance, F (1,15) = .275, *MSE* = .001, p = .61. Thus the error rate analysis did not reveal any significant tradeoff with RTs.

In conclusion, Group 1 in Experiment 9 replicated Beck and Lavie's (2005) findings that distracters within Eriksen-type flanker tasks are more distracting when they are presented at fixation than when they are presented in the periphery. This effect is evident even when location certainty and location predictability of distracters are equivalent across all conditions of distracter position.

Group 2: Rectangle critical stimulus

Figure 3.5 presents the percentage of awareness reports across participants as a function of critical stimulus type (incongruent distracter vs. outline rectangle) and critical stimulus position (fixation vs. periphery). Excluded from the analysis were participants who failed to correctly identify the target on the critical trial (6) and participants who could not correctly identify either shape or location of the critical stimulus after giving a "Yes" awareness response (2). Remaining participants were equally divided between the fixation critical stimulus group (16) and the peripheral critical stimulus group (16).

Awareness The results replicated previous experiments' findings that the retinal location of a critical stimulus does not modulate levels of reported awareness. Similar numbers of participants reported the critical stimulus when it was presented at fixation (11 of 16) and when it was in the periphery (13 of 16), χ^2 (1, $\underline{N}$ = 32) = .66, p = .69.

An analysis of distance from the critical stimulus to the target revealed similar rates of awareness at both near (6 of 8) and far (7 of 8) target-to-critical stimulus distances in the peripheral critical stimulus group. Although greater awareness for critical stimuli appearing at the nearest distance might be expected (e.g. Newby & Rock, 1998), the relatively high level of awareness found here might be concealing this effect of distance in the present experiment.

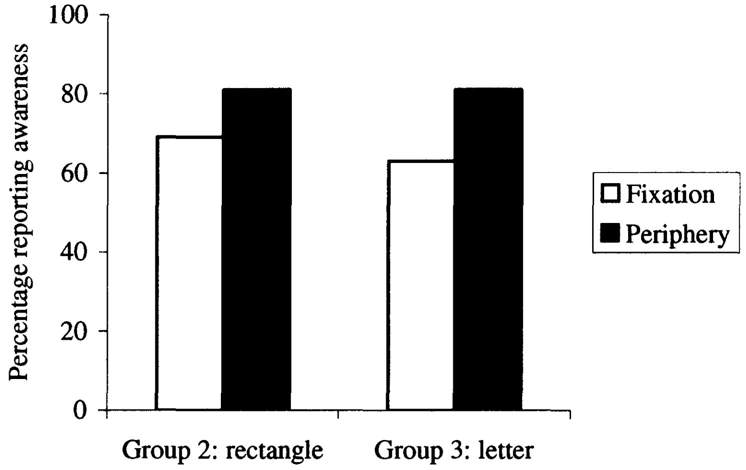

Figure 3.5 Percentage of participants reporting awareness as a function of critical stimulus type (outline rectangle vs. incongruent distracter) and critical stimulus position (fixation vs. periphery) in Group 2 (N = 32) and Group 3 (N = 32).

The results from Group 2 of this experiment therefore generalise the effects reported in previous experiments in this chapter, across different eccentricities of critical stimulus and with a different procedure involving long blocks of trials. Even with long blocks of non-critical trials, there appeared to be no difference in awareness for critical stimuli appearing at fixation compared with critical stimuli appearing in the periphery.

Group 3: Letter critical stimulus

A large number of participants failed to provide a correct target identity response on the critical trial (30) and were discarded from the primary analysis. Their results were looked at separately in another analysis (below). Remaining participants were divided equally between the fixation critical stimulus group (16) and the peripheral stimulus group (16).

Awareness Similar numbers of participants reported the critical stimulus when it was presented at fixation (10 of 16) and when it was in the periphery (13 of 16), χ^2 (1, N = 32) = .022. An analysis of awareness by distance again revealed very similar rates of awareness at both near (5 of 8) and far (7 of 8) target-to-critical stimulus distances in the peripheral critical stimulus condition.

Thus, results from Group 3 support the findings in Group 2 and in previous experiments. Even when critical stimuli utilised the foveal specialisation of high spatial resolution, there appeared to be no advantage for critical stimuli at fixation reaching awareness more frequently than critical stimuli in the periphery.

Effects on critical trial RTs in Groups 2 and 3 Preliminary inspection of the RT data indicated that critical stimulus position had some effects on critical trial RTs for Group 3 (but no clear effects for Group 2). I therefore analysed RT data for both groups. Incorrect trials and trials with RTs longer than 1500 ms were excluded from analyses.

Group 3

A 2 x 2 x 2 mixed model ANOVA on average RTs in Group 3 was conducted, with the within-participants factor of trial type (critical trial RTs vs. final block RTs) and the between-participants factors of critical stimulus position (fixation vs. periphery) and awareness response (aware vs. unaware). The ANOVA revealed a significant main effect of trial type, F (1, 28) = 11.29, *MSE* = 167489.86, p = .002, indicating that the presence of critical stimuli influenced target responding. Critical trial target RTs were significantly longer than RTs on non-critical trials in the final block (714 ms versus 610 ms respectively, pooled across participants and groups), as can be seen in Table 3.2. Although numerical trends showed greater slowing for critical trials with fixation stimuli (127 ms) versus peripheral stimuli (81 ms), there was no significant interaction between trial type and critical stimulus position, F (1, 28) = .60, *MSE* = 4418.56, p = .30. There was no main effect of critical stimulus position, F (1, 28) = .001, *MSE* = 41.81, p = .97, and no main effect of awareness response, F (1, 28) = .09, *MSE* = 88608.62, p = .09. Thus, RTs were equivalent between participants in fixation (663 ms) and peripheral (660 ms) critical stimulus groups and there were no significant differences between participants reporting awareness (636 ms) and those who failed to detect critical stimuli (719 ms), although there was a trend for faster RTs in aware participants. The ANOVA revealed no significant interaction between trial type and awareness response, F (1, 28) = .299, *MSE* = 4442.86, p = .59, and no three-way interaction of trial type, awareness response and critical stimulus position, F (1, 28) = .04, *MSE* = 541.17, p = .85. Overall, this analysis showed that the presence of critical stimuli on critical trials significantly slowed target RTs relative to RTs on non-critical trials (in the final block). Although none of the interactions reached significance, there was a numerical trend for greater slowing on critical trials for fixation compared with peripheral critical stimulus groups.

In order to examine the effects of critical stimuli on target RTs without the possible confound of fatigue in the comparison of critical trial with the rest of the trials in the final block, I ran the same ANOVA but this time compared RTs in critical trials with RTs in penultimate trials (i.e. the final non-critical trial preceding the critical trial). This analysis revealed a similar pattern of findings except that the main effect of trial type did not quite reach significance, F (1, 28) = 3.85, MSE = 101714.22, p = .06. However, this may simply be due to the reduced power of comparing RTs on just one trial in each condition. Alternatively, a comparison between two single trials may be greatly influenced by outliers, thereby diluting any effect. Indeed, critical trial RTs (714 ms) were clearly slower than penultimate trial RTs (631 ms), as indicated by the large numerical trend.

As with the previous ANOVA, effect of trial type did not interact with critical stimulus position in the current analysis, F (1, 28) = .55, *MSE* = 14659.67, p = .46, indicating similar effects of critical trial RT slowing in the presence of fixation (73 ms) and peripheral (93 ms) critical stimuli. There was however, a significant main effect of awareness response, F (1, 28) = 5.43, *MSE* = 37642.02, p = .03, which reflects faster RTs in participants reporting awareness (635 ms) than those failing to detect the critical stimulus (756 ms). Because of the relatively small number of participants failing to report awareness in this experiment (6 in fixation and 4 in periphery), this comparison may have been influenced by large individual differences in response speed and thus firm conclusions cannot be drawn. None of the other effects reached significance in this ANOVA (all Fs < 1 except for the interaction of critical stimulus position and awareness response which approached the marginal significance of p = .09 and the interaction of critical stimulus position, awareness response and trial type, p = .16). Finally, overall RTs across all non-critical trials were equivalent between fixation critical stimulus (633 ms) and peripheral critical stimulus (637 ms) groups, t (30) = .15, p = .88, confirming that any between-group trends were not a result of individual differences in target responding between the groups.

Table 3.2: Mean RTs across participants for Group 3

	Trial type		
Critical stimulus position	Critical trial RTs	Mean non-critical trial RTs (final block)	Penultimate (to critical) trial RTs
Fixation	**727**	**600**	**654**
	(12.8)	(10.15)	(14.3)
Periphery	**701**	**620**	**608**
	(14.5)	(9.1)	(10.6)

Note: Standard errors of the mean are given below in parentheses

Therefore, the presence of an unexpected but incongruent stimulus in critical trials significantly slowed target RTs relative to RTs in non-critical trials or penultimate trials (although the comparison with penultimate trials did not reach significance, perhaps due to reduced statistical power), even when participants did not report awareness of that stimulus. Numerical trends suggest that this slowing effect was larger when critical stimuli appeared at fixation than when they appeared in the periphery, perhaps indicating a dissociation of awareness and RT results within the same experiment.

Thirty participants in total were discarded from both fixation (N = 11) and peripheral (N = 19) critical stimulus conditions in Group 3 because they gave an incorrect target response on the critical trial. An analysis of their awareness responses shows equivalent levels of awareness between fixation (9 of 11) and peripheral (17 of 19) critical stimulus conditions, χ^2 (1, N = 30) = .35, as with participants who scored correctly on the critical trial. In the light of the previous RT effects in critical trials, a 2 x 2 mixed model ANOVA with the within-participants factor of trial type (critical RT vs. final block RT) and the between-participants factor of critical stimulus position (fixation vs. periphery) was conducted. This revealed a significant main effect of trial type within this subset of discarded participants, F (1, 28) = 13.78, *MSE* = 747768.52, p = .001. As with participants included in the analysis, RTs on critical trials (840 ms) were significantly slower than RTs on non-critical trials in the final block (608 ms). The effect of trial type did not interact with critical stimulus position, F (1, 28) = .27, *MSE* = 14816.91, p = .60, although again, the numerical trend found greater slowing effects from fixation critical stimuli (264 ms) compared with peripheral critical stimuli (199 ms, Table 3.3). Note that slowing of RTs in critical trials was also much greater for this group of participants (who made errors on the critical trials) compared with those who made the correct response (in the above analysis). This may indicate that participants making errors processed the incongruent critical stimulus to a greater extent that those subsequently making a correct response. Finally, there was no main effect of critical stimulus position, F (1, 28) = .03, *MSE* = 2814.32, p = .86, confirming that overall RTs were similar between fixation (731 ms) and peripheral (717 ms) critical stimulus groups.

Table 3.3 Mean RTs across discarded participants in Group 3

	Trial type	
Critical stimulus position	Critical trial RTs	Mean non-critical trial RTs (final block)
Fixation	**863**	**599**
	(18.6)	(9.1)
Periphery	**817**	**618**
	(19.6)	(10.8)

Note: Standard errors of the mean are given below in parentheses

Group 2

In view of these findings, data from Group 2 were reanalysed for effects of task-neutral critical stimuli on RTs. However, a 2 x 2 x 2 ANOVA with the within-participants factor of trial type (critical RT vs. final block RT) and the between-participants factors of critical stimulus position (fixation vs. periphery) and awareness response (aware vs. unaware) did not reveal a significant main effect of trial type, F (1, 28) = 1.76, *MSE* = 25325.02, p = .20. Thus, critical stimuli did not significantly slow target RTs in critical trials (628 ms) relative to non-critical trials (final block only, 573 ms) when they were task-neutral, although there was a numerical trend for slower RTs in critical trials as before. The ANOVA found no other significant effects (all Fs < 1, except for the main effect of awareness response, p = .20 and the interaction of trial type and awareness response, p = .29).

These results suggest that the incongruence of critical stimuli presented to Group 3 was responsible for target slowing on critical trials. This shall be discussed further in the chapter discussion.

Table 3.4 Mean RTs across participants in Group 2

	Trial type		
Critical stimulus position	Critical trial RTs	Mean non-critical trial RTs (final block)	Penultimate (to critical) trial RTs
Fixation	**663**	**577**	**590**
	(17.4)	(12.4)	(14.7)
Periphery	**594**	**552**	**570**
	(13.2)	(9.8)	(13.0)

Note: Standard errors of the mean are given below in parentheses

Overall, although participants in Group 1 displayed an advantage for processing distracters at fixation versus distracters in the periphery, participants in Groups 2 and 3 showed no evidence for a similar effect on awareness.

Taken together, results from Groups 1-3 in this experiment convincingly establish a dissociation between indirect measures of awareness (e.g. compatibility effects on RTs) and direct measures of awareness in assessing the relative processing of stimuli falling at fixation versus in the periphery. Indirect measures of processing on target RTs suggest that fixation distracters receive preferential processing over peripheral distracters (Group 1). By contrast, direct measures (explicit report) indicate similar levels of awareness when an irrelevant visual stimulus is presented at fixation or in the periphery (Groups 2 and 3). This dissociation between RT measures of distracter interference and explicit measures of awareness has been shown both with stimuli equal in complexity and meaning to distracters in RT studies, and with visually simpler, neutral critical stimuli.

Indeed, results from Group 3 provide an illustration of the dissociation between the differential effects of incongruent stimuli on RTs depending on retinal location (fixation versus periphery) whilst the retinal location of critical stimuli seems to have no effect on awareness: Similar levels of awareness were observed when critical stimuli appear at fixation and in the periphery, whereas fixation critical stimuli appeared to produce greater RT costs than equivalent peripheral ones.

Overall levels of awareness in the current experiment (Groups 2 and 3; 74%) appeared to be elevated compared with previous experiments using the high load visual search task (~50% awareness; Experiments 2, 3 and 5, Chapter 2). This is likely to be due to the significantly increased amount of practice in the task that participants received in the present experiment over the considerably longer blocks of experimental trials. Practice and familiarity with a task may have made the task easier for participants, releasing more capacity for awareness in turn.

The effects of incongruent critical stimuli on target RTs found in Experiment 9, Group 3 support previous evidence that stimuli in inattentional blindness paradigms may undergo some online processing despite being "unseen". Here, RTs to targets were significantly longer when an incongruent letter stimulus appeared in critical displays, even if participants failed to report awareness of that letter. In previous studies, responses made on critical trials (e.g. judgment of line-length) have been influenced by the appearance of critical displays, even if participants were unaware of that appearance. For example, Moore and Egeth (1997) asked participants to judge the longer of two horizontal lines which were presented over a random-dot background pattern. They found that line length judgments were biased in critical trials where the dots in the background pattern formed a Müller-Lyer illusion (by being grouped by similarity), even if participants were unaware of any change in the random-dot pattern.

It can be concluded from these studies that there is an important dissociation in the processing of fixation versus peripheral stimuli between direct measures that assess awareness and indirect measures that assess distracter interference. Withdrawing attention (and withdrawing expectation) may prevent an irrelevant incompatible distracter from entering awareness, with levels of awareness being equal irrespective of position in the visual field. Simple instruction to ignore the same distracters (this time expected) however, creates greater disruption from fixation versus peripheral distracters. Possible explanations for this dissociation shall be covered in the chapter discussion, alluding to important methodological differences between the paradigms used.

3.6 Experiment 10

It could be argued that the initial fixation mark preceding each trial increased rates of awareness at fixation by cuing attention to that location. As such, a fixation disadvantage in awareness (Mack & Rock, 1998) might be concealed in the previous experiments.

Furthermore, by presenting fixation stimuli inside, but peripheral stimuli outside, the target letter-circle, rates of awareness may be biased towards fixation stimuli due to effects of perceptual grouping (e.g. Baylis & Driver, 1992; Driver & Baylis, 1989). For example, fixation critical stimuli may be perceived as appearing in the same group as the targets, whereas peripheral critical stimuli may be perceived as belonging to a separate group (appearing outside the ring of letters; see Treisman, Kahneman & Burkell, 1983, for an illustration of perceptual grouping within versus outside a frame in a similar display arrangement). Such an effect may again have concealed a fixation disadvantage in awareness (as found by Mack & Rock, 1998) by favouring fixation over periphery.

Experiment 10 therefore addressed the possibility that initial fixation cuing and effects of perceptual grouping may have concealed a fixation disadvantage as reported in previous inattentional blindness experiments (Mack & Rock, 1998). In this experiment, the position of the target letter-circle moved from trial to trial, with half appearing centred about fixation and half the letter-circles appearing in the periphery (counterbalanced between left and right across trials). On critical trials, critical stimuli always appeared inside the letter circle. Thus, the fixation critical stimulus appeared at the centre of the central ring of letters; left peripheral critical stimuli appeared at the centre of a left-side ring of letters; and right peripheral critical stimuli appeared at the centre of a right-side ring of letters. In addition, fixation displays consisted of several small crosses, each marking one of the possible target-letter locations in all possible circle positions (see Figure 3.6). If awareness of fixation critical stimuli was raised by their appearance inside the target letter-circle and following the initial fixation cue, then there should be a significantly lower rate of awareness for fixation versus peripheral stimuli as originally reported by Mack & Rock (1998).

Method

Participants Forty-one undergraduate students of the University of London (18-25 years) were paid to participate in this experiment. All reported normal or corrected-to-normal vision.

Apparatus and stimuli The experiment was run on a laptop with a screen size of 15" (resolution 1024 x 768) and viewing distance was held constant at 60 cm with a chin-rest.

Fixation displays consisted of fourteen small crosses positioned over the fourteen possible target locations (see Figure 3.6). Target displays comprised the circle of six letters (one target X or Z; and five other non-targets J, P, S, U and F, as before) with the same radius and letter-dimensions as in Experiment 8. However, in this experiment the letter-circle was centred around fixation for half the trials and around an imaginary point in the periphery for the other half of the trials, 3.3° to the left or right (counterbalanced across trials) of fixation. On critical trials, an additional outline rectangle appeared at the centre of the letter circle. For one group of participants the critical stimulus appeared at fixation and within a fixation letter-circle (0.74° x 0.67°). For another group of participants the critical stimulus appeared in the periphery (1.50° x 1.35°), 3.3° to the left or right of fixation (counterbalanced between participants) within a left or right-side peripheral letter-circle respectively. The visual mask was as in previous experiments.

Procedure Each trial began with the fixation display (1000 ms) followed by a brief blank interval (100 ms), the target display (200 ms) and finally the visual mask (500 ms). A blank screen then appeared for 3000 ms, during which time participants provided their target response, pressing either "X" or "Z" as appropriate on the keyboard. A further blank interval of 1500 ms then followed response entry or elapsing of the 3000 ms response window (whichever occurred sooner), before the next trial began.

Each participant completed one experimental block of 36 non-critical trials preceded by a practice block of 36 trials. Target identity, target location and letter-circle position were all fully counterbalanced and randomised within each block. Target identity, target location and letter-circle position were also counterbalanced between participants on critical trials. The procedure for measuring awareness was as in Experiment 4 (Chapter 2). Again, this included the force-choice shape and location judgments following initial awareness responses.

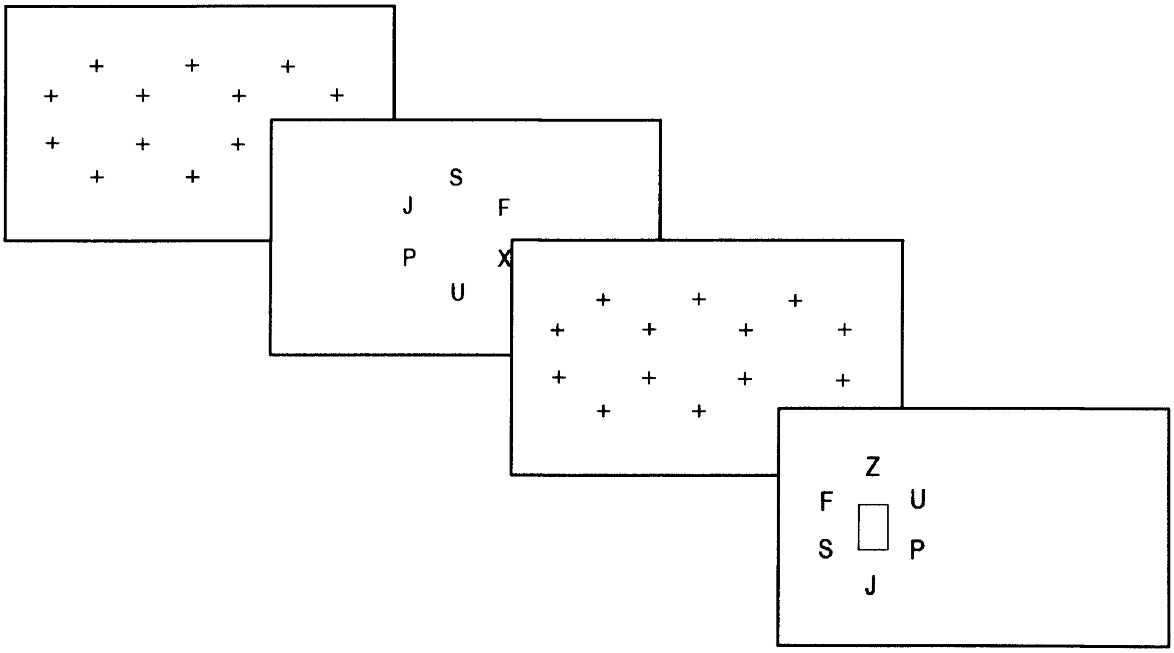

Figure 3.6 An illustration of the fixation displays and two of the three possible target letter-circle locations (one example of a non-critical trial with the letter circle at fixation; one example of a critical display with the critical stimulus and the letter circle in the left periphery).

Results and Discussion

Figure 3.7 presents the percentage of reported awareness across participants as a function of critical stimulus position (fixation vs. periphery). Excluded from the analysis were participants who could identify neither shape nor location after giving a "Yes" awareness response (2), participants who gave an incorrect response on the critical trial (1), and participants who failed the visual control trial (2). Remaining participants were divided equally (18 per group) between the fixation versus peripheral critical stimulus groups.

Identical levels of awareness were reported for peripheral critical stimuli appearing in the left (3 of 9) and right (3 of 9) positions. There were also no significant differences between left and right peripheral critical stimulus groups in error rates (5% vs. 4%), t (16) = .54, p = .60; non-critical trial RTs (755 ms vs. 711 ms), t (16) = .73, p = .48; or critical trial RTs (945 ms vs. 653 ms), t (16) = 1.25, p = .23. Results from these two groups were therefore collapsed into one "peripheral group" for following analyses.

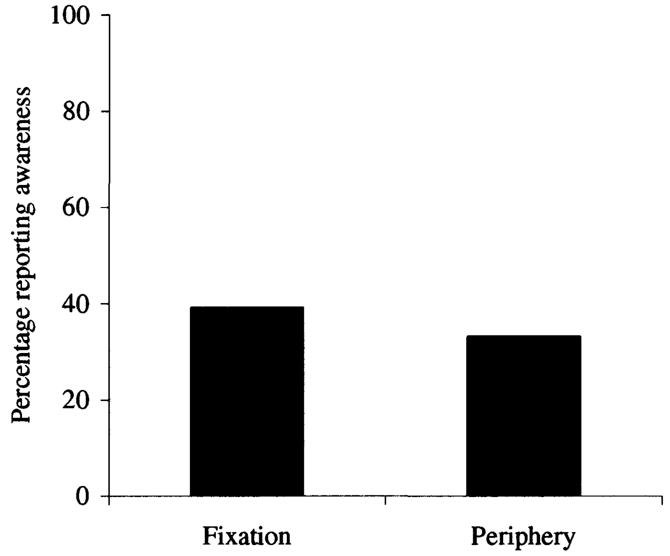

Figure 3.7 Percentage of participants reporting awareness as a function of target position (fixation vs. periphery), N = 36.

The results showed no significant difference between the rates of awareness reports for a fixation critical stimulus (7 of 18) compared with a peripheral critical stimulus (6 of 18). Therefore, as with Experiments 6-9, equivalent levels of awareness were found for stimuli appearing at fixation and in the periphery, even when both fixation and peripheral critical stimuli appeared inside the target letter-circles, and hence all critical stimuli were equally likely to be perceptually grouped with the relevant letter circle. In addition, the current experiment finds no fixation advantage in awareness despite an even distribution of attention across fixation and peripheral space by the relevant task and the initial fixation display.

Overall rates of awareness in Experiment 10 (36%) were lower than previous experiments (e.g. Experiment 8, 50%). This can be attributed to the introduction of spatial uncertainty of letter circles as well as poorer visual acuity in the periphery raising the difficulty of performing the letter discrimination task in the periphery.

No RT analyses were performed due to the relatively small number of experimental trials used in this experiment (single block of 36 trials) preventing stable RTs measures.

Overall, rates of awareness reports of fixation versus peripheral critical stimuli seem to be unaffected by possible effects of cuing from the initial fixation cue, perceptual grouping, or the distribution of attention across a contiguous region of space. Experiment 10 replicates the findings of previous experiments in this chapter, showing no difference in awareness of a fixation versus a peripheral critical stimulus. Therefore, cuing effects, perceptual grouping and contiguous attentional spotlights do not differentially impact awareness as they do indirect measures (RTs), at least they do not seem to have an impact within these specific experimental conditions.

3.7 Experiment 11

The experiments reported in this chapter have shown equivalent levels of awareness for visual objects presented at fixation and those presented in periphery. This result contrasts with previous findings of greater reported "blindness" for critical stimuli at fixation (Mack & Rock, 1998). However, as I suggested earlier, the results of greater inattentional blindness at fixation could be attributed to the relatively greater demands of the peripheral task (fixation critical stimulus) compared with the fixation task condition (peripheral critical stimulus), due to decreased retinal acuity and increased spatial uncertainty of the peripheral task stimuli compared with the fixation task stimuli. This hypothesis was tested directly in the current experiment, using neutral objects (outline square shapes) as critical stimuli. In Experiment 11, participants performed line length judgments upon a series of cross stimuli appearing either at fixation (low task demands) or in one of four peripheral positions (high task demands). On the fifth critical trial, an outline square critical stimulus was presented exactly halfway between fixation and peripheral cross-target positions (see Figure 3.8).

With this design, participants saw critical stimuli of identical size, shape and locations and equal distances from targets under the two different task demand conditions. In accordance with results in Chapter 2 establishing that perceptual load is the critical determinant of awareness, it was predicted that participants performing the peripheral-target task would report awareness for critical stimuli less often than those performing the fixation-target task, given the different demands of load placed upon the perceptual system between the two conditions (greater in the peripheral target task).

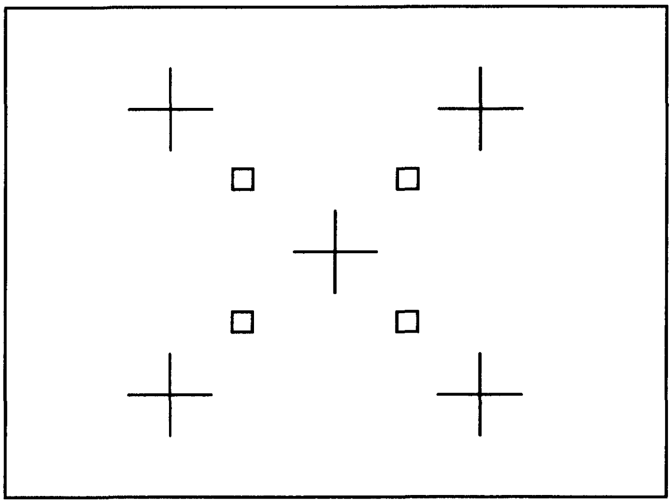

Figure 3.8 A schematic diagram of all possible target and critical stimulus positions in Experiment 11. One cross target was presented in each trial, either always at fixation (for one group of participants) or in one of the four possible peripheral positions changing randomly from trial to trial (for another group of participants).

Method

Participants Thirty-four students attending a University selection day at University College London participated in this study. All had normal or corrected-to-normal vision and were under 25 years old.

Stimuli and Apparatus Targets were black cross targets on a white background, with a longer arm subtending 4.5° and a shorter arm subtending 2.35°. Crosses appeared always at fixation for one group. For another group, cross targets appeared in one of four possible peripheral positions (in each corner of the display, 7.4° from fixation) with equal likelihood, and changing randomly from trial to trial. An outline black square subtending 0.8° x 0.8° was presented in critical displays, located 3.7° away from fixation, along the diagonal between fixation cross-target centres and peripheral cross-target centres (Figure 3.8). All other stimuli were as for Experiment 6.

Apparatus was as for previous experiments except that the program was run and presented on a laptop, with a 15" display (1024 x 768 resolution).

Procedure and Design Each trial began with a fixation dot (1400 ms) followed by a blank interval (100 ms), the target display (110 ms) and finally the visual mask (500 ms). A blank screen then remained on the screen until participants' verbal responses ("horizontal longer" or "vertical longer") were entered by the experimenter on the keyboard: "0" for "horizontal" or "2" for "vertical". Subsequent trials began when the experimenter pressed the space bar. All participants were instructed to fixate centrally throughout.

Five experimental trials were presented. Target location was counterbalanced across trials in the peripheral task condition so that targets appeared once, unpredictably in each peripheral location for the four non-critical trials, and equal numbers of participants viewed targets at the four peripheral positions on critical trials. Target response (horizontal or vertical) was counterbalanced across trials and across participants: Half the targets on non-critical trials and half the targets on critical trials had a longer horizontal arm (the vertical longer on the other half). Critical stimulus position was counterbalanced across participants so that equal numbers saw the critical stimulus at each of the four possible positions. Procedures for assessing awareness were as for Experiment 4 (Chapter 2), which included the forced-choice test of shape and location judgments.

Results and Discussion

One participant failed to identify either shape or location of the critical stimulus correctly after a "Yes" awareness response, and one participant gave an incorrect response on the critical trial; both were excluded from the analysis. Remaining participants were divided equally between the two experimental groups: fixation-target task (16) and peripheral-target task (16).

Analysis of reported awareness

Figure 3.9 presents the percentage of participants reporting awareness for the critical stimulus as a function of task type (peripheral-target task vs. fixation-target task).

As predicted, with the current manipulation of task demands via spatial certainty (fixation/certain vs. periphery/uncertain) and retinal acuity, there were significantly different levels of awareness across task conditions. Fewer participants reported awareness for a critical stimulus whilst performing a line length judgment in the periphery (6 of 16) than reported awareness for an identical stimulus whilst performing the same line length judgment at fixation (15 of 16), χ^2 (1, $\underline{N}$ = 32) = 11.22, p = .001.

Overall, the current experiment confirms that tasks performed on targets presented at a spatially uncertain, peripheral location consume a significantly greater proportion of attentional capacity than tasks performed on equivalent targets presented always at fixation. These results are in line with findings of Chapter 2, where increasing the task demands on attention (i.e. the perceptual load of the relevant task) leads to a reduction in awareness for critical stimuli. These new results provide a plausible account for the surprising finding of greater inattentional blindness at fixation (with a peripheral task) than in the periphery (with a fixation task), reported by Mack and Rock (1998). Although Mack and Rock (1998) reported greater inattentional blindness for fixation critical stimuli, this may have been due to greater demands of the attended task in the fixation critical stimulus condition (where targets appeared in the periphery in one of four positions) than the peripheral critical stimulus condition (where targets always appeared at fixation).

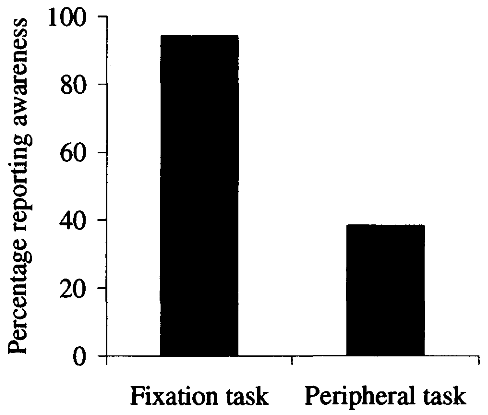

Figure 3.9 Percentage of participants reporting awareness as a function of target position (fixation vs. periphery), N = 32.

3.8 Experiment 12

In order to account for the greater cortical representation of foveated versus non-foveated stimuli, all previous experiments in this chapter have used Virsu and Rovamo's (1979) cortical magnification formula to scale peripheral critical stimuli according to their retinal eccentricity. However, the sizes used in the current experiments produced critical stimuli that were clearly visible, whereas magnification formulae are based on near-threshold perception. Perhaps then, the lack of a fixation advantage in awareness resulted from unnecessary magnification in the periphery. I therefore sought to examine whether awareness of critical stimuli in the periphery would be less than at fixation when stimuli were of equal sizes at the two positions (i.e. when peripheral stimuli were not cortically magnified). Experiment 12 thus compared awareness for a magnified peripheral critical stimulus

(Experiment 8) to awareness for an unmagnified peripheral critical stimulus. The procedure from Experiment 8 was adopted, except that here, one group of participants was presented with a critical stimulus in the periphery which had not been enlarged to account for cortical magnification. Existing results from Experiment 8 were used as comparison data (fixation and peripheral critical stimulus groups).

Method

Participants Twenty new undergraduate students from University College London, with normal or corrected-to-normal vision participated in the experiment.

Apparatus and stimuli Apparatus and stimuli were similar to Experiment 8 except that on the critical trial, an outline square subtending 0.74° x 0.74° (i.e. the same dimensions as the fixation critical stimulus in Experiment 8) was presented in the periphery, either to the left or to the right of fixation, counterbalanced across participants.

Procedure The procedure was identical to Experiment 8.

Results and Discussion

Figure 3.10 presents the percentage of awareness reports across participants for a peripheral critical stimulus, with equivalent results from Experiment 8 for comparison (fixation critical stimuli and magnified peripheral critical stimuli). Excluded from the analysis were participants who gave an incorrect target response on the critical trial (3) and participants who failed the visual control trial (1). Results from Experiment 12 were compared against those found in Experiment 8.

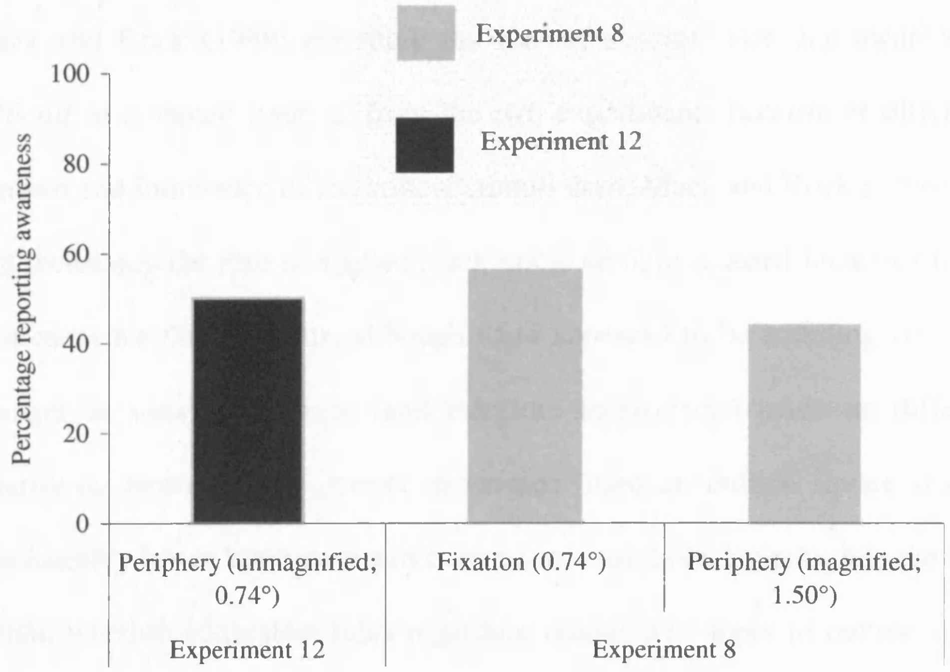

Figure 3.10 Percentage of participants reporting awareness as a function of location (fixation vs. periphery) and cortical magnification, Experiment 8, N = 32; Experiment 12, N = 16.

The results indicated that cortical magnification of a peripheral stimulus had no effect on awareness: Similar numbers of participants reported awareness for an unmagnified stimulus (8 of 16, Experiment 12) as a magnified stimulus (7 of 16; Experiment 8, peripheral group), χ^2 (1, N = 32) = .125. In addition, there was no difference in awareness for a fixation stimulus (9 of 16; Experiment 8, fixation group) compared to an unmagnified critical stimulus, χ^2 (1, N = 32) = .125.

Overall, Experiment 12 suggests that for clearly visible stimuli, the absolute size of the critical stimulus does not play a crucial role in determining whether that stimulus reaches awareness or not. This is true at least with stimuli of the sizes used here, although it remains possible that with critical stimuli of far larger absolute sizes, a difference may be revealed.

Although the present results might appear to contrast with those reported by Mack and Rock (1998) regarding the role of absolute size and awareness, it is difficult to compare findings from the two experiments because of differences in contrast and luminance of the critical stimuli used. Mack and Rock (1998) reported that increasing the size of a filled black circle stimulus caused increases in rates of awareness for that stimulus, although there appeared to be a ceiling size at which changes in viewing distance (and therefore retinal size) made no difference in awareness. However, the current experiment used an outline square shape, with considerably lower luminance and contrast to a solid black circle. It is therefore not certain whether equivalent rules regarding retinal size apply to outline stimuli, or further, whether there is a different retinal size threshold for such stimuli.

3.9 Chapter discussion

Experiments reported in this chapter have found no fixation advantage in awareness. Similar rates of awareness were reported for stimuli appearing at fixation and stimuli appearing in the periphery, and this finding was replicated in several experiments (Experiments 6-10, 12). This result was shown to be stable across different overall levels of awareness (e.g. Experiment 8 vs. 9), different absolute sizes of critical stimuli (e.g. Experiments 7 vs. 8 and 12), and with letter critical stimuli as well as simple outline square critical stimuli (Experiment 9, Groups 2 & 3). The same pattern was also found whether attention was distributed evenly around fixation and peripheral locations (Experiment 10) or whether attention was distributed in a ring-like shape (e.g. Experiment 6 vs. Experiment 8) and was demonstrated with different target tasks (Experiments 6 & 7 vs.

Experiments 8-10, 12). Cortical magnification of peripheral critical stimuli did not appear to contribute to this pattern of awareness (Experiment 12), neither could it be explained by differential effects of perceptual grouping nor initial cuing by the fixation point on awareness at fixation versus periphery (Experiment 10). Experiment 11 suggests that Mack and Rock's (1998) previous finding of comparatively reduced awareness at fixation were due to differences in the task demands between experimental conditions resulting from greater spatial uncertainty (as well as decreased visual acuity) in the peripheral target task condition. Experiment 9 demonstrates an important dissociation between the effects of retinal position of stimuli on interference effects (from irrelevant distracters) and on awareness (of critical stimuli). Although indirect RT measures suggest that fixation distracters were more disruptive than peripheral distracters, there was no such difference in awareness for fixation versus peripheral critical stimuli.

Results reported in this chapter generalise findings from Chapter 2 across critical stimuli appearing directly where a participant is looking. Perceptual load was found to modulate awareness to the same extent for both fixation and peripheral critical stimuli. Further, Experiment 11 demonstrates that perceptual load may be varied in the standard inattentional blindness cross-task procedure by varying the retinal eccentricity and spatial certainty of cross-targets. Significantly lower rates of awareness were seen when cross-targets appeared unpredictably in peripheral locations compared to when they appeared predictably, always at fixation. Results from the longer block procedure used in Experiment 9 suggest that extensive practice on a task may reduce the effect of perceptual load on awareness, causing higher rates of awareness reports at a set size of six.

Experiment 9 also highlighted an interesting dissociation between the lack of a fixation advantage in awareness versus the fixation advantage revealed with distracter interference effects on RTs. The findings from Experiment 9 Group 3 (with incongruent letter critical stimuli) are particularly convincing in confirming this dissociation, as the very same critical stimulus produced greater interference effects on RTs when presented at fixation versus the periphery but reached awareness at similar levels between these two positions. Thus, implicit effects on RTs revealed a fixation advantage when incongruent letters were presented as critical stimuli, despite a lack of advantage for fixation on awareness reports.

This contrast might reveal a true difference in effects of fixation (vs. periphery) on awareness versus distracter interference. For example, the preferential processing of fixation distracters as shown by interference effects on RTs, but not in awareness could be driven by effects on response selection (i.e. later stages of processing). As response selection can be dissociated from awareness, there need not be an equivalent bias in awareness as the experiments in this chapter have repeatedly shown.

However, there are several differences between the methodologies used in these two paradigms (direct vs. indirect measures) which could account for the advantage for stimuli appearing at fixation versus periphery in RTs but equivalence in awareness. Firstly, this contrast could be due to differences in expectation: Since critical stimuli within the inattentional blindness paradigms are not expected, whereas distracters in the response competition paradigm are expected on each trial and deliberately ignored, it could be that the fixation bias appears only when strategies for responding (i.e. “ignore irrelevant items”) are set up. In inattentional blindness paradigms, without such strategies, unexpected stimuli will be processed for awareness similarly regardless of retinal position. Secondly, this dissociation may stem from habituation to distracters (in the RT experiment where distracters were presented on every trial) differentially impacting peripheral but not fixation distracters. Thirdly, the bias in responding to targets slower in the presence of fixation versus peripheral distracters might reflect the activity of implicit unconscious processing. If this were the case, then a corresponding bias towards greater conscious awareness of fixation stimuli need not be predicted. Finally, this dissociation may simply reflect a difference in sensitivity between RT measures which may be finely graded, and the present explicit awareness measures which are binary (Yes/No).

Chapter 4

Effects of stimulus type: inattentional blindness to faces

4.1 Introduction

The previous chapters have addressed the extent to which neutral task-irrelevant stimuli (outline square shapes or letters) reach awareness when attention is engaged in a task. The overall conclusion from Chapter 2 was that the level of perceptual load in the relevant task critically determines the extent of awareness for task-irrelevant stimuli. The purpose of Chapter 4 was to examine the effects of perceptual load on awareness for biologically and socially significant face stimuli. Previous research on the relationship between attention and faces has suggested a specialised status for faces in attention. More recently, studies have favoured the notion of a general attentional bias leading to the preferential processing of distracter faces. These have been shown to produce interference and priming effects even under conditions of high perceptual load (e.g. Lavie, Ro & Russell, 2003; Jenkins, Burton & Ellis, 2002). However, as yet, there have been no studies examining the effects of attention on explicit awareness for face stimuli. In this chapter therefore, I use the perceptual load model to investigate the role of attention in determining awareness for irrelevant faces within the inattentional blindness paradigm. I will begin with a brief review of neuro-scientific evidence supporting the specialised status of faces in visual processing, before turning to a review of behavioural studies which have investigated the relationship between attention and face processing.

Neuro-scientific evidence

Support from multiple lines of evidence underlines the inherent importance and biological significance of human faces. Developmental studies have shown preferences for, and better detection abilities of, face-like patterns over scrambled faces or blank face outlines even within an hour of birth (e.g. Goren, Sarty & Wu, 1975; Maurer & Salapatek, 1976; Morton & Johnson, 1991). Evidence from single cell studies (Perrett, Rolls & Caan 1982; Perrett, Hietanan, Oram & Benson, 1992) has revealed the existence of cells in the superior temporal sulcus (STS) of macaque temporal cortex that respond exclusively to faces. Similarly, in several human fMRI studies, the presentation of face stimuli has been associated with a selective responses in a distinct region of the fusiform gyrus, termed fusiform face area (FFA; e.g. Kanwisher, McDermott & Chun, 1997; Puce, Allison, Gore & McCarthy, 1995; Puce, Allison, Asgari, Gore & McCarthy, 1996).

Within neuropsychology, several patients have been documented with a selective impairment in face (but not non-face) processing abilities, usually following damage to the right ventral occipitotemporal lobe (identity recognition in prosopagnosia; e.g. Farah, Levinson & Klein, 1995; Farah, Wilson, Maxwell Drain & Tanaka, 1995; McNeil & Warrington, 1993). By contrast, the opposite pattern of non-face object agnosia but intact face recognition has been seen in neurological patients with left occipitotemporal lobe damage (so-called “anti-prosopagnosia”; e.g. Feinberg, Rifkin, Schaffer & Walker, 1986; McCarthy & Warrington, 1986; McMullen, Fisk, Phillips & Maloney, 2000). Thus, evidence from neuropsychology has found evidence of a highly selective impairment in face processing.

Accumulated evidence therefore supports the notion that human faces represent a special category of stimuli to which we are predisposed to attend to from birth, and whose processing is subserved by a distinctive and highly selective anatomical substrate. Such findings have led some to propose the existence of a specialised neural system that is dedicated to the processing of faces in particular (e.g. Kanwisher, 2000; Farah, Wilson, Drain & Tanaka, 1998; Puce et al, 1996).

Behavioural evidence

The face perception literature has revealed the existence of some unique perceptual principles which apply specifically to faces (e.g. they are more sensitive than non-face objects to effects of inversion, Yin, 1969; Carey & Diamond, 1977). Thus, neuro-scientific and behavioural evidence of face perception has led some to suggest that face perception is modular, in the sense that it operates independently from attention; proceeding automatically, involuntarily and free from capacity limits (e.g. Fodor, 1983; Allison, Ginter, McCarthy, Nobre, Puce, Luby & Spencer, 1994). This leads to the prediction that visual search for face targets should exhibit parallel search slopes. In the following section, I give a brief review of studies investigating this hypothesis.

Visual search studies

On the whole, studies of visual search have failed to find evidence of parallel search for faces or facial expressions which would have indicated automatic, capacity-free face perception.

Northdurft (1993) found serial search patterns when participants were asked to detect targets (either faces or particular facial expressions) among varying numbers of non-targets (either rearranged/inverted faces, or non-target facial expressions) when simple schematic drawings were used (see Figure 4.1). Northdurft (1993) only found evidence of parallel search when face targets could be identified on the basis of a unique and salient, low-level feature (e.g. when a black chevron represented the "hair" in a schematic face, participants' search strategy was apparently reduced to a simple feature search for an upward chevron among inverted chevrons). Similar evidence of serial search for faces amongst rearranged or inverted faces has also been found in more recent studies using high-quality digitised faces (e.g. Brown, Huey & Findlay, 1997; Kuehn & Jolicoeur, 1994). Kuehn and Jolicoeur (1994) for example, found that RTs to target (upright) faces slowed as the number of oriented distracter faces (which were rotated 180°) in the display increased.

This evidence argues against automatic, capacity-free face perception. In support of this, Purcell, Stewart and Skov (1996) found no "pop-out" when participants searched for a target angry face among happy faces (or vice versa) when all face stimuli were matched for contrast.

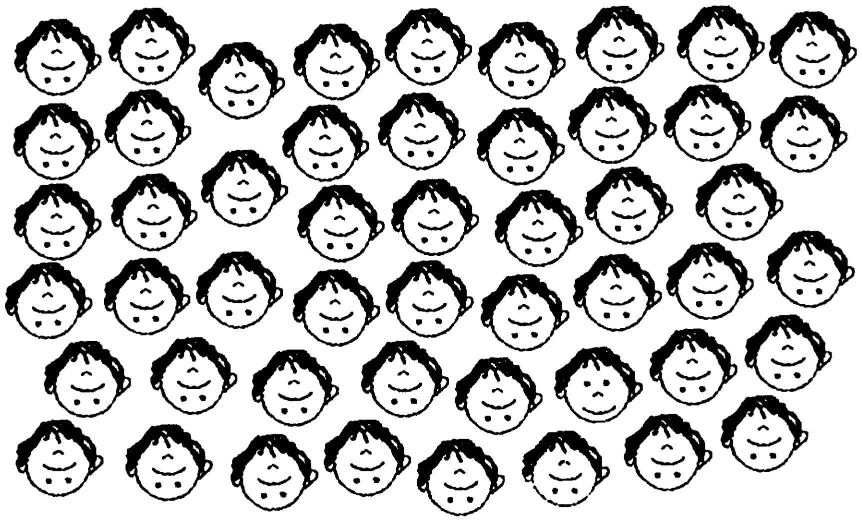

Figure 4.1 A demonstration of the failure of an intact schematic face among rearranged faces to "pop out" (adapted from Nothdurft, 1993; Series 7).

Overall, studies of visual search have failed to find incontrovertible evidence supporting modularity and automaticity of face processing, as might be suggested by its distinctive functional specificity and precise anatomical localisation (e.g. Kanwisher et al, 1997). However, although such studies did not find evidence of parallel search for face targets, one study by Suzuki and Cavanagh (1995) actually showed that a conjunction search was slowed when the separate features of a target (upward and downward arcs) formed a schematic face than when they formed a meaningless pattern (see Figure 4.2). This suggests that perception of facial configuration is automatic in the sense of involuntary processing, because the perception of irrelevant facial configuration harmed search performance.

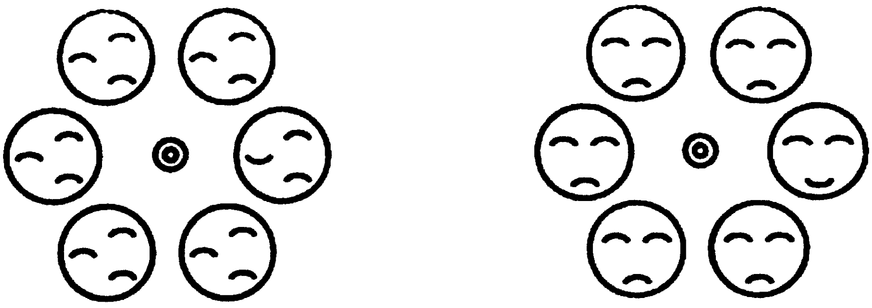

Figure 4.2 Examples of the search arrays used by Suzuki & Cavanagh (1995). The left array shows a feature search (upturned curve) without facial configuration implied. The right array shows the same feature search (upturned curve) with facial configuration implied. Both targets are in the right-most circle position.

Change blindness studies

On the whole, studies of visual search for faces have not found evidence suggesting capacity-free face processing. However, all of these studies examined searches for face (vs. non-face) targets when those targets appeared among other inverted faces (e.g. Northdurft, 1993; see Figure 4.1). If face processing suffers from its own face-specific capacity constraints, then the failure to find a behavioural advantage in such searches does not rule out the possibility that face processing is free from capacity limits. Indeed, other studies have contrasted search for face targets (vs. non-face targets) amongst other objects, and have found a clear advantage for faces over non-faces. I turn to review this evidence now, beginning with studies of change blindness.

Using the flicker technique (Rensink, O'Regan & Clarke, 1997), Ro, Russell and Lavie (2001) compared the rate and speed of change detection in faces versus other meaningful non-face objects in multiple object displays. They found that changes to upright faces (from one face to another) were detected faster and more accurately than changes to non-face objects within different categories (e.g. from a toaster to an electric fan in the "appliances" category) when faces and objects appeared together in mulit-item displays (i.e. one face and five other object). A further experiment clarified that face-changes were not detected faster simply because specific face-changes were more obvious than the within-category object-changes. In fact, the opposite pattern was revealed: Changes were detected faster for objects than faces when stimuli were presented alone (i.e. in a single-item display; Ro et al, 2001), presumably because objects within each category were more dissimilar (e.g. a rectangular toaster compared with a round fan) than the six possible faces (of similar round shape and same sex). This clarifies that faces have a competitive advantage, being more capable of competing for attention than other objects.

Other change blindness studies involving faces have provided further demonstrations of a face-processing advantage. Austen and Enns (2000) found that changes (e.g. of identity or emotional expression, Figure 4.3) were detected faster and more accurately when they occurred in faces than when comparable changes (to local or global letters) occurred within compound letters. Austen and Enns (2003) found that detection of configural changes (e.g. eyes translated) was also faster and more accurate in upright faces compared with inverted faces, although this advantage effect was diluted by the addition of more upright faces in the display (from one face to three faces).

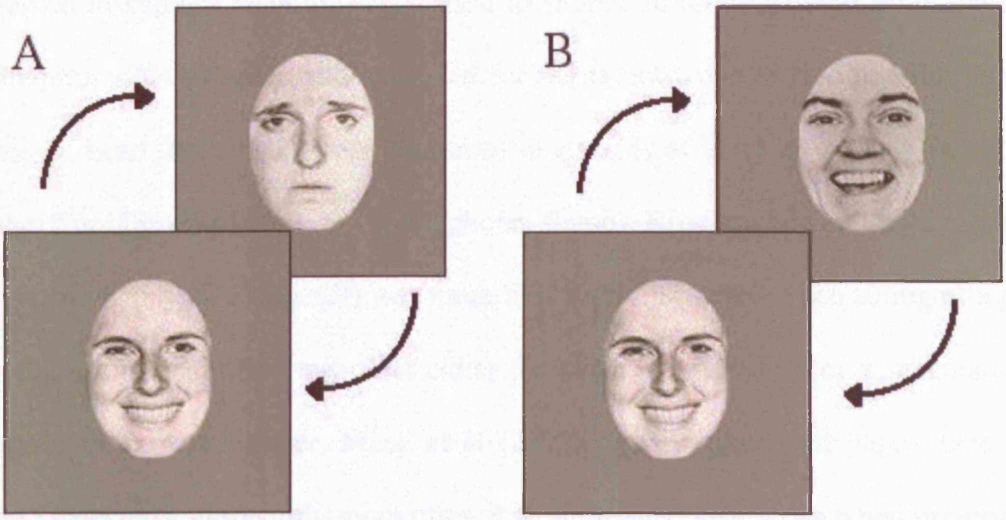

Figure 4.3 Examples of (A) an emotional change and (B) an identity change within upright faces in Austen & Enns (2003).

Meta-contrast masking, attentional blink and stimulus crowding studies

The preferential processing of faces in situations of competition has been illustrated within a variety of methodological paradigms. For example, Ramachandran and Cobb (1995) and Shelley-Tremblay and Mack (1999) found that happy faces were less susceptible than other non-face objects (identical to faces in spatial frequency and luminance) to meta-contrast masking effects (i.e. disruption of stimulus detection by a "masking" stimulus at certain stimulus onset asynchronies). Shelley-Tremblay and Mack (1999) found further, that schematic face stimuli were not only detected more frequently than non-face control stimuli, but face stimuli proved to be more effective than control stimuli when serving as masks within this method. Other studies have reported detection thresholds of schematic faces at stimulus-to-mask intervals of less than 40 ms, which is considerably lower than detection thresholds for scrambled faces (e.g. Gorea & Julesz, 1990; Purcell & Stewart, 1988). In another study, Mack, Pappas, Silverman and Gay (2002) found that faces seemed to capture attention when used as probes in an attentional blink paradigm (Shapiro, 1994). Participants searched for red targets (one of five possible familiar shapes: heart, bell, fish, apple, teardrop) in streams of black distracters (a range of other familiar shapes, e.g. boat, telephone, flame). Results showed that a schematic icon of a happy face (e.g. ☺) was more likely to be detected when acting as a probe in this attentional blink task than either the same icon inverted or a schematic tree figure. In the same paper, Mack et al (2002) also reported that happy face icons were detected significantly more often than scrambled face icons when presented as targets in conditions of stimulus crowding – a phenomenon thought to reflect competition within the limited resolution of spatial attention.

Therefore, although behavioural visual search studies reviewed above do not unambiguously support a specialised face-processing system, more recent work in change blindness and attentional blink paradigms offers converging evidence for a processing advantage for faces, particularly under conditions of competition.

It is therefore possible that the discrepancy between findings from visual search (which do not indicate capacity-free face perception) and other behavioural studies (which indicate an advantage for face processing over non-face processing) is due to face stimuli competing for attention with other face-like objects in visual search studies. If face processing is subject to its own face-specific capacity limit then a face processing advantage would be revealed where faces compete with non-face objects but not where faces compete with other faces for attention.

Studies of distracter face processing

Behavioural studies examining the processing of irrelevant face stimuli (i.e. presented as distracters) have also indicated a special status for faces.

Young, Ellis, Flude, McWeeny and Hay (1986) found that RTs in a name-classification task (politician or popstar?) were slowed by incongruent famous face distracters (also politicians or popstars) indicating that processing of irrelevant faces was obligatory and automatic (see Figure 4.4). However, as printed name targets were presented inside speech bubbles which extended from distracter faces in this study, effects of perceptual grouping (e.g. Baylis & Driver, 1992) could be responsible for the heightened processing of irrelevant faces.

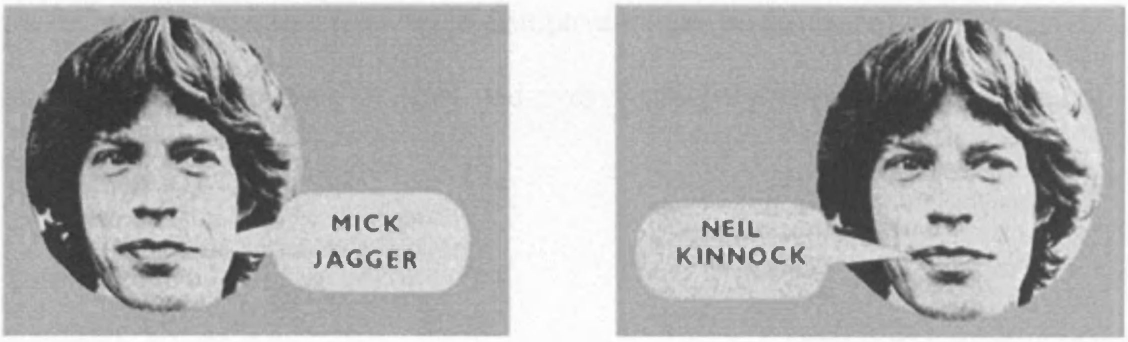

Figure 4.4 Examples displays from Young et al (1986). Participants responded to printed target names classifying them as either pop-star or politician, while ignoring the irrelevant distracter face (also pop-star or politician) appearing in the display. Distracters faces were either congruent (left) or incongruent (right) with the target name response.

Lavie et al (2003) used Young et al's (1986) face-name flanker paradigm, but separated the distracter famous faces from name targets in each display (Figure 4.5, top box) and manipulated perceptual load in the name-task by varying search set size from one to two, four or six letter-strings in the displays. Congruency effects from the distracter faces were still found despite this spatial separation and despite the elimination of perceptual grouping of target names with face distracters. Moreover, congruency effects on name-targets showed no modulation of the distracter face by any increase in perceptual load in the name-classification task. By contrast, increasing the load in a similar name-classification task (categorising the names of fruits and musical instruments while ignoring their photographs) which used photographs of meaningful, three-dimensional, non-face stimuli as distracters eliminated the interference effects from distracters on speeded target responses. The sustained influence of face but not non-face distracters on target-responding (regardless of the task-relevant load) suggests that faces specifically may be preferentially processed, (and hence disruptive to task performance) despite load on attention when they are irrelevant and even when participants attempt to ignore them.
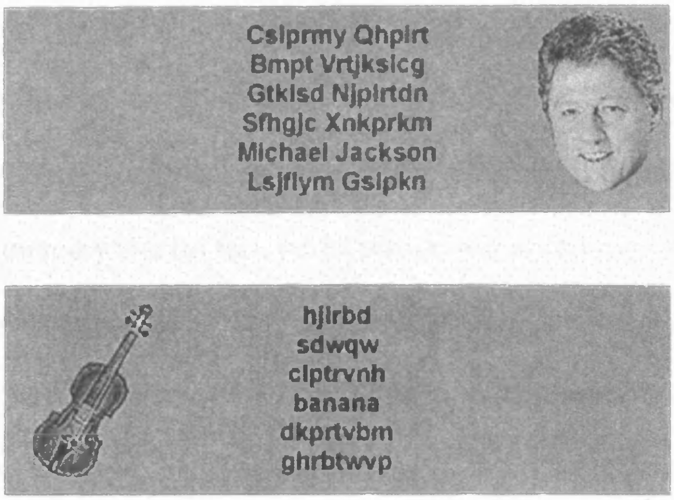
Figure 4.5 Example displays from Lavie et al (2003). Participants classified the target word (politician or popstar in the top display; fruit or musical instrument in the bottom display). In the low load condition, words appeared alone and in the high load condition words appeared amongst five other nonsense words (as in both examples here). Words were flanked by a distracter which was either congruent or incongruent (as in both examples here).

Famous but irrelevant distracter faces have also been shown to produce consistent long-term covert priming effects despite increases in task-relevant perceptual load. Jenkins et al (2002) varied the perceptual load of an attended letter-string task (colour search for low load or target-letter search for high load) where letter-strings were superimposed on a series of irrelevant famous faces. Repetition priming was measured later in a face familiarity judgment task ("Do you recognise this face?"; familiar faces mixed with unfamiliar faces). In line with Lavie et al's (2003) results using a face-name flanker task, Jenkins et al (2002) found equivalent levels of repetition priming for all of the ignored distracter faces regardless of the level of perceptual load in the attended letter-string task.

By contrast, the long-term explicit recognition of irrelevant famous face distracters has been found to be modulated by effects of perceptual load. In Jenkins et al's (2002) study, a surprise name recognition test was presented after the attended task whereby participants indicated which famous identities they thought they had seen during the attended task. Using this explicit measure, increasing the relevant-task load from low load to high load significantly reduced performance in this recognition memory test (in fact, performance was at chance level in high load).

The dependence of explicit face recognition memory on task-relevant perceptual load has also been found by Jenkins, Lavie and Driver (2005) when unfamiliar faces were presented as irrelevant background distracters during an attended letter-string task (see Figure 4.6).

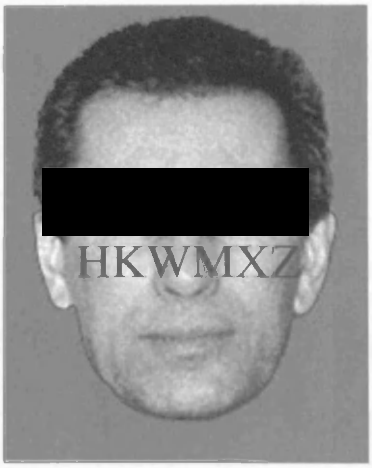
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Figure 4.6 An example display from Jenkins et al (2005). Participants responded to a string of letters superimposed on a task-irrelevant unfamiliar face. In the low load condition, participants performed a colour discrimination task (red vs. blue). In the high load condition, participants performed a visual target search task (X vs. N).

In this experiment, recognition memory was tested either by presenting a sequence of isolated faces (participants either responded "yes" (seen before) or "no" (not seen before)) or a series of two-alternative forced-choices (participants chose which of two faces they had seen before) immediately following the attended task. Results from both types of test revealed that the level of perceptual load in the attended task (low load vs. high load) determined participants' recognition memory performance for unfamiliar faces seen incidentally in target displays.

The results from these studies therefore do not clearly support the case for automaticity in face processing. However, these findings may be understood if it is assumed that perceptual load determines the level of encoding into long-term explicit memory. Given that explicit long-term memory requires deeper encoding than implicit recognition, it is possible that the relatively shallow encoding afforded by conditions of high perceptual load is sufficient to produce priming or interference effects, but not sufficient to support long-term recognition. In this way, implicit measures such as interference effects or repetition priming may simply be more sensitive than explicit measures to reveal the processing of irrelevant face distracters.

In the studies reviewed above, distracter effects and implicit memory (priming) from faces were shown to be independent of perceptual load, indicating face processing free from capacity limits. However, it is possible that face processing is merely free from the general capacity dedicated to other non-face objects.

Interestingly, in line with this suggestion, one study has shown that distracter effects from irrelevant famous faces are reduced by the presence of another face. Jenkins et al (2003) found that, while congruency effects exerted by non-face distracters (e.g. musical instruments, fruits) on name-classification RTs were reduced or "diluted" to the same extent by the addition of any another response-neutral object (e.g. a phase-shifted face, an intact face or a non-meaningful object), interference from an irrelevant distracter face was only diluted by the addition of another intact face stimulus. The congruency effects of famous face distracters on RTs in a name-classification task (politician or popstar) were not changed when a phase-shifted face, an inverted face or a non-meaningful object was added to the display. By contrast, congruency effects from famous distracter faces diminished when an intact anonymous face was added to the display (see Figure 4.7). This suggests that faces may be processed differently from other kinds of distracters, and may possibly possess a unique salience which can only be reduced by the presence of competing face stimuli.

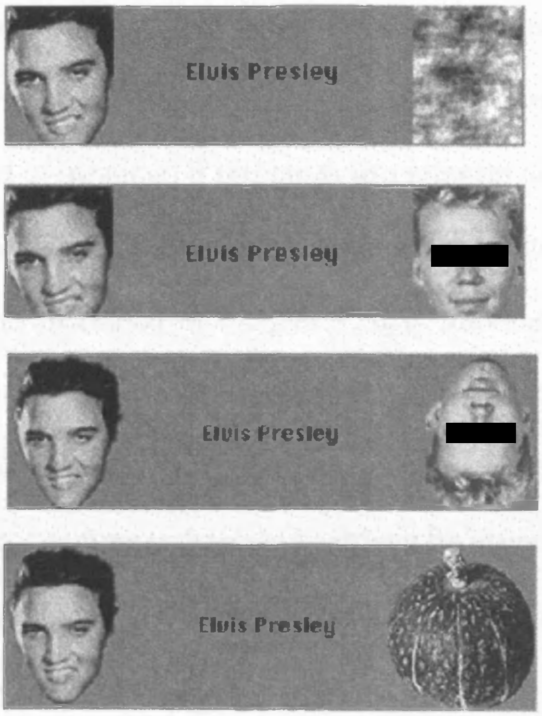

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Figure 4.7 Example displays from Jenkins et al (2003). Participants classified a target name (politician vs. popstar) while a distracter face which could be either congruent or incongruent flanked the word on one side (here on the left). An additional stimulus (a phase-shifted face, an intact face, an inverted face, or a non-face object) flanked the word on the other side (here, on the right).

In summary, studies of distracter-face processing have produced results consistent with a system which processes faces even when they are irrelevant and when participants are specifically asked to ignore them. Furthermore, the face-processing system appears to operate independently from the normal attentional capacity constraints (i.e. insensitive to effects of perceptual load) when measuring implicit but not explicit effects.

Conscious awareness of faces under load

What are the implications of such an attentional face-processing bias for the effects of attention on conscious awareness of faces? Many of the behavioural studies I have summarised above have relied upon indirect measures to index face perception. For example, an irrelevant distracter face is assumed to have been processed (to the level of meaning) if responses in a relevant naming task are slower or less accurate when the face is incongruent (rather than congruent) with that target response. However, as discussed in Chapter 1, it is impossible to infer anything about the nature of subjective conscious awareness of a stimulus from such indirect measures of RTs in another task. For example, the influence of irrelevant distracter faces on RTs in a target naming task might be driven by unconscious recognition of the association between target and distracter, without the distracter face necessarily entering conscious awareness.

With similar reasoning, conclusions about the experienced awareness of a face cannot be drawn from single cell recordings or functional imaging data which measure cortical activity related the presence of face (vs. non-face) stimuli. For example, the selective neural responses to face stimuli may not correlate with conscious awareness of those stimuli: Activity in specific face regions alone may be insufficient to support conscious awareness of faces.

Evidence from change blindness studies (Ro et al, 2001; Austen & Enns, 2003) provides the first hints that faces demonstrate an advantage in awareness (in this instance, awareness of a change). This is supported by neuropsychological evidence showing that, although non-face objects (including scrambled faces and familiar names) are extinguished in the neglected field in patients with spatial neglect, faces show resistance to such extinction (e.g. Vuilleumier, 2000; Vuilleumier & Schwartz, 2001; Ward & Goodrich, 1996). However, because perceptual load was not directly varied in change blindness studies, and because of the difficulties extrapolating conclusions from brain damaged patients to normal populations, it is impossible to infer anything from these results about the specific effects of attention on conscious awareness.

Jenkins et al (2002, 2005) specifically varied levels of perceptual load in their studies and found that availability of attention determines the extent of explicitly reported recognition of famous and unfamiliar faces. However, in these studies and all of the other studies discussed so far, face processing was measured for large numbers of faces that either competed for attention or were deliberately ignored (e.g. long blocks of trials in which an irrelevant distracter face appears in each trial). In this way, existing experiments cannot provide information about awareness for a single face stimulus that is not expected (and therefore participants do not attempt to ignore), as in an inattentional blindness study.

Although most inattentional blindness experiments have typically presented neutral unexpected stimuli on critical trials, a few studies have measured awareness for stimuli of greater biological relevance. Mack and Rock (1998) reported that participants experienced significantly less blindness on critical trials for a smiling face icon (☺) compared to a scrambled face or other non-face cartoon schematics, including a tree, a house or a dollar sign. Typically, around 85% of participants reported awareness of the unexpected face on critical trials whilst performing the cross-task typically used in Mack and Rock's (1998) studies, compared to a significantly reduced number (around 35%) reporting awareness for the control stimuli. Equivalent levels of awareness were found for the happy face and control stimuli on full attention trials.

However, Mack and Rock (1998) also reported the surprising finding that sad faces (☹) were reported less often than the control stimuli. At best, this result points to specific effects of emotional expressions in awareness. However, the primary interest in the present chapter is the effects of attention on awareness of faces, irrespective of their emotional expression. Also, in addition to the anomalous finding with sad faces, Mack and Rock (1998) found lower rates of awareness for neutral faces than other control stimuli (e.g. a schematic house or schematic tree). This unexplained pattern of results raises questions about their previous findings, and certainly does not provide a satisfactory or complete investigation of awareness for faces in inattentional blindness paradigms.

In addition, as with previous studies of inattentional blindness, Mack and Rock's (1998) experiments compared awareness levels for a stimulus that is both unattended and unexpected on the critical trial, with awareness levels for the same stimulus which then becomes attended and expected on a full attention control trial. As discussed in Chapter 1, such a comparison is critically confounded with expectation. In such inattentional blindness paradigm, expectation may affect differentially the processing of biologically meaningful stimuli versus controls such that the less meaningful controls (e.g. telephone) might have suffered disproportionately in the absence of expectation. This confound could be avoided by comparing levels of awareness for biologically meaningful versus neutral stimuli between different levels of load when all stimuli are equally unexpected.

Much face information (as well as ecological validity) is lost by the use of relatively impoverished schematic face critical stimuli in these studies. Therefore, the current chapter examines awareness of photographic images of real faces compared to controls in the inattentional blindness paradigm.

More recently, Downing et al (2004) presented schematic images of human figures (e.g. stick figures, silhouettes of bodies or hands) as critical stimuli whilst participants performed the same line judgment task on cross targets that appeared either at fixation or in the periphery. Awareness for these biologically meaningful stimuli was compared with awareness for control stimuli (including scrambled stick figures, object silhouettes, scrambled silhouettes of bodies/body parts/objects) across critical trials. Significantly greater detection rates were found for human bodies (but not body parts) in either schematic form (silhouette or stick figure; around 60%) compared to control stimuli (around 25%). This therefore suggests that biologically meaningful stimuli may receive attentional prioritisation for awareness where other stimuli, sharing identical low level visual features, would remain undetected. This is encouraging for the hypothesis that faces would also reach awareness more frequently than non-face objects and that awareness of faces may be resistant to increases in perceptual load.

Therefore, in the present chapter I seek to examine the impact of perceptual load on inattentional blindness for an unexpected photographic human face stimulus compared with its own inversion as a visual control. Since inversion severely disrupts normal face processing and recognition (e.g. Valentine, 1988) and since inverted faces share identical low level visual properties with upright faces (e.g.

luminance, brightness, shading, contrast), inverted faces are used to represented non-face stimuli in the present comparison. By manipulating perceptual load, I will be able to compare awareness for faces across conditions varying only in the availability of attention that the relevant task leaves for irrelevant processing. Importantly, expectation is held constant across conditions. The cross-task procedure established in Chapter 2 was used throughout this chapter as the means of varying perceptual load. In Experiment 13, awareness for a familiar face (a black and white photograph of Tony Blair) was tested under both low load and high load, at upright and inverted orientations. In Experiment 14, the same design was used to test awareness for photographs of an unfamiliar face under conditions of low load and high load, with the face upright and inverted. Finally, Experiment 15 compared awareness for an upright meaningful non-face object (a musical instrument) between situations of low load and high load. If faces have a unique priority for attention then (upright) faces should enter awareness regardless of the perceptual demands in the relevant task, whereas inverted faces and meaningful non-face objects should only be reported under conditions of low perceptual load when spare capacity is available for processing. On the other hand, if faces are processed for awareness no differently to other neutral meaningful non-face stimuli, then awareness of all stimuli including upright faces should only be found when the perceptual demands of the relevant task are low: Levels of awareness for upright faces, inverted faces and musical instruments should be reduced by increasing the perceptual demands of the relevant task.

4.2 Experiment 13

In Experiment 13, participants were presented with a series of coloured cross-targets (as in Experiment 1, Chapter 2), and either judged which arm was blue (low load group) or which arm was longer (high load group). Half the participants in each load condition were presented with an upright famous face in the periphery (Tony Blair) on critical trials, while the other half were presented with an inversion of the same face (also in the periphery). On the basis of previous findings of an advantage for faces (e.g. Ro et al, 2001; Lavie et al, 2003), I hypothesised that there would be higher rates of awareness for upright versus inverted faces. In addition, if explicit awareness for irrelevant faces is subject to the same attentional principles as those revealed with RT measures of distracter compatibility (e.g. Lavie et al, 2003), then I predicted that, whereas inverted faces should be susceptible to the usual effects of perceptual load (i.e. reducing awareness under high load), the higher rates of awareness for the upright face should be unaffected by increases in task-load. Therefore, a difference was predicted in the extent to which awareness would be reduced by perceptual load for upright versus inverted faces.

Method

Participants Eighty-four experimentally-naïve visitors to the Science Museum, London participated in this experiment. All were between 18 and 45 years and all had normal or corrected-to-normal vision.

Stimuli and Apparatus Apparatus was as for Experiment 1 (Chapter 2). Viewing distance to the 17" monitor was maintained at 60 cm with a chin rest. Stimuli were as in the cross-task of Experiment 1 (Chapter 2). In addition, with the current question of awareness for faces, a black and white photographic image of Tony Blair's face was presented as a critical stimulus on critical trials. As with all faces presented in the following experiments, all extraneous background around the photographs was removed so that only the actual face shape (with ears and hair) was presented (see Figure 4.8). The face could appear in either of four quadrants of the cross (counterbalanced between participants), located 2.7° from the centre of the cross, on an imaginary 45° diagonal bisection of two cross-arms. Figure 4.8 presents an example critical display for each group (face upright versus face inverted) in Experiment 13. The face image subtended 2° in height and 1.55° in width, and was presented in normal upright orientation to one group of participants and in a fully-inverted orientation to a second group of participants. A new visual mask was used in this experiment: a random checkerboard pattern composed of quartered pieces of ten scrambled face images. Faces were scrambled by passing stimuli through different bandpass filters.

The additional face presented during the two-alternative forced-choice questioning of identity awareness was a black and white photographic image of Sean Connery. This image matched the critical stimulus face (Tony Blair) in sex, age, hair colour, size dimensions and low level characteristics (contrast, luminance) as far as possible in Adobe Photoshop. The same image (Sean Connery) inverted was used as the alternative face-choice in the inverted face condition.

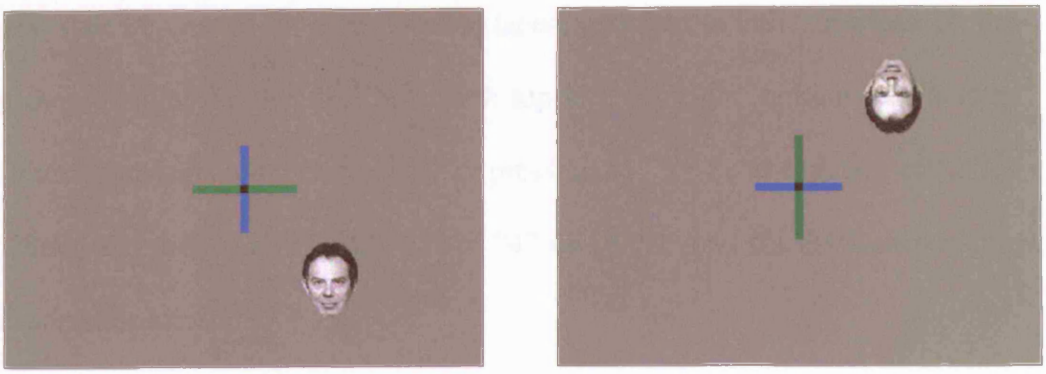

Figure 4.8 Example critical displays from Experiment 13 in the upright face condition (bottom right critical stimulus position) and inverted face condition (top right critical stimulus position). Participants in the low load group decided which arm was blue (horizontal or vertical). Participants in the high load group decided which arm was longer (horizontal or vertical).

Procedure The procedure was similar to Experiment 1 (Chapter 2). A black fixation dot (1500 ms) was followed by a brief blank interval (100 ms), the cross target display (150 ms) and then finally the visual mask (500 ms). A blank screen (4000 ms) then appeared at which point participants entered their response: pressing "0" for horizontal or "2" for vertical on the computer keyboard. Following entry of response, or termination of the response window (whichever was sooner) another blank interval of 750 ms was presented before the subsequent trial began. As in Experiments 1 and 3 (Chapter 2), participants were either asked to judge which arm of the cross was longer (high load condition), or to judge which arm of the cross was blue (low load condition): horizontal or vertical?

Each participant was presented with six experimental trials following two demonstration displays and two practice trials. The critical stimulus face appeared on the sixth, critical trial. Counterbalancing was identical to Experiment 1 (Chapter 2). Following the usual questioning of awareness, participants were asked to choose which of two possible faces had appeared on the screen, either Tony Blair or Sean

Connery, (see Figure 4.9 for both possible faces) and then to indicate where on the screen they thought the face had appeared: top left, top right, bottom left, bottom right. Participants entered their choices by pressing “1” for Sean Connery or “2”for Tony Blair; and numbers “1”, “2”, “3” or “4” on the keypad for the four possible critical stimulus locations.

A control trial repeating these measures was included (as in Chapters 2 and 3) after the critical trial and questioning of awareness. In addition, after the awareness questioning in these trials was complete, participants were asked a series of questions designed to confirm that they were familiar with the faces of Tony Blair and Sean Connery. Firstly, participants were asked directly whether they had seen the faces before, indicating “Y” for yes or “N” for no. Next, they were asked whether the face belonged to an actor or a politician, pressing “A” for politician or “B” for actor.

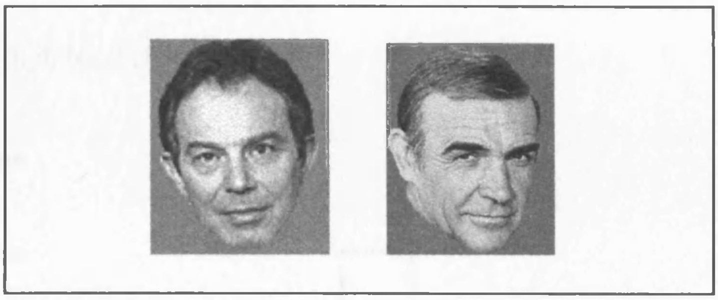

Figure 4.9 Critical famous face (Tony Blair) and alternative famous face (Sean Connery) in the two-alternative forced-choice test of identity in Experiment 13.

Results and Discussion

Figure 4.10 presents the percentage of reported awareness as a function of face orientation (upright vs. inverted) and perceptual load (low load vs. high load). Ten participants who were unfamiliar with Tony Blair (4) or Sean Connery (6) were excluded. In addition, exclusion criteria from Chapter 2 were applied to all experiments reported in this chapter. In the current experiment, this led to the exclusion of participants who could identify neither identity nor location after a "Yes" awareness response (one from the high load, inverted face group); participants who made an error in the cross-task on the critical trial (5 in total; one from the high load, upright face group; three from the low load, upright face group; one from the low load, inverted face group), participants who were familiar with the inattentional blindness phenomenon (2); and participants who failed to detect the critical stimulus in the visual control trial (2; both from the low load, upright face group). All other participants performed the task adequately making no more than three errors. On average, participants answered 1.28 trials incorrectly (corresponding to 21%) in the high load condition compared to an average of 1.06 trials incorrect (corresponding to 15%) in the low load condition. Remaining participants were divided equally between the four experimental groups: face upright, low load (16); face upright, high load (16); face inverted, low load (16); and face inverted, high load (16).

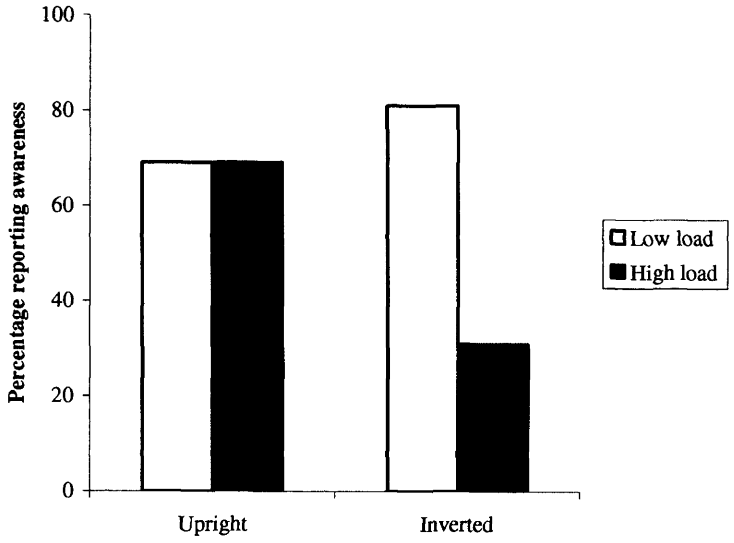

Figure 4.10 Percentage reporting awareness for an unexpected famous face stimulus as a function of face orientation (upright vs. inverted) and perceptual load (low load vs. high load), N = 64.

Awareness results

Results only showed a trend for a higher frequency of awareness reports for upright (22 of 32) than inverted (18 of 32) photographic famous faces, and this did not reach significance, χ^2 (1, N = 64) = 1.07 p = .30. Importantly however, as can be seen in Figure 4.10, there was no effect of perceptual load on awareness for upright faces (11 of 16 in low load and 11 of 16 in high load). By contrast, awareness of an inverted famous face was significantly modulated by load from low load (13 of 16) to high load (5 of 16), (χ^2 (1, N = 32) = 8.13 p = .01 for the interaction of perceptual load and face orientation).

Note that the overall level of awareness (even for inverted faces under conditions of low perceptual load; 81%) was higher in this experiment than those reported for an outline square in equivalent low load conditions of Experiments 1 and 3 (Chapter 2; 60% in low load conditions across experiments). This is likely to be a result of the larger size and better contrast of the face stimuli used here compared to outline square shapes used in previous experiments. Importantly though, imposing high perceptual load produced equivalent effects on awareness for inverted famous faces (50% reduction from low load to high load) and neutral stimuli (48% reduction, Experiments 1 and 3, Chapter 2). By contrast, there was no such reduction of awareness when perceptual load in the relevant task was increased (from low load to high load) if upright famous faces were presented as critical stimuli.

Forced-choice results

Almost all of the participants who reported awareness of the critical face stimulus (i.e. made a "Yes" response to the critical question) were able to identify correctly the location of the face (35 of 40 Yes responses correct) and 29 of 40 also reported correctly its identity. Closer inspection of the face recognition results (see Table 4.1) showed that significantly fewer participants were able to correctly identify facial identity of an inverted face (10 of 18) than an upright face (19 of 22) following a Yes response, χ^2 (1, N = 40) = 4.71, p = .03. The effect of face orientation on identity recognition was evident in both conditions of load: Fewer participants correctly identified inverted faces compared with upright faces at both low load (7 of 13 vs. 9 of 11, χ^2 (1, N = 24) = 2.10, p = .15) and high load (3 of 5 vs. 10 of 11, χ^2 (1, N = 16) = 2.16, p = .14) although these did not reach significance due to the small numbers of participants in each group. These findings are in line with evidence that recognition of facial identity is considerably disrupted by face inversion (e.g. Valentine, 1988). Overall, there was no significant effect of perceptual load on face identification after "Yes" responses: Equivalent proportions of correct identifications were made in low load (16 of 24; 67%) and high load (13 of 16; 81%), χ^2 (1, N = 40) = 2.22, p = .14, and there was no interaction between load and orientation, χ^2 (1, N = 40) = .07.

Table 4.1 Frequencies of correct face identity reports in the forced-choice task following "Yes" awareness responses as a function of face orientation and load (number correct identifications / total Yes responses).

"Yes" responses only			
Upright face		**Inverted face**	
Low load	High load	Low load	High load
9 / 11	10 / 11	7 / 13	3 / 5

Thus, the present results support the hypothesis that faces have a higher priority for attention: Participants were aware of faces even in tasks of high perceptual load which typically eliminates awareness for more neutral stimuli (e.g. Chapter 2). The results may either indicate (i) that unexpected face stimuli always capture sufficient attentional resources for awareness regardless of attentional demands in the current task, or (ii) that face stimuli are free from the capacity limits involved in processing other stimuli. I will elaborate on these alternatives in the chapter discussion.

The current results also concur with previous findings regarding the fate of other biologically meaningful stimuli such as body parts and smiling faces within inattentional blindness paradigms (e.g. Downing et al, 2004; Mack & Rock, 1998). Present findings extend this work by showing that photographic faces are immune to the effects of perceptual load on inattentional blindness.

These findings are also consistent with previous studies reporting preferential processing of famous faces that have relied upon indirect measures to assess processing (e.g. Lavie et al, 2003; Jenkins et al, 2002). Further, the current data (using an inattentional blindness paradigm) extend the previous results concerning distracter face processing into the realm of awareness, by showing that the magnitude of explicit awareness of an upright famous face reported by participants is not modulated by perceptual load. However, the results from Experiment 13 may be confined to awareness for famous faces. In the next experiment I therefore address the case of anonymous face awareness under different conditions of perceptual load.

4.3 Experiment 14

The robust levels of awareness for upright faces across different levels of perceptual load in Experiment 13 might have been driven by the recognition of the critical face stimulus as familiar (the face stimulus was identifiable by all of the participants as the politician, Tony Blair). Here I examine whether upright anonymous faces similarly reach awareness regardless of high perceptual load or whether awareness is affected by load when the unexpected face is unfamiliar.

Both Lavie et al (2003) and Jenkins et al (2002) used images of famous celebrities when measuring the impact of perceptual load on face processing. With famous faces, these studies found that both RT interference effects on a name-classification task (Lavie et al, 2003) and long-term covert priming effects (speeding of familiarity judgments following pre-exposure of a face; Jenkins et al, 2002) were unaffected by the level of task-relevant perceptual load. By contrast, increasing the level of perceptual load significantly reduced correct performance on long-term recognition memory tests when anonymous faces (Jenkins et al, 2005) were presented as irrelevant distracters in target displays. The same modulation of recognition memory by perceptual load was also found by Jenkins et al (2005) with an immediate test of recognition memory was used. Perceptual load significantly decreased face recognition when the forced-choice test was presented immediately following stimulus presentation (Jenkins et al, 2005; Experiment 3). This finding might suggest that inattentional blindness to anonymous face critical stimuli may similarly be modulated by perceptual load.

However, unlike the inattentional blindness paradigm, the general procedure used in Jenkins et al's (2005) experiment involved the presentation of a face on every trial which participants deliberately attempted to ignore. Hence, one cannot draw any firm conclusions regarding effects of load on inattentional blindness from this study.

In Experiment 14 therefore, I examined the effects of perceptual load on awareness for an upright unfamiliar face, by presenting an anonymous face as the critical stimulus within the same paradigm as Experiment 13. As before, these results were contrasted with the effects of perceptual load on awareness for the same unfamiliar face presented in full inversion. The same cross-task procedure was used, with two conditions of perceptual load (low load and high load). If awareness of an upright face in situations of high perceptual load (as seen in Experiment 13) depends on recognition of that face as familiar, then upright anonymous faces should exhibit the same modulation in awareness by perceptual load as inverted faces and neutral objects. On the other hand, if the ability of faces to gain access to awareness irrespective of general attentional availability results from a more basic face processing mechanism (e.g. one that is responsible for configuration effects which are evident both with famous and unfamiliar faces), then unfamiliar faces should demonstrate an equivalent immunity to effects of perceptual load when they are upright (but not inverted).

Method

Participants Ninety-five experimentally-naïve visitors to the Science Museum, London participated in this experiment. All were between 18 and 45 years and all had normal or corrected-to-normal vision.

Apparatus and stimuli Apparatus was as for Experiment 13. Stimuli were as for Experiment 13 with the exception of the faces used as critical stimuli. In the current experiment, a black and white photographic image of an unfamiliar face was presented on critical trials. This anonymous face appeared in the same positions as the familiar face used in Experiment 13, and was matched in size, age, sex, hair colour, hair line and eye colour (dark in the black and white photograph) to the image of Tony Blair. The unfamiliar faces appeared upright for half the participants and fully inverted for the other half. A second unfamiliar face (matched in size, sex, age, hair colour and eye colour to the critical anonymous face) was used in the two-alternative forced-choice test of identity recognition (see Figure 4.11).

Procedure The procedure was identical to Experiment 13 except for the post-experiment control questions measuring familiarity with the new anonymous face stimuli. Following termination of the visual control trial, participants were simply asked whether they had seen the anonymous test faces before or not.

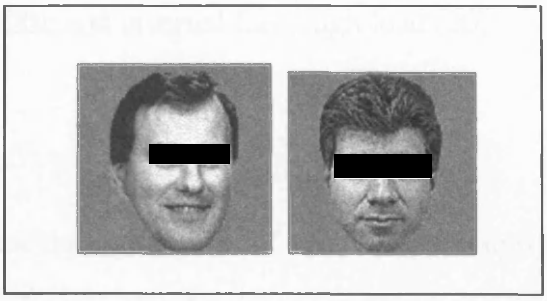

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Figure 4.11 The critical anonymous face (left) and the alternative anonymous face (right) in the two-alternative forced-choice test of identity used in Experiment 14.

Results and Discussion

Figure 4.12 presents the percentage of reported awareness as a function of face orientation (upright vs. inverted) and perceptual load (low load vs. high load). Participants made an average of 1.32 trials incorrect (corresponding to 22%) in the high load group compared to an average of 0.62 trials incorrect (corresponding to 10%) in the low load group. Excluded from this experiment were participants who failed to identify either location of identity correctly following a "Yes" awareness response (four in total, two from the high load, upright face group; two from the low load; upright face group), participants who failed to perform the task correctly giving fewer than three correct responses (11 in total; three from the high load, upright face group; eight from the high load, inverted face group); participants who gave an incorrect response in the critical trial (seven in total; two from the high load, upright face group; two from the high load inverted group; one from the low load, upright face group; two from the low load, inverted face group); and one participant who did not understand instructions. Finally, all participants included in the analysis reported that they were unfamiliar with the face stimuli, and had never seen them before. Remaining participants were divided between the four experimental groups thus: upright face, low load (16); upright face, high load (16); inverted face, low load (20); and inverted face, high load (20).

Awareness results

Results revealed significantly higher rates of awareness for upright (25 of 32) than inverted (22 of 40) unfamiliar faces, χ^2 (1, $\underline{N}$ = 72) = 4.19, p = .05. In addition, there was a significant interaction between perceptual load and face orientation, χ^2 (1, $\underline{N}$ = 72) = 4.96, p = .05, indicating an effect of load on inverted but not upright unfamiliar faces. Inverted unfamiliar faces showed the typical sensitivity to perceptual load: Significantly fewer participants reported awareness of an inverted unfamiliar face under conditions of high load (6 of 20) compared with low load (16 of 20), χ^2 (1, $\underline{N}$ = 40) = 10.1, p = .02. By contrast, there was no significant difference between the number of participants reporting awareness for upright familiar faces whilst performing tasks of low perceptual load (13 of 16) and tasks of high perceptual load (12 of 16).

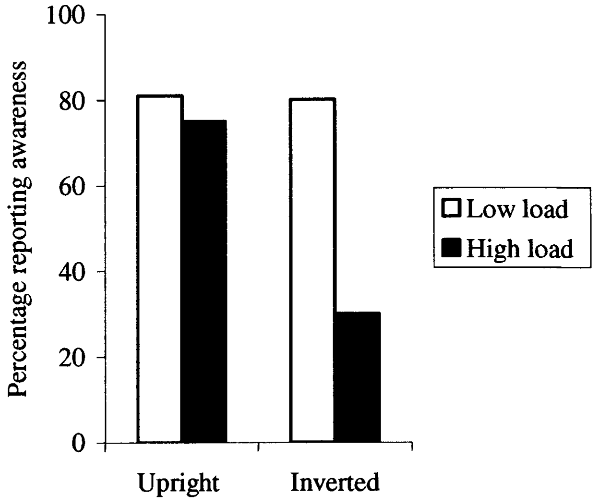

Figure 4.12 Percentage reporting awareness for an unexpected anonymous face stimulus as a function of face orientation (upright vs. inverted) and perceptual load (low load vs. high load), N = 72.

Forced-choice results

As with Experiment 13, nearly all of the participants who reported awareness of the critical face stimulus were able to identify correctly either the location of the anonymous face (46 of 47 Yes responses) or its identity (33 of 47 Yes responses). Closer examination of the face recognition results (see Table 4.2) revealed that significantly fewer participants were able to choose the correct facial identity of an inverted face (12 of 22) compared with an upright face (21 of 25) following a Yes response, χ^2 (1, $\underline{N}$ = 47) = 4.86 p = .05. This effect of face orientation (upright vs. inverted) was evident at both low load (11 of 13 vs. 9 of 16) and high load (10 of 12 vs. 3 of 6), although as before, small populations reduced the power of the statistical tests to reveal a significant result. There appeared to be no effect of perceptual load on rates of identity recognition in the two-alternative forced-choice test after "Yes" awareness responses: Similar proportions of participants identified the correct face in the low load (20 of 29; 69%) and high load (13 of 18; 72%) conditions, χ^2 (1, N = 47) = .05. Results thus showed no interaction of face orientation by load on recognition of faces, χ^2 (1, N = 47) = .18. This confirms the disrupting effect of inversion on the recognition memory of a face stimulus following awareness questioning.

Table 4.2 Frequencies of correct face identity reports in the forced-choice test following "Yes" awareness responses as a function of face orientation and load (number correct identifications / total Yes responses).

"Yes" responses only			
Upright face		**Inverted face**	
Low load	High load	Low load	High load
11 / 13	10 / 12	9 / 16	3 / 6

Overall, the effects of perceptual load on awareness of unfamiliar faces described in this experiment reflect the same pattern, and are of the same magnitude as those seen in Experiment 13 with familiar, famous faces. This suggests that the advantage for faces in gaining access to awareness independent of normal attentional capacity constraints, does not depend upon those faces being recognised as familiar, or their related semantic processing (e.g. of name, job description etc). Importantly, recognition of facial identity is not necessary for unexpected faces to enter awareness, regardless of the perceptual load in the relevant task. Instead, the bias for upright faces but not inverted faces to enter awareness appears to be driven by a mechanism which operates independent of familiarity.

By generalising inattentional blindness results across familiar and unfamiliar unexpected faces the previous findings can be broadened considerably (Experiment 13; Lavie et al, 2003). The processing bias illustrated by distracter face awareness may not be limited to situations involving familiar facial identities, but can be seen also with anonymous, unfamiliar faces as well. Thinking in terms of evolutionary utility, it seems quite logical that awareness of strangers as well as of friends be prioritised given the potential danger that a stranger may signal (e.g. a member of a hostile group).

The current results in inattentional blindness contrast with those reported by Jenkins et al (2005) where perceptual load was found to modulate performance in post-stimulus tests of recognition memory for anonymous faces. This contrast suggests that perception and awareness of faces may occur even when attentional capacity is exhausted, but transferral of such representations into long-term memory is reduced under conditions of high perceptual load. Such an account could conceptualise a face processing module where input is restricted to face-specific information only, but output is directed into a general resource (e.g. memory) shared by all (face and non-face information). Although processing for perception and awareness may proceed within the specialised face module regardless of general capacity constraints, the transferral into long-term memory would be carried out by the general resource which is also responsible for processing non-face information. If this general capacity is exhausted by conditions of high perceptual load, then transferral of face (and non-face) information into long-term memory would be limited, giving rise to the current pattern of findings.

Jenkins et al (2005) also found that perceptual load influenced recognition in an immediate recognition memory test (Experiment 3) for the distracter face presented in the final trial. There are several important differences between the methods used in the present study and Jenkins et al's (2005) study which might explain this discrepancy. Firstly, in Jenkins et al's (2005) study, target letter-strings were superimposed over the irrelevant distracter faces (centred around the nose), giving the impression of two separate objects in three-dimensional space: Distracter faces appeared deeper than letter-strings (see Figure 4.6). By contrast, critical faces in the current inattentional blindness study appeared in the periphery, clearly separated in space from the target and therefore on the same depth plane in space. It is thus possible that participants using a three-dimensional separation in Jenkins et al's (2005) study more efficiently blocked face processing than participants in the present study. There is also an important difference in expectancy between these two methods. As confirmed in post-experiment questioning, critical face stimuli were entirely unexpected in the inattentional blindness paradigm. By contrast, as irrelevant faces appeared in every trial of Jenkins et al's (2005) study, it can be assumed that participants were expecting (and indeed attempting to ignore) the faces in these experiments. This highlights the further crucial difference, between the number of faces presented in each of the studies (one face vs. dozens of faces). It is possible therefore, that participants in Jenkins et al's (2005) study became habituated to the repeated presentation of ignored faces, lowering their overall salience. It turn, faces may have been processed to a lesser extent under high load when capacity for attention was stretched. By contrast, a single, unexpected face may have captured attention even under high perceptual load by virtue of its distinctive arrival and high salience.

It is therefore not clear whether differences between effects of load in the two studies indicate real differences between recognition memory and immediate detection of presence for faces, or whether procedural differences are responsible for this discrepancy. It would be interesting to see whether face-recognition memory would be modulated by load if an unexpected face was presented in an early trial in Jenkins et al's (2005) task. In other words, would face recognition still be modulated by attention when irrelevant faces and targets are presented in a way that can allow their separation in depth, and when effects of expectation and habituation are removed?

Habituation to repeatedly presented and expected faces may also explain another apparent discrepancy between the current findings and existing literature on effects of attention on face processing. Although perceptual load did not influence awareness of faces, recent imaging research (fMRI, MEG and ERP) has shown that face-related neural activity (measured across several trials) can be modulated by attention (Downing, Liu & Kanwisher, 2001; Holmes, Vuilleumier & Eimer, 2003; O'Craven, Downing & Kanwisher, 1999; Wojciulik, Kanwisher & Driver, 1998). Perhaps then, attention influences face processing when faces are expected and once participants have become habituated to their presence. Alternatively, the residual face-related activity remaining under conditions of focused attention may be sufficient to support awareness.

4.4 Experiment 15

The experiments reported in previous chapters in this thesis (excepting perhaps Experiment 9, Chapter 3 which used an incongruent distracter letter as a critical stimulus) have measured the magnitude of awareness for relatively neutral stimuli (e.g. an outline square). Numerous replications have shown that imposing perceptual load in the relevant task significantly reduces awareness across several studies which use such neutral critical stimuli. On the other hand, Experiments 13 and 14 in this chapter have shown that awareness of one class of highly meaningful stimuli (upright faces, famous or unfamiliar) is not modulated by increases in perceptual load. However, Experiments 13 and 14 on their own only provide preliminary evidence of a general attentional bias towards the processing of faces for entry into awareness. For example, it could be argued that *any* meaningful stimulus is immune to the effects of load, and this specialisation is not confined to faces per se.

To test this possibility, I presented musical instruments (in the upright orientation only) as critical stimuli under varying conditions of perceptual load in Experiment 15. A manipulation of perceptual load identical to the previous experiments was used. If all meaningful critical stimuli reach awareness regardless of load, then similarly high levels of awareness should be seen for upright musical instruments under high perceptual load as well as low perceptual load. Alternatively, if faces represent a particularly special category of meaningful stimuli in resisting inattentional blindness, increasing perceptual load in the current experiment should lead to reduced levels of awareness for the musical instruments compared to low load. Awareness should be reduced by load to a similar extent as previous experiments with this method and neutral critical stimuli (e.g. Experiment 1, Chapter 2).

Method

Participants Twenty-two undergraduate students from University College London and 15 undergraduate students from the University of Oregon participated in this experiment. All were aged between 18 and 25 and reported normal or corrected-to-normal vision.

Apparatus and stimuli Apparatus was as for Experiments 13 and 14 except that the program was run and presented on a laptop with a 15" display (1024 x 768 resolution). Stimuli were as for previous experiments in this chapter, with the exception of the critical stimuli. With the current test of meaningful stimulus category, critical stimuli were musical instruments (either a violin or a euphonium, counterbalanced between participants). The instruments measuring 2° in height and 1.55° in width were of identical dimensions to the faces used in Experiments 13 and 14. The musical instruments were presented at an orientation of 45° so that the distance from the centre of the target-cross to the nearest edge of the instruments remained the same at all locations of presentation (in each of the four quadrants). The mask was as for Experiment 13 and 14.

Procedure The procedure was as for the previous experiments, with the exclusion of the face-familiarity checks at the end of the experiment. Both instruments (violin and euphonium) were presented in the two-alternative forced-choice recognition test following the questioning of awareness. All other aspects of the procedure were as for previous experiments in this chapter.

Results and discussion

Figure 4.13 presents the percentage of reported awareness as a function of perceptual load (low load vs. high load) with comparable date from Experiments 13 and 14 (inverted faces only). Excluded from this experiment were participants who failed the final control trial (2), participants who did not perform the task adequately (2), and one participants who was familiar with inattentional blindness. Remaining participants were divided between the two experimental groups, low load (16) and high load (16). All of the participants who reported awareness of the musical instrument (i.e. made a "Yes" response to the critical question) were able to describe correctly its location or its identity (violin or euphonium) as in Experiments 13 and 14.

A clear effect of perceptual load on awareness reports is seen in the results. As illustrated in Figure 4.13, fewer participants reported awareness of an unexpected musical instrument under conditions of high perceptual load (6 of 16) than low perceptual load (13 of 16), χ^2 (1, $\underline{N}$ = 32) = 6.37, p = .01. Thus, Experiment 15 demonstrates that awareness for one class of complex, meaningful, non-face stimuli (musical instruments) is susceptible to effects of perceptual load to the same extent as non-meaningful, neutral stimuli. This supports the idea that faces in particular are immune to load effects on awareness; meaningfulness by itself does not determine awareness. These findings therefore support the notion of face specificity, although it is noted that this experiment only tests class of stimuli.

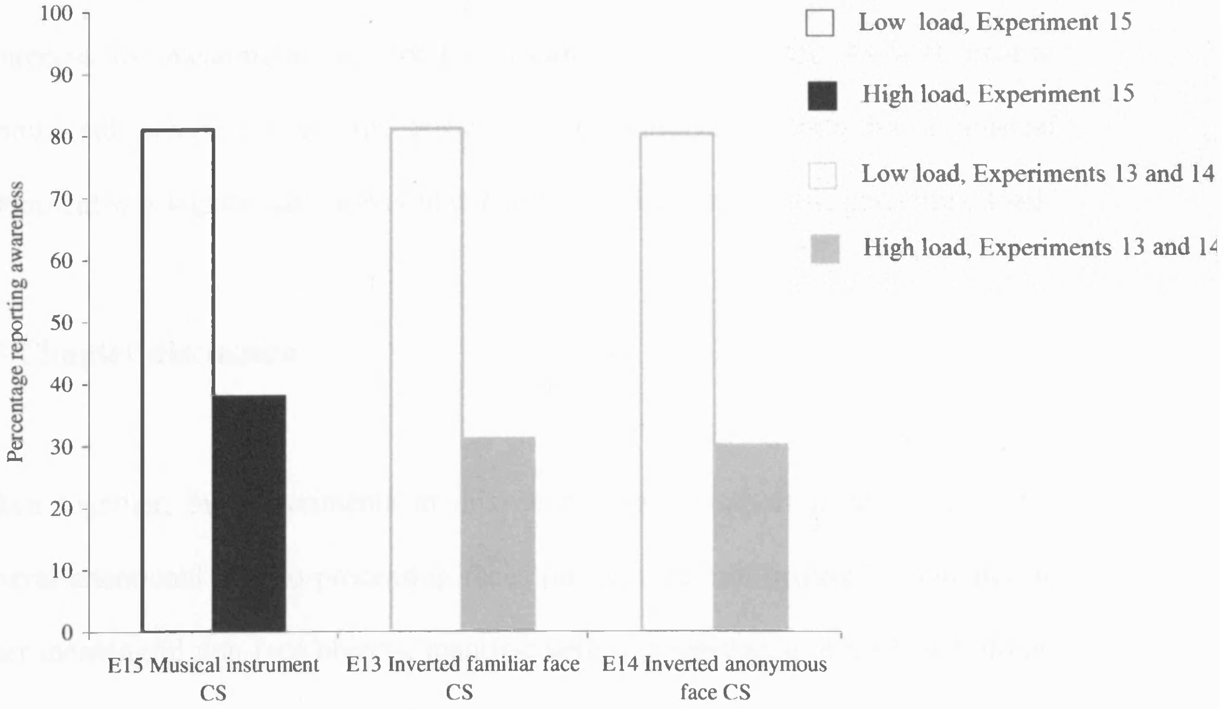

Figure 4.13 Percentage reporting awareness for an unexpected musical instrument critical stimulus as a function of perceptual load (low load vs. high load), N = 32. For comparison, data from Experiments 13 (inverted face only, N = 32) and 14 (inverted face only, N = 40) are also presented.

In support of findings in previous chapters, the extent of load modulation in Experiment 15 is of similar magnitude to those seen in other experiments using the same method of imposing perceptual load. Overall levels of awareness in the present experiment (59% overall) is greater than that reported in Experiment 1 (Chapter 2) with an outline square shape (33%). However, this may either be due to the meaningfulness or to lower level visual differences, for example, the greater size (area) covered by the musical instruments in contrast to the outline square shapes. This finding of greater awareness with critical stimuli of larger sizes is also consistent with results from Mack and Rock (1998) outlined in the general introduction (Chapter 1).

In conclusion, Experiment 15 shows that perceptual load determines awareness for meaningful but not biologically-relevant stimuli. As with neutral stimuli and inverted faces, the frequency of awareness reports for a musical instrument was significantly lower in conditions of high versus low perceptual load.

4.5 Chapter discussion

Taken together, the experiments in this chapter lend support to the notion of a general attentional bias to processing faces (upright but not inverted) compared to other meaningful non-face objects, manifest here in a resistance to the usual effects of perceptual load on awareness. The frequency of awareness reports of an upright face (whether familiar or anonymous) was unaffected by increases in perceptual load, whereas significantly fewer participants reported awareness for an inverted face or a meaningful non-face object when load was raised from low load to high load.

The significant effects of perceptual load on awareness of inverted faces (either familiar or unfamiliar) rules out the possibility that some intrinsic low-level visual feature of upright faces was responsible for their attracting attention and reaching awareness. In addition, the generalisation of this finding across both familiar and unfamiliar faces indicates that familiarity with a face is not responsible for the uniquely high awareness for upright faces under conditions of high perceptual load. Furthermore, because the experiments in this chapter have directly varied the availability of attention whilst holding expectation constant across all conditions, the current results are able to delineate the precise role of attention (rather than expectation) in determining awareness of faces.

There are three possible mechanisms which could account for the pattern of results described in this chapter. Firstly, faces might be processed automatically, independent of volition and irrespective of demands placed on the perceptual system. This account is consistent with the notion of a specialised module dedicated to the processing of faces, since mandatory processing (i.e. independence from attention) is generally held to be a key feature of "modularity" defined by Fodor (1983). Such an explanation would predict that upright faces (but not inverted faces of other meaningful non-face objects) would reach awareness regardless of the load demands in a relevant task, as reported in these experiments.

A second explanation posits that although face processing may depend on availability of the general capacity of resources which also governs non-face processing, faces possess the unique ability to capture attention away from competing non-face stimuli by virtue of their unusually high biological salience. Thus, the appearance of an unexpected face in the present experiments may have captured attention away from the relevant cross-task, affording sufficient processing to reach awareness. This is in line with other findings of attentional capture by faces in the presence of competing non-face stimuli (e.g. Ro et al, 2001; Shelley-Tremblay & Mack, 1999; Mack et al, 2002).

Finally, consistently high levels of awareness for upright faces across varying levels of perceptual load could be understood if separate processing mechanisms are assumed for faces versus non-faces. Such a view would propose one general capacity-limited system for the processing of non-face stimuli, and another independent capacity-limited pool of resources exclusively dedicated to the processing of faces. Exhaustion of the general capacity (e.g. by increasing load) would result in reduced awareness for irrelevant non-face stimuli (including inverted faces and meaningful non-face objects) but would not influence awareness for faces. By contrast, selectively taxing the separate face-specific system should have not influence on the processing of non-face stimuli but should reduce processing, and thus awareness, of faces. This idea receives support from Jenkins et al's (2003) study which finds that, unlike non-face distracters (where interference is reduced by the addition of any other stimulus), interference effects produced by face distracters are diluted only by the presence of another face stimulus (but not an inverted or phase-shifted face). In a similar manner, Austen and Enns (2003) found that the change detection advantage for faces diminished as the number of target-faces in a display increased. These studies imply that, unlike non-face stimuli, the processing of faces is influenced (and reduced) specifically and exclusively by the presence of other faces. Future experiments may address this issue by comparing the effects of face load and non-face load on face awareness.

Findings in this chapter are consistent with all of these accounts and the methodology used in the current experiments is unable to distinguish between them. However, the specific resistance of upright faces (but not inverted faces or meaningful non-face objects) to effects of load on awareness lends support to the notion that faces hold a special, privileged status within attention, such that they are not susceptible to the usual effects of perceptual load. Results in this chapter therefore support findings reported by Jenkins et al (2002) and Lavie et al (2003) of persisting distracter and priming effects from irrelevant familiar faces under conditions of high perceptual load. These results go further in demonstrating that perceptual load also fails to influence conscious awareness of irrelevant faces, even if they are unfamiliar.

Chapter 5

Development of awareness: Effects of age and perceptual load on inattentional blindness

5.1 Introduction

An extensive body of developmental research suggests that processes of selective attention and attentional control improve with age over childhood. Empirical evidence supporting the development of attention has utilised a range of different experimental paradigms which typically use indirect RT measures to assess the magnitude of irrelevant processing across different age groups. This research has revealed much about age-related differences in the influence of attention on information processing (e.g. highlighting the improvement of cognitive processing speed or inhibitory control over childhood). As yet however, this research has not provided information about age-related changes in the effects of attention on visual awareness. This chapter seeks to explore the extent of reported awareness for a surprising, task-irrelevant stimulus across adults compared with different age groups of children within the capacity-based framework of perceptual load.

Overview

Converging lines of research indicate age-related improvements in selective attention. I begin with a brief review of evidence from studies of spatial cuing and visual search which illustrate developmental deficits in early perceptual selection. Next I review evidence from Stroop and response competition studies of childhood deficits and age-related improvements in the later response-stage selection processes as well as early, perceptual selection. I then discuss the recent adoption of the perceptual load model to account for the development of attention in terms of a gradual expansion in attentional capacity throughout childhood. This review will demonstrate the importance of examining the development of awareness as well as the effects of perceptual load on awareness over childhood.

Perceptual (early) selection deficits in children

Age-related improvements in the efficiency of early, perceptual selection have been well-documented. Here I shall review evidence from studies of spatial cuing and visual search that indicate specific inefficiencies in this early perceptual filtering mechanism.

Evidence from spatial attention studies

Research into spatial attention finds some evidence of mature spatial cuing effects from an early age: Children appear able to orient their attention successfully and efficiently on the basis of meaningful valid cues. However, children incur greater RT costs compared to adults when such cues are invalid.

Several studies examining the orienting of visual attention towards an abrupt onset cue (exogenous cues, e.g. Miller, 1989; Theeuwes, 1990) have revealed that children and adults derive similar benefits from valid exogenous pre-cues as measured by RTs to targets. For example, Brodeur and Enns (1997) presented children aged 6, 8 and 10 years and adults with either peripheral or central predictive cues during a visual discrimination task. No age-related differences were found across the three age groups of children in the extent to which they oriented to either peripheral or central cues: Children and adults demonstrated equivalent facilitation of attentional deployment and resulting speeding of target RTs when abrupt onset cues were presented. However, cuing effects were abolished in children by a 400 ms cue-to-target interval, whereas adults continued to benefit from cues even after an 800 ms interval. In addition, all groups of children together showed larger overall cuing effects than adults when composite scores of costs and benefits of spatial cuing were examined. This suggests that children suffered greater costs than adults from invalid spatial cues.

Similarly, using a typical Posner-type cuing paradigm (e.g. Posner 1980; Posner & Cohen, 1984), Enns and Brodeur (1989) found that speeding of target RTs following valid cues was equal across all age groups when testing 6 and 8 year-old children and adults in a discrimination task with predictive and non-predictive exogenous peripheral cues. By contrast, the RT cost associated with invalid cues was significantly larger for younger children than for adults.

Other spatial cuing studies have found age-related changes in both costs *and* benefits of spatial cuing. Pearson and Lane (1990) presented peripheral and central cues (valid, neutral and invalid) to 8, 11, and 21 year-olds performing a letter-discrimination task. They found that older participants were faster than younger participants across all cuing conditions, and the effects of cuing decreased with age: Children demonstrated slightly smaller facilitation of target detection than adults and considerably greater slowing following invalid cues. Similarly, Nichols, Townsend and Wulfeck (1995) reported age-related changes across 7-12 year-olds in the attentional costs and benefits to a detection task when peripheral and central cues preceded target displays.

A similar pattern of orienting has been reported for exogenous spatial cues within more complex attended tasks. Brodeur and Boden (2000) for example, found that children aged 6 to 8 years demonstrated larger orienting effects than adults in a shape discrimination task involving considerable spatial uncertainty (the task involved multiple possible locations of the target). Costs incurred on invalid cue trials were considerably greater for children than adults. Moreover, varying the cue predictability showed that, although adults were able to moderate their orienting depending on the usefulness of a spatial cue (measured by % valid cues), children oriented their attentional resources following abrupt visual cues even when those cues were not beneficial to performance. Brodeur and Boden (2001) similarly found that young children, aged 6 and 8 years, were unable to control the extent of their orienting in accordance with the varying predictability of a spatial cue whereas adults showed reduced orienting responses as cues became less predictive (lower % valid trials).

In addition, Pearson and Lane (1991) found children to be less successful than adults at consciously orienting their attention towards a particular spatial location following explicit instruction in a dichotic listening study. Children aged 8 years took 3.5 seconds to switch from monitoring a list of items in one ear to the other, whereas older children (11 years) and adults only required 2.5 seconds to complete the switch.

In summary, although there is some evidence of children demonstrating adult-like facilitation of target RTs following valid cues, attention-orienting effects are generally larger in children than adults, and children consistently suffer greater costs to RTs from invalid cues. This greater cost is thought to reflect an inability to disengage attention from the invalidly cued location and then redirect attention to the appropriate location. Moreover, children also fail to modulate their orienting responses in the face of varying cue predictability suggesting that control processes which govern orienting develop over childhood.

Evidence from visual search studies

Although children typically show normal, adult-level performance in feature search tasks, much evidence demonstrates markedly worse performance in children (vs. adults) during conjunction searches (e.g. Kaye & Ruskin, 1990; Brodeur, Trick & Enns, 1997; Thompson & Massaro, 1989). Visual search studies therefore also support the suggestion that early perceptual selection stages of visual filtering develop over childhood. These findings imply that the efficiency of perceptual selection (and gating of irrelevant information) is generally poorer in children than adults at early stages in the processing stream, but such selection shows improvements with age.

Studies which combine attentional tasks with psychophysiological measures of processing have provided complementary evidence of age-related changes in attentional abilities. For example, Wijker (1991) used a colour selection task (Wijers, Mulder, Okita, Mulder & Scheffers, 1989b) to isolate electrophysiological responses to attended versus unattended stimuli in 5-year olds and adults. Participants lifted their right index fingers to stimuli in a specific (attended) colour if they belonged to a pre-memorised set of target stimuli (no responses were made to non-target stimuli). Results showed the usual target detection enhancement of the ERP P3b for attended targets versus unattended non-targets at all age groups. However, target detection effects on P3b ERPs were also evident for unattended stimuli (albeit to a lesser extent than for attended stimuli) in younger age groups of children but not for older children or adults. This finding suggests that the children in this study were unable to adequately screen out the irrelevant information as adults were able to do, and demonstrated greater processing of irrelevant (competing) non-targets as a result.

These findings therefore support the notion that poor filtering in children can be attributed to inefficient selection at the early (input) stages of information processing. In line with this suggestion, Shepp and colleagues (e.g. Shepp & Schwartz, 1976; Barrett & Shepp, 1988; Shepp & Barrett, 1991) found that Garner interference effects (where target responses are slowed by mere variation within irrelevant streams of information regardless of identity) were relatively large for younger children aged 4-5, 6-7 and 10-11 years (compared with adults), and the extent of interference effects gradually decreased with age. In these studies, younger children showed significantly larger interference effects from irrelevant dimensions than older children and adults when target and distracter dimensions were conjoined in one stimulus, and therefore not easily separable. This suggests that the ability to gate irrelevant information (that may be contained within relevant items) from early processing improves over childhood.

Response-stage (late) selection deficits in children

The studies reviewed above have suggested that a child's attentional filter operates comparatively inefficiently at early stages of information processing. Another line of developmental studies provides evidence that, in addition to developmental deficits in early perceptual selection, selection at later response-stages also operates inefficiently in children relative to adults, and develops across childhood in a comparable manner.

Evidence from Stroop studies

Early studies have shown that children are more susceptible to Stroop-like (Stroop, 1935) interference effects than adults. For example, in a life-span study utilising the standard colour-word Stroop task, Cormalli, Wapner and Werner, (1962; see also MacLeod, 1991) reported that interference effects from incongruent words on colour-naming latencies were significantly greater for children than adults. Furthermore, such interference effects were found to decrease as age increased over childhood and into adulthood (age range 7 – 80 years).

This age-related improvement in filtering over childhood has been shown in other studies using Stroop-like tasks (e.g. Posnansky & Raynor, 1977; Guttentag & Haith, 1978). In these studies, younger children took longer than older children or adults to name pictures or line-drawings when a word (vs. non-word or letter string) was superimposed (printed over) the target image. Because the distracting dimension within Stroop studies is associated with an incompatible response and therefore demands response suppression in addition to perceptual selection of the relevant dimension, these findings provide preliminary evidence that the response stage of attention is relatively immature in children, but improves with age over childhood.

If efficient perceptual filtering relies on the separability of relevant from irrelevant dimensions, it is perhaps not surprising that younger children were unable to perform such selection in the Stroop studies reported so far, where targets (e.g. ink colour) and distracters (e.g. colour words) typically occupy the same spatial location.

However, this developmental trend for response-stage selection was also replicated when relevant and irrelevant dimensions were spatially separated in Stroop-like tasks. For example, similar age trends were found when non-target pictures (Day & Stone, 1980; Well, Lorch & Anderson, 1980) or printed words (Guttentag & Ornstein, 1990) interfered with a spatially-separated picture-naming task. Such findings from spatially-separated Stroop paradigms provide particularly strong evidence in support of the development of the response selection component, as perceptual selection is easier (location-based) in these tasks.

Moreover, greater Stroop interference effects on RTs have also been shown for younger age groups when the two dimensions within the Stroop-like task are separated by modality. For example, Hanauer and Brooks (2003) tested three age groups of children spanning 4 to 11 years and found a developmental trend for decreasing Stroop effects with increasing age when an auditory distracter (word) accompanied a visual target (colour). RTs for the identification of a target colour patch decreased significantly with age in the presence of an auditorily-presented (spoken) colour word (versus a spoken non-colour word).

Evidence from response competition studies

Evidence that children are less able than adults to filter out distracters, even when targets and distracters are spatially separated, has also been obtained within response competition tasks (e.g. the Eriksen flanker task). In one study by Enns & Akhtar (1988), participants aged 4, 5, 7, and 20 years were asked to make speeded responses to central targets which were accompanied by distracters on either side. In order to allow the measurement and separation of perceptual conflict from response competition, distracters could be response-neutral (but similar in visual complexity to the target), response-congruent, or response-incongruent. Although all types of distracters exerted significant interference effects, only interference from neutral distracters (indicating perceptual interference) was shown to be significantly greater in younger age groups than adults, and demonstrated a large reduction in magnitude with age. Therefore, in contrast to other findings, there appeared to be no developmental trend in the magnitude of response-stage interference in this study.

Other studies have found developmental trends in filtering distracters of any level of congruence (neutral, congruent or incongruent). Ridderinkhoff, van der Molen, Band and Bashore (1997) showed that RT costs associated with variations in the congruency of distracters in Eriksen-type flanker tasks decreased with age when examining children aged 5-7 years, 8-9 years and 10-12 years, and adults. Enns and Girgus (1985) found the same pattern of results with children aged 5 to 10 years compared to adults. In these experiments, participants responded to the direction of a central arrow flanked by congruent or incongruent direction-pointing arrows (e.g. ←←←←← versus ←←→←←). Results from both studies showed that children demonstrated greater interference effects than adults, with the youngest children showing the most pronounced facilitation and inhibition effects. Moreover, congruency effects from flanking arrows decreased with age, indicating that improvements in response-selection stages must in part underlie the age-related changes in visual selective attention.

Ridderinkhof and van der Molen (1995) measured ERPs across three age groups of children (from 5 to 12 years) and adults while participants performed the arrow-target response competition task. Results showed that, across all age groups, incongruent distracters produced longer RTs than congruent or neutral distracters, and were also associated with delays in LRP onsets (Lateralised Readiness Potentials measured over motor cortex sites contralateral to the moving limb which provide a reliable and highly sensitive index of preferential motor preparation according to Kutas & Donchin, 1977; Rohrbaugh & Gaillard, 1983) and P3b latencies (generally regarded as reflecting the completion of the process of evaluating the stimulus significance of attended targets, cf. Kutas, McCarthy & Donchin, 1977; McCarthy & Donchin, 1981; Magliero, Bashore, Coles & Donchin, 1984; Coles, Gratton, Bashore, Eriksen & Donchin, 1985). Importantly, the costs to RTs and ERP latencies associated with incongruent distracters subsided with increasing age: Younger children suffered greater RT costs from incompatible distracters than adults. By contrast however, no age-related changes were observed in interference effects on the P3b peak latency, indicating an equal sensitivity in children and adults to the perceptual competition induced when a central target is surrounded by response-incompatible flankers. The dissociation between ERPs sensitive to age-related changes versus those signalling stability across age groups in this study suggests that the locus of developmental change lies primarily in later response competition stages of attention.

Developmental deficits in early selection and late selection

The review so far has demonstrated evidence that supports the development of both early and late selection components of attention across childhood. In a recent study, Huang-Pollock, Carr and Nigg (2002) found evidence of development in both early and late selection components within one task by using the framework of perceptual load. Huang-Pollock et al (2002) manipulated load in a relevant task by varying visual search set size, and measured interference effects from distracters (compatible, incompatible or neutral) in children aged 7-8 years, 9-10 years and 11-12 years, comparing each of them to adults. The results revealed larger distracter effects in children than adults under low perceptual load, with children exhibiting higher error rates and slower RTs overall than adults. This indicates a developmental deficit in early selection, in line with previous studies. Results also showed that children demonstrated greater compatibility effects (incongruent minus congruent trials) than adults. This is consistent with findings from previous studies (e.g. Enns & Girgus, 1985) and supports the notion that late response selection mechanisms mature relatively slowly. In addition, Huang-Pollock et al (2002) found that lower levels of perceptual load (smaller set sizes) were sufficient to eliminate interference effects in children compared to adults. This result suggests that the capacity of attention in children aged 7 to 12 years was exhausted by smaller increases in relevant-task perceptual demands (vs. the increase needed to exhaust capacity in adults), in line with the prevalent notion that information processing capacity develops from childhood to adulthood. Importantly, children in Huang-Pollock et al's (2002) study demonstrated equally efficient selection to adults at higher set sizes. For example, a relevant set size of six eliminated the effect of distracters on target RTs equally for both adults and children. Thus, accounts suggesting that children have an overall deficit in ability to inhibit distracters may be dismissed.

Huang-Pollock et al's (2002) study shows that the developmental deficit in late selection is confined to situations of low perceptual load. This highlights an important implication of children's reduced information processing capacity for performance in attention tasks, namely that lower levels of load will exceed children's capacity. Thus, when items are separated as in the flanker task, children demonstrate efficient early selection under conditions of high perceptual load. This suggests that developmental deficits in selection illustrated in earlier studies may reflect greater visual integration of relevant and irrelevant dimensions at younger ages (e.g. when targets and distracters are not spatially separated).

The current study

All of the previous studies have shown that early and late selection components of attention develop with age over childhood as indexed by distracter effects on target RTs. Huang-Pollock et al (2002) further clarify that late selection deficits are only found with low perceptual load whereas efficient early selection can be found when targets and distracters are spatially separate and the relevant task involves even a small increase in perceptual load. However, as I discuss in the general introduction in Chapter 1, it is impossible to infer anything about conscious awareness from RT effects. Further, no study has yet addressed the issue of the development of awareness over childhood.

The purpose of the current chapter was therefore to examine the effects of attention on awareness in children of different ages. Specifically, I examine whether awareness of a task-irrelevant stimulus that is spatially separated from the target critically depends on the level of load on attention in the relevant task for children as it does for adults (e.g. Chapter 2). Secondly, I investigate whether the effects of perceptual load on awareness develop over childhood as in the case of distracter interference effects on RTs.

If attention determines awareness in children as it does in adults (Chapters 2 and 3), and if distracter effects on RTs in the flanker paradigm reflect conscious perception, then on the basis of Huang-Pollock et al's (2002) results, one might predict that lower levels of load would be required to produce inattentional blindness for younger children than older children and adults. In addition, overall rates of inattentional blindness should decrease with age. This prediction is also in line with developmental theories of cognition which propose that the processes involved in selective attention as well as the capacity and the speed[5] of information processing become increasingly efficient throughout early development and into maturity. On the other hand, if developmental deficits in late selection stem from a reduced ability to focus attention on task-relevant stimuli, then an alternative, perhaps counterintuitive hypothesis might predict greater rates of awareness (of task-irrelevant stimuli) in children than adults under very low levels of load.

In the present experiments, awareness for a neutral stimulus was measured across different age groups of children and adults using the standard cross-task inattentional blindness procedure incorporating a manipulation of perceptual load (Chapter 3, Experiments 6 and 7). In Experiment 16, cross-targets were always presented at fixation and awareness for a peripheral critical stimulus was measured. In Experiment 17, cross-targets were presented in the periphery, allowing awareness to be contrasted for critical stimuli appearing in the periphery versus at fixation. Perceptual load was varied in both experiments by increasing the difficulty of the line-length judgment to be performed on each cross-target.

5.2 Experiment 16

In Experiment 16, I compared levels of awareness for an unexpected, peripheral square shape across five different age groups of participants: 7-8 year-olds, 9-10 year-olds, 11-12 year-olds, 13-14 year-olds and adults (age range 18-56 years). The cross task was used to avoid differences in letter-search performance due to variations in letter-reading efficiency between children in younger age groups. Each

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[5] It has been suggested by Kail (1991) and Perfetti (1985) that speed of processing may interact with or partially underlie developmental differences in capacity. I shall return to this issue in the chapter discussion.

participant judged which arm was longer on a centrally-presented cross target in each of six trials. The manipulation of load was as in Chapter 2 (Experiment 4) and Chapter 3 (Experiments 6 and 7). The low load condition was identical to the low load of Chapter 3, with an obvious difference in line-length between the two cross-arms. For a higher level of load, a smaller line-length difference was used. Note however, that the higher load condition in the current experiment entailed a less difficult line length comparison than the high load of experiments in Chapter 3. I therefore refer to this condition as an "intermediate" level of perceptual load. Because previous load experiments (Lavie & Cox, 1997) have found no difference in the extent of distracter processing between low and intermediate levels of load (at varied set sizes of 1, 2 of 4) in adults, I expected awareness to be equivalent at the two levels of load for the adult group of participants. However, as Huang-Pollock et al (2002) found intermediate levels of load (e.g. set sizes 2 and 4) to reduce distracter interference effects in children, I expected children to demonstrate lower rates of awareness whilst performing tasks of intermediate versus low perceptual load.

Method

Participants Two-hundred-and-three participants from the Science Museum, London volunteered to take part in this experiment. After exclusions (see Results section), experimental age groups consisted of the following participants (**N**, mean age in years and months, **SD**): 7-8 year-olds (**40**, 7 yrs 11 m; **5.5 m**), 9-10 year-olds (**44**, 9 yrs 11 m; **6.7 m**), 11-12 year-olds (**40**, 12 yrs 0 m; **7.4 m**), 13-14 year-olds (**32**, 14 yrs 0 m; **7.0 m**), and adults (for whom months were not counted; **32**, 30 yrs; **10 yrs**). All participants reported normal or corrected-to-normal vision.

Stimuli and Apparatus Target displays consisted of a black cross target centred at fixation upon a white background. The longer cross-arm subtended 3.9° whilst the shorter arm subtended either 0.7° (low load condition) or 2.0° (intermediate load condition). A black outline square with sides subtending 0.3° was also presented in critical displays. This critical stimulus appeared in one of four peripheral locations (counterbalanced between participants) all equidistant from fixation (the centre of the cross) at 3.35° eccentricity, and positioned exactly half-way between two neighbouring cross-arms. The fixation and mask stimulus displays were as for Experiment 1 (Chapter 2).

Procedure The procedure was as for Experiment 6 (Chapter 3) except that cross-targets always appeared at fixation.

Results and Discussion

Excluded were: participants who failed the visual control trial (11) or the critical trial target response (1); participants who failed to perform the task (1); and participants who gave uninterpretable awareness responses (3). Remaining participants were divided among the experimental groups thus: 7-8 years, low load (20) and intermediate load (20); 9-10 years, low load (24) and intermediate load (20); 11-12 years, low load (20) and intermediate load (20); 13-14 years, low load (16) and intermediate load (16); and adults, low load (16) and intermediate load (16).

All participants included in the analysis performed the task adequately, with four or more correct line-length judgments entered. All of the participants who reported awareness of the critical stimulus (i.e. made a "Yes" response to the critical question) were able to describe correctly its location and at least two of its major features (shape, size or colour).

Figure 5.1 presents the percentage of reported awareness across participants as a function of age (7-8, 9-10, 11-12, 13-14, adults) and perceptual load (low load, intermediate load). In order to analyse this 2 x 5 data, a multi-way frequency analysis using log linear modelling was used. This analysis allows the examination of potential interactions in such data.

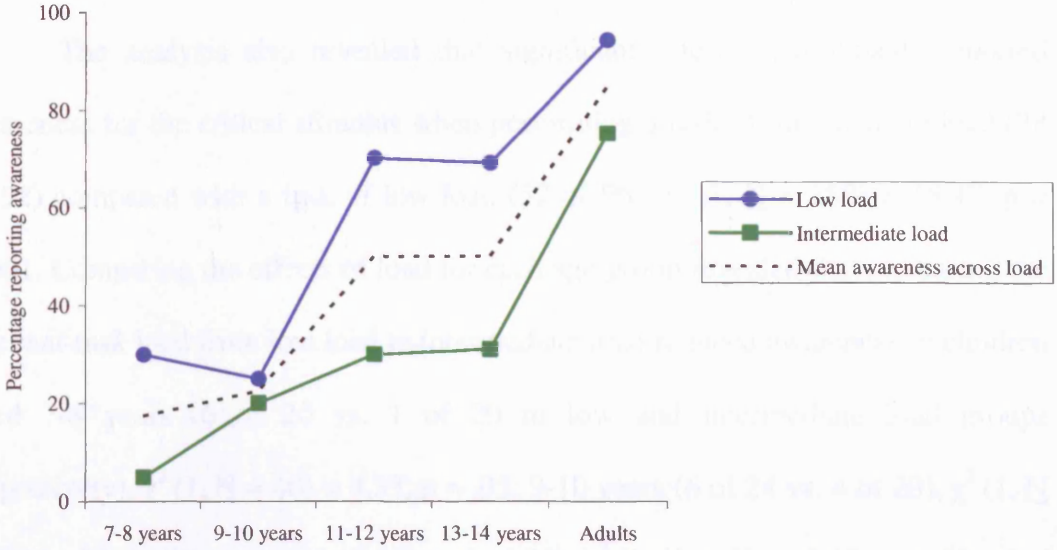

Figure 5.1 Percentage of reported awareness as a function of perceptual load (low vs. intermediate) and age group, N = 188.

The analysis revealed a significant increase in rate of awareness reports over age, χ^2 (4, N = 188) = 49.14, p = .0001: The rates of awareness reports increased with age across participants from 7 year-olds to adults (see Figure 5.1, mean awareness across load).

Specific χ^2 comparisons of rates of awareness between the different age groups revealed similar levels of awareness at the two youngest age groups, 7-8 year-olds (7 of 40) versus 9-10 year-olds (10 of 44), χ^2 (1, N = 84) = .36. However, children aged 9-10 years gave significantly lower proportions of aware reports than children aged 11-12 years (20 of 40), χ^2 (1, N = 84) = 6.79, p = .009. Children aged 11-12 years showed the same rates of awareness to children aged 13-14 years (16 of 32), χ^2 (1, N = 72) = 0. However, children of 13-14 years gave significantly fewer reports of awareness than adults (27 of 32), χ^2 (1, N = 64) = 8.58, p = .003. Therefore, the pattern in these data shows awareness developing with age in a stepwise manner at ages 7-10 and 11-14.

The analysis also revealed that significantly fewer participants reported awareness for the critical stimulus when performing a task of intermediate load (28 of 92) compared with a task of low load (52 of 96), χ^2 (1, N = 188) = 15.47, p = .0001. Comparing the effects of load for each age group revealed that increasing the relevant-task load from low load to intermediate load reduced awareness in children aged 7-8 years (6 of 20 vs. 1 of 20 in low and intermediate load groups respectively), χ^2 (1, N = 40) = 4.33, p = .05; 9-10 years (6 of 24 vs. 4 of 20), χ^2 (1, N = 44) = .02; 11-12 years (14 of 20 vs. 6 of 20), χ^2 (1, N = 40) = 6.40, p = .01); and 13-14 years (11 of 16 vs. 5 of 16), χ^2 (1, N = 32) = 4.5, p = .04. Although the effect of load did not reach significance for participants aged 9-10 years, this is likely to be due to the low level of awareness in low load, producing a floor effect which limited any further reduction.

Although adults showed some decrease in awareness from low load (15 of 16) to intermediate load (12 of 16), this effect was not significant χ^2 (1, N = 32) = 2.1, p = .14. Notice also that, by virtue of the higher overall levels of awareness in adults, the trend for the load effect on awareness in adults was proportionally far smaller (non-significant 20% reduction from low to intermediate load) than for children (e.g. an 83% in 7-8 year olds).

A 2 x 5 multi-way frequency analysis of load (low, intermediate) by age (7-8, 9-10, 11-12, 13-14, adult) did not reveal a significant interaction, χ^2 (4, N = 188) = 3.08, p = .54. However, inspection of Figure 5.1 suggests that the effect of load was smaller for adults than for children aged 11-12 and 13-14. Further, it is possible that the restricted load effect in the younger age groups of children (7-8 and 9-10 years) was due to a floor effect from the already low baseline level of awareness under low perceptual load. Thus, data for children aged 11-12, 13-14 and adults were entered into a multi-way frequency analysis to examine whether effects of load were different for these age groups, although this also failed to reveal a significant interaction of load by age, χ^2 (2, N = 104) = .01. When the two age groups of children were combined (11-12 and 13-14) and compared with adults however, the interaction of load (low, intermediate) by age (11-14, adults) reached significance, χ^2 (1, N = 104) = 4.57, p = .027. This suggests that the previous non-significant results were due to lack of statistical power. This finding indicates that increasing perceptual load in the relevant task reduced awareness to differing extents depending upon the age of the participant. This effect is illustrated in Figure 5.1 which shows a greater reduction in awareness by perceptual load in children compared with adults.

In summary, Experiment 16 shows that overall levels of awareness increase with age in an inattentional blindness study. Importantly, increasing the relevant task load to an intermediate level can reduce awareness for an unexpected stimulus in children. In addition, the degree to which awareness is diminished by load has been shown to depend upon the age of the participant: Younger children (aged 7-

10) already show a low level of awareness at low load and these therefore did not show much modulation of awareness by any further increase in load. The older children (aged 11-14) showed greater modulation of awareness by increased load compared with adults. For the adults, the effects of imposing an intermediate load were far smaller than imposing a higher level of load demonstrated in Experiment 4 (Chapter 2). For example, awareness was reduced by (20%) in the current experiment compared to a reduction of (49%) in Experiment 4 (Chapter 2). These results are in line with findings that lower levels of load are required to modulate distracter processing in children than in adults, as established by Huang-Pollock et al (2002) using RT effects.

In conclusion, Experiment 16 shows decreased rates of awareness in younger age groups. The data also suggest that this capacity develops with age because the load effect appeared to be larger for children than adults. However, because this was a weaker effect and because the overall interaction of load by age did not reach significance, the data are only suggestive of capacity development at this point.

5.3 Experiment 17

The aims of Experiment 17 were firstly to replicate the findings of Experiment 16 with a task already shown to demonstrate effects of load on awareness in adult participants, and secondly to ask whether awareness for stimuli at fixation is influenced by perceptual load and effects of age in the same way as awareness for peripheral stimuli. For these purposes, Experiment 17 compared awareness across adults and different age groups of children (7-8, 9-10, 11-12, 13-14, adults) when the peripheral cross-task of Experiment 6 (Chapter 3) was performed. Thus, participants in the current experiment made line-length judgments on cross-targets which appeared unpredictably either in an upper-left position or a lower-right position. Critical stimuli were presented in the periphery (directly above or directly below fixation) in Experiment 17A and at fixation in Experiment 17B.

5.3.1 Experiment 17A

Method

Participants Two-hundred-and-ten visitors to the Science Museum, London took part in this experiment. After exclusions (see Results section), participants (**N**, mean age in years and months, **SD**) were divided between the age groups thus: 7-8 year-olds (**40**, 8 yrs 0 m; **6.7 m**), 9-10 year-olds (**44**, 9 yrs 11 m; **7.0 m**), 11-12 year-olds (**40**, 11 yrs 11 m; **7.1 m**), 13-14 year-olds (**36**, 14 yrs 0 m; **7.0 m**), and adults (for whom months were not recorded; **32**, 36 yrs; **11 yrs**). All participants reported normal or corrected-to-normal vision.

Stimuli, Apparatus, Procedure and Design Stimuli and apparatus were identical to those in Experiment 6 (Chapter 3), as were procedure and design. Critical stimuli appeared in the periphery on critical trials in Experiment 17A.

Results and Discussion

Excluded were: participants who failed the visual control trial (7), the main target task (2), or the critical trial target response (2); participants who gave uninterpretable awareness responses (2); participants who were not naïve to the experiment (3); and participants who could not understand instructions (2).

Remaining participants were divided among the experimental groups in the following manner: 7-8 years, low load (20) and intermediate load (20); 9-10 years, low load (24) and intermediate load (20); 11-12 years, low load (20) and intermediate load (20); 13-14 years, low load (16) and intermediate load (20); and adults, low load (16) and intermediate load (16).

Awareness results: peripheral critical stimuli

Figure 5.2 presents the percentage of reported awareness for a peripheral critical stimulus across participants as a function of age and perceptual load (low load vs. intermediate load). All of the participants who reported awareness of the critical stimulus (i.e. made a "Yes" response to the critical question) were able to describe correctly its location and at least two of its major features (shape, size or colour).

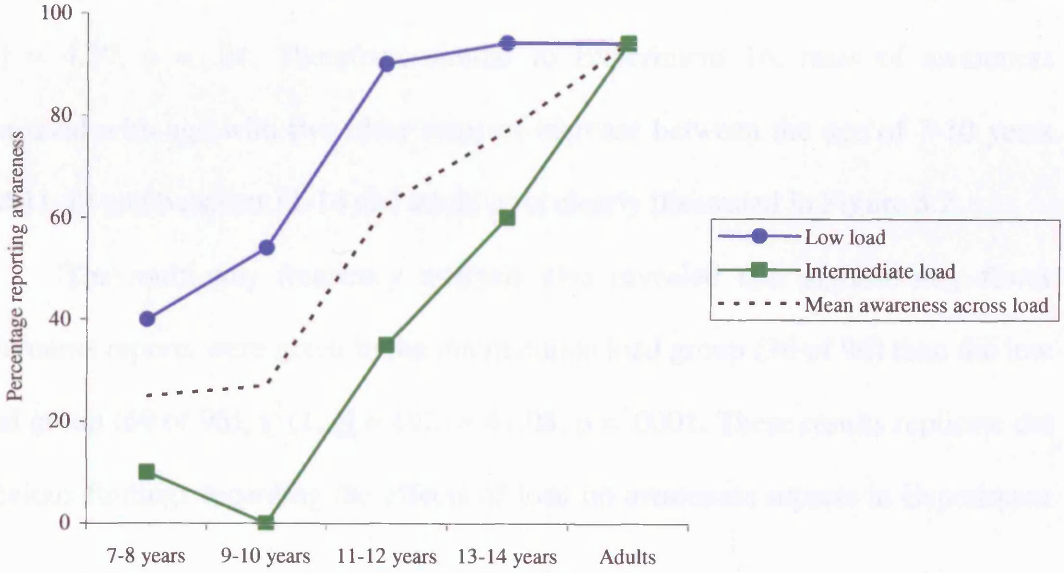

Figure 5.2 Percentage of reported awareness of a peripheral critical stimulus across age groups as a function of perceptual load (low load vs. intermediate load), N = 192.

A multi-way frequency analysis using log linear modelling revealed that rates of awareness reports significantly increased with age across participants aged 7-8 years to adults, χ^2 (4, N = 192) = 76.40, p = .0001. The effects of age on awareness found in Experiment 16 are therefore replicated in the current experiment where attended cross-targets were presented in the periphery.

Separate comparisons of awareness rates between different age groups revealed no difference in reported awareness between 7-8 year-olds (10 of 40) and 9-10 year olds (13 of 44), χ^2 (1, N = 84) = .22. However, rates of awareness reports increased significantly from children aged 9-10 years to 11-12 years (25 of 40), χ^2 (1, N = 84) = 9.19, p = .002, as in Experiment 16. Again, as in Experiment 16, there was no difference between the rates of awareness reports given by 11-12 year-olds and 13-14 year-olds (27 of 36), χ^2 (1, N = 76) = 1.37, although children aged 13-14 years reported awareness significantly less often than adults (30 of 32), χ^2 (1, N = 68) = 4.39, p = .04. Therefore, similar to Experiment 16, rates of awareness increased with age with two clear steps of increase between the age of 7-10 years and 11-14 and between 11-14 and adult, as is clearly illustrated in Figure 5.2.

The multi-way frequency analysis also revealed that significantly fewer awareness reports were given in the intermediate load group (36 of 96) than the low load group (69 of 96), χ^2 (1, N = 192) = 41.08, p = .0001. These results replicate the previous findings regarding the effects of load on awareness reports in Experiment 16.

Separate χ^2 analyses showed that increasing perceptual load in the relevant task caused a significant reduction in awareness for a peripheral critical stimulus at every age group of children in Experiment 17A. Awareness reports significantly decreased from low load to intermediate load for 7-8 year-olds (8 of 20 vs. 2 of 20;

low load vs. intermediate load respectively), χ^2 (1, $\underline{N}$ = 40) = 4.8, p = .05; 9-10 year-olds, (13 of 24 vs. 0 of 20), χ^2 (1, $\underline{N}$ = 44) = 15.38, p = .0001; 11-12 year-olds olds (18 of 20 vs. 7 of 20), χ^2 (1, $\underline{N}$ = 40) = 12.91, p = .0001; and 13-14 year-olds (15 of 16 vs. 12 of 20), χ^2 (1, $\underline{N}$ = 36) = 5.4, p = .02. By contrast, there was no difference in the rates of awareness reported by adults under conditions of low load (15 of 16) versus intermediate load (15 of 16) in line with previous results with distracter effects on RTs (e.g. Experiment 1, Lavie & Cox, 1997).

A 2 x 5 multi-way frequency analysis on the interaction of load (low, intermediate) by age (7-8, 9-10, 11-12, 13-14, adult) did not reach significance, χ^2 (4, $\underline{N}$ = 192) = 7.70, p = .10. However, a multi-way frequency analysis of load (low, intermediate) by age (9-10, 11-12, 13-14, adult) excluding the 7-8 year age group (which showed smaller effects of load on awareness, likely to be due to a floor effect in awareness) revealed a significant interaction, χ^2 (3, $\underline{N}$ = 152) = 8.25, p = .04. This interaction illustrated in Figure 5.2 suggests that the effect of load on awareness became smaller as age increased.

Overall, Experiment 17A demonstrates an increase in awareness capacity with age, from 7 years old to adults. This is consistent with Experiment 16 and with the proposed theory that capacity for attention gradually increases with age. In addition, the current results show a stronger interaction pattern than the previous experiment, with the effect of load on awareness becoming significantly smaller with increases in age. This indicates that capacity for awareness expands over childhood, with capacity limits being reached sooner (with lower levels of load) and therefore reducing awareness to a greater extent for the younger age groups.

Finally, in contrast to Experiment 16 which found only a minimal effect of load on awareness in children aged 9-10, the current results confirms that awareness of 9-10 year-olds can be modulated by the level of perceptual load in the relevant task as with other age groups. It is likely that the previously small effect of load on this age group of participants was a result of their low baseline level of awareness under conditions of low load.

5.3.2 Experiment 17B

Method

Participants Two-hundred-and-three visitors to the Science Museum, London took part in this experiment. After exclusions (see Results section), participants (**N**, mean age in years and months, **SD**) were divided between the age groups thus: 7-8 year-olds (**32**, 7 yrs 11 m; **6.9 m**), 9-10 year-olds (**40**, 9 yrs 11 m; **7.0 m**), 11-12 year-olds (**48**, 12 yrs 0 m; **8.0 m**), 13-14 year-olds (**38**, 14 yrs 0 m; **7.0 m**), and adults (for whom age in months was not recorded; **32**, 34 yrs; **9 yrs**). All participants reported normal or corrected-to-normal vision.

Stimuli, Apparatus, Procedure and Design Stimuli and apparatus were identical to those in Experiment 6 (Chapter 3), as were procedure and design. Critical stimuli appeared at fixation on critical trials in Experiment 17B.

Results and Discussion

Excluded were: participants who failed the visual control trial (4), the main target task (3), or the critical trial target response (1); participants who gave uninterpretable awareness responses (4); and participants who could not understand instructions (1). Remaining participants were divided among the experimental groups in the following manner: 7-8 years, low load (16) and intermediate load

(16); 9-10 years, low load (20) and intermediate load (20); 11-12 years, low load (24) and intermediate load (24); 13-14 years, low load (20) and intermediate load (18); and adults, low load (16) and intermediate load (16).

Awareness results: fixation critical stimuli

Figure 5.3 presents the percentage of reported awareness for a critical stimulus appearing at fixation across participants as a function of age and load (low load vs. intermediate load). All of the participants who reported awareness of the critical stimulus (i.e. made a "Yes" response to the critical question) were able to describe correctly its location and at least two of its basic features (shape, size or colour).

A multi-way frequency analysis using log linear modelling revealed an increase in rates of awareness reports with age, from 7-years to adults, χ^2 (4, $\underline{N}$ = 190) = 44.50, p = .0001, (see Figure 5.3, mean awareness across load).

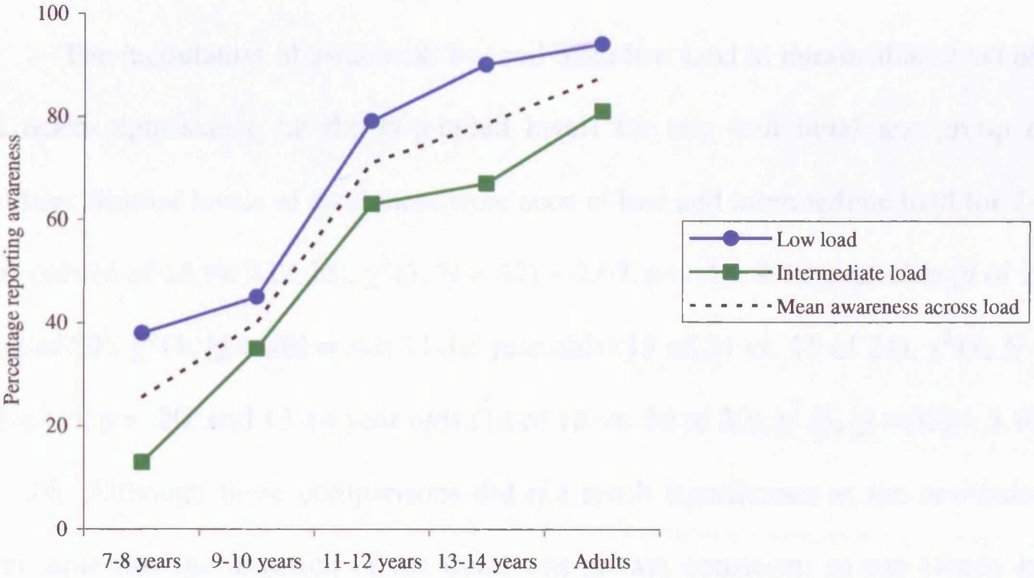

Figure 5.3 Percentage of reported awareness for a fixation critical stimulus across age groups as a function of perceptual load (low load vs. intermediate load), N = 190.

Separate χ^2 comparisons between different age groups showed that children aged 7-8 years (8 of 32) reported awareness significantly less often than children aged 9-10 years (16 of 40), χ^2 (1, N = 72) = 3.78, p = .05. Similarly, children aged 9-10 years showed a significantly smaller proportion of aware reports than 11-12 year-olds (34 of 48), χ^2 (1, N = 88) = 8.45, p = .004. However, there was no significant difference in the rates of awareness reports between children aged 11-12 years and 13-14 years (30 of 38), χ^2 (1, N = 86) = .73, and no significant difference in rates of awareness reports between 13-14 year-olds and adults (28 of 32), χ^2 (1, N = 70) = .90.

A multi-way frequency analysis revealed that significantly fewer awareness reports were given when participants performed a task of intermediate load (49 of 94) versus a task of low load (67 of 96), χ^2 (1, N = 190) = 7.74, p = .005. This replicates the effects of load found in Experiment 16 and Experiment 17A with peripheral critical stimuli.

The modulation of awareness by load from low load to intermediate load did not reach significance (at the two-tailed level) for any individual age group of children: Similar levels of awareness were seen at low and intermediate load for 7-8 year-olds (6 of 16 vs. 2 of 16), χ^2 (1, N = 32) = 2.67, p = .10; 9-10 year-olds (9 of 20 vs. 7 of 20), χ^2 (1, N = 40) = .42; 11-12 year olds (19 of 24 vs. 15 of 24), χ^2 (1, N = 48) = 1.6, p = .20; and 13-14 year olds (12 of 18 vs. 18 of 20), χ^2 (1, N = 38) = 3.10, p = .08. Although these comparisons did not reach significance at the two-tailed level, note that the direction of the trend was always consistent as can clearly be seen from Figure 5.3: More children reported awareness under low versus intermediate perceptual load.

The multi-way frequency analysis of the age (7-8, 9-10, 11-12, 13-14, adult) by load (low, intermediate) interaction was not significant in this experiment, χ^2 (4, N = 190) = 1.44, p = .84. Figure 5.3 shows similar effects of load between age groups except perhaps 7-8 years and also 13-14 years versus adults.

Overall, the trends in the current data set regarding awareness of fixation critical stimuli replicated the results reported for Experiment 17B with an equivalent stimulus in the periphery. Although some specific contrasts did not reach significance when the critical stimulus was presented at fixation, the same effects of age and load on awareness are evident. Awareness increased with age but decreased with a higher level of load.

Comparison of Experiment 17A and Experiment 17B

Overall levels of awareness in Experiment 17 appeared to be higher when critical stimuli were presented at fixation (Experiment 17B; 116 of 190) versus in the periphery (Experiment 17A; 105 of 192). Although this comparison did not reach significance when considering all age groups of participants together, χ^2 (1, N = 382) = 1.59, p = .21, an analysis contrasting effects of critical stimulus position (fixation vs. periphery) on awareness reports given only by children (112 of 158 vs. 75 of 160, i.e. without adults) revealed significantly higher rates of awareness for fixation than peripheral critical stimuli, χ^2 (1, N = 318) = 18.92, p = .0001. By contrast, there was no difference in rates of awareness reports for fixation versus peripheral critical stimuli in adults (28 of 32 vs. 30 of 32), supporting the result established and replicated throughout Experiments 6-10 (Chapter 3). A multi-way frequency analysis did not, however, reveal a significant interaction of age (7-8, 9-

10, 11-12, 13-14, adult) by position (Experiment 17A – periphery, Experiment 17B – fixation), χ^2 (4, $\underline{N}$ = 382) = 1.81, p = .77.

Experiments 17A and 17B showed similar results with respect to the effects of age on awareness: Rates of awareness clearly increased with increasing age in both experiments (Figures 5.2 and 5.3). The overall effect of load on awareness was also similar between Experiments 17A and 17B with reduced rates of awareness under higher levels of load, although this load effect did not reach significance for each age group separately in Experiment 17B. The interaction between age and load was significant in Experiment 17A but not in Experiment 17B. In Experiment 17A, the effect of imposing an intermediate load on awareness decreased with increasing age. In summary, children displayed greater awareness of unexpected stimuli appearing at fixation (vs. periphery) irrespective of the relevant task load, even though the same levels of load modulate awareness when critical stimuli appeared in the periphery.

In conclusion, Experiment 17 demonstrates that awareness increases with age when critical stimuli appear at fixation as well as in the periphery. This experiment also provides some support for the suggestion that capacity for awareness develops over childhood, with a larger effect of load seen in children than adults when critical stimuli are presented in the periphery. This interaction was not seen however, when stimuli appeared at fixation. The finding of overall greater awareness at fixation in children may be due to an inability to disengage attention from fixation. This possibility will be discussed further in the chapter discussion.

5.4 Chapter discussion

The experiments reported in this chapter have shown that visual awareness increases with age. As demonstrated clearly in each of the experiments (see Figures 5.1, 5.2 and 5.3), the number of awareness reports increased as participants' age increased from 7 years through to adult. This finding generalised across tasks with different spatial locations of targets (always at fixation in Experiment 16 vs. one of two possible peripheral locations in Experiments 17A and 17B) as well as different spatial locations of the critical stimulus (periphery as in Experiments 16 and 17A vs. fixation in Experiment 17B). This overall increase in awareness with age can safely be attributed to an increase in attention (e.g. Huang-Pollock et al, 2002) as age-related changes in awareness were only evident when children attended to a task, and not in the final control trial (where rates of awareness were equal across age groups). Capacity for awareness therefore depends on capacity for devoting attention to task-relevant stimuli. This conclusion is further supported by findings that for almost all age groups in Experiment 16 (with the exception of 9-10 year-olds) and for all age groups in Experiment 17A, rates of awareness were significantly reduced by an increase in the level of relevant-task load. By contrast, the same increase in relevant-task load did not affect rates of awareness reports in adult age groups.

These results appear to demonstrate a sound ability to focus on task-relevant stimuli in children of all ages: At least in the tasks used here, children were able to attend to relevant targets to successfully perform a task. Notice, for example, that only one participant was excluded from Experiment 16 for failing to perform the task adequately; two from Experiment 17A and three from Experiment 17B. Clearly then, the current data do not represent results only from a subset of participants who were able to perform the task (i.e. excluding those who could not perform the task and may process irrelevant stimuli to a greater extent). It is possible that children are able to focus their attention (and demonstrate efficient early selection) for short periods of time (e.g. for only a few trials as in the experiments reported here). In this way, developmental deficits in the ability to focus on task-relevant stimuli as shown in previous studies may have been a result of children's attention waning during long tasks. Differences between results derived from RTs and those in awareness may only be compared meaningfully when the two types of measures are indexed within the same task (e.g. when awareness is tested within a long procedure as in Experiment 9, Chapter 3). Future studies could therefore examine effects of age on awareness for task-irrelevant stimuli when long procedures are used and RTs could also be established.

The current results provide some evidence for Huang-Pollock et al's (2002) conclusion that lower levels of load were required to reduce distracter processing in children compared with adults. An intermediate level of load decreased reports of awareness to a greater extent for younger children than older children or adults in Experiments 16 and 17A. Thus, the present chapter extends previous findings by measuring effects of age on explicit reported awareness. The current suggestion that capacity for awareness increases with age and may develop over childhood is supported by existing findings using indirect measures (e.g. Huang-Pollock et al, 2002).

It is important to note however that there are at least two alternative explanations which may account for the pattern of findings reported in this chapter.

Firstly, the lower rates of awareness in children may be caused by slower RTs to the target task in younger age groups allowing greater forgetting of the critical stimulus. Many previous studies have established a decrease in RT over age (Kail, 1991; Wickens, 1974; Goodenough, 1935; Elliot, 1970). For example, in a meta-analysis conducted on 70 studies, Kail (1991) found that the average RTs of children and adolescents decreased linearly as a function of adult RTs in corresponding conditions. Therefore, it is possible that children in the present experiments simply took longer to respond to the target task, thereby affording a greater time window in which they could forget the appearance of the critical stimulus.

Further complicating the issue of slower RTs in children are variations in speed of language comprehension and development of the rapid parsing system (Trueswell, Sekerina, Hill & Logrip, 1999) across age groups. Again, because younger children may be slower to comprehend the verbally presented awareness question, they may have had a greater opportunity to forget the critical stimulus. Future experiments could address this alternative account by controlling for differences in RTs across age groups possibly in a similar manner to Experiment 5 (Chapter 2), such that the time interval from stimulus presentation to questioning of awareness is equivalent.

Secondly, the pattern of decreased awareness in children could be attributed to children's greater susceptibility to backward masking of task-irrelevant stimuli when attention is focused on performing a task[6]. For example, because the current experiments presented a zero inter stimulus interval mask following critical displays, age-related increases in awareness may simply be showing a stronger

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[6] The results cannot be explained by age-related changes in susceptibility to backward masking in general because children showed no greater blindness than adults on visual control trials which also used the visual mask.

effect of backward masking in children versus adults when attention is engaged in a task. Alternatively, children might show greater integration of visual stimuli between successive displays. For example, studies have shown that children integrate more than adults both within and across displays (e.g. Kovács, Kozma, Fehér, & Benedek, 1999). Therefore, critical stimuli may not have reached awareness as much in younger age groups if children were unable to separate critical stimuli effectively either from the visual mask. Future studies could rule out these explanations simply by examining effects of age on awareness with a procedure that does not incorporate visual masks.

The pattern of larger modulations by load in children compared with adults reached significance in some experiments but not others, lending partial support to the hypothesis that capacity for attention develops over childhood. In Experiment 16, interpretation of this interaction effect (load by age) was compromised by floor levels of awareness at the youngest age groups placing restriction on the size of the load effect. This floor effect was also seen to a lesser extent in Experiment 17A. However, examination of the reduction in awareness by intermediate load as a proportion of the absolute level of awareness at each age group clearly showed larger effects of load in children than adults.

Awareness at fixation

As suggested earlier, the pattern of greater awareness at fixation in children (Experiment 17B) may be due to the process of disengaging attention from fixation being less well developed in children. Several studies have suggested developmental deficits in the disengagement of attention from fixation as measured by subsequent responding to peripheral targets. For example, Akhtar and Enns

(1989) and Enns and Brodeur (1989) both reported larger RT costs in children (aged 3 to 8 years) compared with adults associated with invalid cues in a Posner-style cuing task. Similarly, Brodeur and Boden (2000) showed that children (aged 6 to 8 years) were slower than adults to respond to peripheral targets following an invalid (central) orienting cue suggesting that children had difficulty disengaging attention from that location. This relative inability of children to disengage attention from a cued location was also evident when neutral cues were used at fixation. In the current study, it is possible that the children found it harder to disengage attention from fixation following the fixation dot cue relative to adults. This may have led to artificially inflated level of awareness for critical stimuli appearing at fixation versus in the periphery despite concurrent performance of a relatively demanding task. In this way, Experiment 17B therefore provides an illustration of a developmental deficit in disengaging attention from fixation as indexed by subsequent awareness responses to fixation critical stimuli.

Chapter 6

General Discussion

6.1 Overview of findings and implications for previous research

The role of perceptual load

The experiments presented within this thesis have established the role of perceptual load in determining awareness in inattentional blindness tasks (Chapter 2) in line with perceptual load theory (Lavie, 1995; 2005). Rates of awareness for an irrelevant critical stimulus were consistently reduced by increases in perceptual load in the relevant task. This finding generalised across experiments which varied load by increasing the difficulty of a perceptual judgment across identical displays (Experiments 1 and 3 (Group 1)) or displays with the same number of items (Experiment 4), and experiments which varied load by increasing the number of relevant items in displays (Experiments 2, 3 (Group 2) and 5). Generalisation across different manipulations of perceptual load demonstrates that results cannot be attributed to differences in physical appearance or differences in task requirements between low and high load trials. Furthermore, as results were replicated with a central cross target, effects of perceptual load on awareness in the visual search task (Experiments 2, 3 (Group 2) and 5) cannot be attributed to greater visual crowding in high load (vs. low load) displays. Finally, results also showed that perceptual load determines shape recognition as measured by a forced-choice task (Experiment 3) as well as rates of awareness.

Load and "inattentional amnesia"

Effects of perceptual load on awareness were also replicated when RTs in low load and high load trials were equated (Experiment 5). Explanations of inattentional blindness that allude to effects of memory rather than attention may therefore be disregarded. For example, Wolfe (1999) proposed that failures to report awareness on critical trials in inattentional blindness paradigms were due to participants forgetting the critical stimulus during the interval between stimulus presentation and probing of awareness. On this account, unexpected stimuli may simply be forgotten ("inattentional amnesia", Wolfe, 1999) since the often-used neutral objects (e.g. a small outline square) are neither unusual nor memorable. Results from Experiment 5 in this thesis speak against this hypothesis however. Here, rates of inattentional blindness were found to vary with attention (as manipulated through perceptual load) despite equal target RTs, and hence equal opportunities to forget, across all conditions (low load and high load). Thus, attention is shown to be the critical factor in determining rates of inattentional blindness when the confound of forgetting during the delay is controlled.

Load or strategy?

Evidence for reduced awareness under high perceptual load was also shown in two different experiments where perceptual load in the relevant task varied randomly from trial-to-trial (Experiments 4 and 5). In this way, neither expectations (of task difficulty) nor strategies associated specifically with performance of low load or high load tasks can account for the results, since participants could not predict the level of load of a particular trial prior to its presentation. This research is in line with previous studies showing effects of load on RTs despite unpredictable trial-to-trial variability (Lavie, 1995).

Relation to distracter RT interference studies

The role of perceptual load in determining rates of inattentional blindness in adults (Chapter 2) concurs with existing findings regarding the effects of perceptual load on indirect measures of distracter processing. As replicated across many studies, increasing perceptual load in the relevant task reduces the extent of distracter interference on RTs and error rates (e.g. Lavie, 1995; Lavie & Fox, 2000). The current findings extend the scope of the perceptual load theory to encompass effects on explicit visual awareness. Aside from Rees et al's (1997) motion after effect modulation by load, this thesis presents the first evidence that perceptual load influences explicit awareness of irrelevant stimuli.

Load versus expectation

Inattentional blindness is assumed to result from a lack of attention (hence "inattention") because objects fail to reach awareness when they are unattended and unexpected (as in critical trials) yet enter awareness when they are attended and expected (as in control trials). As discussed in earlier sections, this comparison is critically confounded with expectation. Moreover, although past research has argued for a role of attention in inattentional blindness by assessing the impact of factors such as spatial separation, or attentional capture by stimuli that are either of biological relevance or are similar to targets (e.g. Newby & Rock, 1998; Downing et al, 2004; Most et al, 2005), these studies have not varied attention directly. In addition, effects of task-relevance could reflect effects of stimulus priming rather than effects of attention on awareness.

Load versus previous task difficulty effects

Those studies which have directly examined effects of task difficulty on inattentional blindness either failed to establish the efficacy of the difficulty manipulation (Neisser, 1979) or may have confounded task difficulty with eye movements and hence extent of visual blurring (Simons & Chabris, 1999). By comparing awareness across different conditions of perceptual load (which hold expectation constant), the present results confirm the role of attention in inattentional blindness: Chapter 2 provides the first demonstration that the availability of attention (as varied by loading attentional capacity at different levels) determines rates of inattentional blindness. Thus, the present results represent a significant contribution to an understanding and explication of the phenomenon of inattentional blindness.

Potential effects of load on encoding into memory

The present experiments cannot however determine whether perceptual load influences awareness by reducing perception of stimuli or whether attention influences awareness by reducing the encoding of stimuli into memory (as suggested by Moore, 2001). It would be interesting for future studies to disentangle effects of perceptual load on awareness via perception versus via encoding into memory, by investigating online measures of critical stimulus processing in addition to the post-stimulus awareness probe.

The concept of perceptual load

According to perceptual load theory, attentional capacity becomes exhausted and corresponding limits of irrelevant processing are reached, when the load in the relevant task is increased. Load can be imposed either (i) by increasing the number of relevant items in a display, or (ii) by increasing the perceptual demands for the same number of items. The set size variation of load used in this thesis (Chapter 2) is well-established. Previous experiments have shown that five or fewer relevant items can be incorporated within capacity and will therefore produce conditions low perceptual load. Conversely, six or more relevant items in a display will exhaust capacity and produce situations of high perceptual load (Lavie & Cox, 1997). A similar step-wise function in awareness would thus be predicted following gradual increases in set size. As this hypothesis was not directly investigated here, this remains a topic for further research.

Past studies have also demonstrated effects on distracter processing (e.g. Treisman & Gelade, 1980; Bonnel, Possamamai & Schmitt, 1987; Lavie, 1995) when load is manipulated by line length difficulty (as in Chapters 2-5), although the effects of gradual manipulations are perhaps less clear and have not been established as yet. Perceptual load theory does predict however, that when line discrimination difficulty is increased (to the extent that it consumes full attentional capacity), inattentional blindness should be produced. Whether such gradual increases would render gradual or step-wise variations in awareness remains to be seen.

It is noted that the concept of perceptual load is a relative one: It can only be said with certainty whether a given visual display is of high or low perceptual load if external measures of error rates or RTs are influenced (either increased under high load or reduced under low load). Perceptual load is a complex concept however, and will interact with other factors, such as practice. Hence, perceptual load experiments will always compare two levels of load rather than examining effects of a single display. This method of comparison allows confirmation that load is manipulated, either by significant increases in RT (as in Experiment 4, Chapter 2) or by greater error rates under high levels of perceptual load.

Awareness at fixation versus awareness in the periphery

Experiments in Chapter 3 showed that perceptual load modulates awareness to the same extent for critical stimuli appearing in the periphery and those appearing at fixation (Experiments 6 and 7). Previous research has typically measured effects of load over long blocks of trials. As such, these experiments provide the first evidence that effects of perceptual load may be demonstrated after only a few trials. This again confirms that load effects on awareness are not a result of the long-term strategies set-up over several trials of either low or high perceptual load in long blocks.

Experiments in Chapter 3 consistently found no difference between awareness for critical stimuli appearing at fixation and awareness for critical stimuli appearing in the periphery, that is, results showed no evidence of a fixation advantage in awareness. This pattern of results generalised across different distributions of attention across space in tasks of high spatial certainty (Experiments 8-9 and 12) as well as low spatial certainty (Experiments 6, 7 and 10). Further experiments showed evidence of equivalent awareness at both fixation and periphery during tasks which equated effects of perceptual grouping and cuing (by the initial fixation mark) at fixation and periphery (Experiment 10). Thus, the findings cannot be explained by (i) the spatial distribution of attention, (ii) effects of perceptual grouping, or (iii) effects of cuing by the initial fixation display. Interestingly, equivalent levels of awareness for fixation and peripheral critical stimuli remained (i.e. no advantage for fixation critical stimuli) even when the peripheral stimuli were not magnified (Experiment 12). This suggests that, at least for critical stimuli that are clearly visible, variations in the extent of cortical representation are unimportant for determining rates of awareness.

Relation to distracter RT interference studies

The lack of a fixation advantage in awareness in Chapter 3 in this thesis represents a major departure from predictions derived from previous literature. A recent study reported evidence that fixation distracters were more disruptive to target responding than peripheral distracters (Beck & Lavie, 2005). Indeed, these effects were replicated in a reaction time experiment in this thesis (Experiment 9, Chapter 3). In contrast, the present results found no evidence for an advantage in awareness for fixation over peripheral stimuli. Instead, equivalent levels of awareness were consistently found for critical stimuli appearing at fixation and in the periphery. The contrast between effects of position (fixation vs. periphery) on previous RT results and the present awareness results could either reveal a true difference between awareness and implicit effects, or be due to methodological differences between the paradigms used. For example, it is possible that the fixation processing bias operates on an unconscious implicit level, or on response-selection stages, neither of which necessarily imply an attendant advantage in awareness. It is also possible that binary awareness measures are simply insufficiently sensitive to detect the effect compared to the subtlety of finely graded RT data (although it is noted that the more sensitive forced-choice shape and location judgments also failed to reveal the fixation/periphery distinction). Alternatively, the discrepancy may have arisen from different levels of habituation, expectation, or intention to ignore irrelevant stimuli between a method involving the presentation of several hundred, ignored, irrelevant distracters and a method presenting one single, unexpected stimulus. This explanation might seem intuitively appealing when considering the utility of certain stimuli reaching awareness for real-life. For example, consciously detecting the presence a potential predator is of crucial importance regardless of its position in the visual field whereas the same cannot be argued for implicit processing. Future research could address these issues by examining awareness at fixation versus periphery within a sustained inattentional blindness paradigm, where participants actively ignore and habituate to several irrelevant distracters.

Relation to previous inattentional blindness studies

The finding that there is no fixation disadvantage suggests also that Mack and Rock's (1998) previous result of greater inattentional blindness at fixation may have been due to unequal task demands between fixation-target and peripheral-target conditions; such task-demands differentially influencing rates of awareness by virtue of their different perceptual loads (Chapter 2). This point was further confirmed in Experiment 11 which found greater awareness with spatially certain targets (always presented at fixation) than spatially uncertain targets (presented in the periphery). It was therefore suggested that relatively low levels of awareness were found for fixation critical stimuli in previous studies (Mack & Rock, 1998; and also RT effects found by Goolkasian, 1999) because the peripheral-target task placed significantly greater demands (and thus a higher level of load) than the fixation-target task.

Awareness for faces

Effects of perceptual load on awareness were generalised to meaningful non-face objects (Experiment 15) and inverted faces (Experiments 13 and 14) in Chapter 4. When perceptual load was imposed in the relevant task, awareness rates for an unexpected musical instrument or an inverted face were reduced to the same extent as neutral non-face objects (e.g. Chapter 2). By contrast, frequencies of awareness reports for upright faces were shown to be unaffected by increases in perceptual load in Chapter 4. Thus, the distinctive resistance of upright faces to effects of perceptual load on awareness cannot be attributed to any low level visual feature associated with faces, since upright and inverted faces share identical physical features. The differential effect of perceptual load on awareness for upright versus inverted faces generalised across highly familiar faces (Experiment 13) as well as unfamiliar faces (Experiment 14). This indicates that identity familiarity is not responsible for the relative resistance of faces to effects of perceptual load.

Relation to previous face attention studies

The demonstration that upright faces always reach awareness (even under high perceptual load) also concurs with effects of load on distracter-face processing and on change detection in face targets. For example, whereas interference effects from non-face distracters were reduced by increases in perceptual load, face distracters continue to exert compatibility effects under high perceptual load (Jenkins et al, 2002). In addition, changes to an upright face were noticed more quickly than changes to inverted faces or changes to non-face objects (Ro et al, 2001; Austen & Enns, 2000). The present findings therefore support the generalised bias towards processing faces (versus non-face objects) that is suggested by these recent studies. The current results extend this notion into awareness for faces that are neither attended nor expected.

Chapter 4 found no modulation of awareness for upright faces in contrast to a recent study by Jenkins et al (2005) showing a reduction in recognition memory for faces by perceptual load. Indeed, the independence of face awareness from attention was replicated across upright faces that were both familiar and unfamiliar in the current thesis. The contrast between immediate recognition of faces (as in Jenkins et al, 2005) and detection of the presence of a face (as in Chapter 4) may be attributed to methodological differences between the two studies, such as effects of habituation, expectation, intention, distinctiveness and ease of separability in depth. Alternatively, both sets of results can be accommodated by a theory proposing that perception and awareness of upright faces occurs regardless of load, but that transferral on information into long-term memory is reduced under conditions of high perceptual load. This possibility could be explored by examining the effects of perceptual load on priming effects from faces that are manifest in the longer-term.

Attention and other biologically relevant objects

The effects of perceptual load on awareness for upright and inverted faces are also consistent with previous studies showing greater awareness for biologically relevant stimuli in inattentional blindness paradigms (Downing et al, 2004; Mack & Rock, 1998). Within the standard cross-task procedure, biologically-relevant critical stimuli such as schematic images of human figures or happy faces have been shown to reach awareness more often than their scrambled or inverted controls (Downing et al, 2004; Mack & Rock, 1998). The present results add to existing findings by demonstrating independence of awareness for faces (upright but not inverted) from the usual limits of attention to other objects. Findings from Chapter 4 also generalise the special role for faces in inattentional blindness from more impoverished schematic images (e.g. Mack & Rock, 1998) to photographs of real three-dimensional faces. As such, the ecological validity of these findings is significantly enhanced.

Is face perception automatic?

Overall, these findings lend support to an automatic face processing module in the sense that faces are free from general capacity limits. Note however, that this does not preclude the possibility that faces are free of face specific limits on capacity. This possibility could be studied in future research manipulating the load on face (versus non-face) processing (e.g. the number of faces present in a display might be varied whilst participants search for a particular face target) whilst assessing effects on awareness of faces. If faces are processed by a face-specific capacity resource then awareness for an additional unexpected face should decrease when the number of relevant faces in the search task is increased. On the other hand, if faces are processed automatically or if faces are particularly salient and attention capturing, then upright faces would continue to gain access to awareness even under conditions of "high face load".

Load and expertise

The present results cannot inform the debate over whether faces alone are special or whether the specialisation of face processing derives from a type of learned expertise as advanced by Gauthier and colleagues (e.g. Gauthier & Tarr, 1996). The recently reported advantage for body parts in explicit awareness (Downing et al, 2004) together with findings of visual areas specialised for processing the human body (Downing, Jiang, Shuman & Kanwisher, 2001) suggests that the special status of certain stimuli in attention may extend to other biologically-meaningful information as well as faces. Research on anxious patients which finds attentional capture for highly-feared stimuli (e.g. spiders) also argues that expert learning may generalise at least to certain biologically-relevant objects. Some research has reported similar behavioural specialisation evolving after extensive learning of biologically-neutral objects (e.g. cars or computer-generated families of "Greebles"). Thus, behavioural suggestions of specialised face processing may indicate a form of expert learning rather than an inherent bias towards faces. In order to distinguish between these two possible explanations, it would be interesting to examine effects of load on an expert's awareness for an unexpected stimulus belonging to their relevant category of expertise. If awareness for such stimuli is reduced by high perceptual load, the argument for an expert module would be weakened and the face-specific processing claim supported. On the other hand, if awareness for very familiar stimuli (e.g. a car for a car expert) is unaffected by the level of perceptual load in the relevant task, explanations of face-processing specialisation in terms of a learned expertise would be favoured.

Development of awareness

Visual awareness was found to increase with age from 7 year olds to adults in Chapter 5. Effects of age were found across tasks of low perceptual load as well as intermediate perceptual load (Experiments 16 and 17) and across tasks with spatially certain central targets (Experiment 16) as well as spatially uncertain peripheral targets (Experiment 17). Rates of awareness also increased with age when critical stimuli were presented at fixation and when they were presented in the periphery (Experiments 17A and 17B). In addition, perceptual load was found to interact with age under some conditions: Intermediate perceptual load caused greater reductions in awareness (from low perceptual load) in younger children than older children, and awareness rates in adults were equivalent for low and intermediate levels of load. Thus, Chapter 5 provides preliminary evidence that capacity for awareness develops over childhood.

Relation to previous developmental studies of attention

The present demonstration of the development of awareness over childhood complements existing findings regarding the age-related development of attention. Converging evidence suggests that children are less able than adults to filter out irrelevant stimuli, and that efficiency of filtering at both early perceptual stages and later response-selection stages improves with age (Chapter 5). The current results in Chapter 5 extend previous work by presenting the first evidence of the effects of age on explicit awareness. Some have argued for the adaptive value of immature cognitive systems that limit the amount of information a child is forced to process (e.g. Bjorkland, 1997). Certainly the current findings in awareness support this claim. Huang-Pollock et al (2002) have shown further that childhood deficits in filtering can be ameliorated. Smaller increases in visual search set sizes were required to produce efficient visual filtering (i.e. lower perceptual demands were sufficient to meet capacity) in children than adults as indexed by distracter effects on target RT. The current results in awareness are in line with this finding. However, as levels of awareness in some experiments were very low at low load, modulation of awareness by load in some of the younger age groups may have been constrained by floor effects. Future experiments with higher levels of overall awareness at low load could address this possibility.

Development of awareness at fixation versus periphery

The current developmental results also highlight an interesting effect of retinal position on children's rates of awareness. In line with suggestions from RT studies examining speeded responses to peripheral targets (e.g. Brodeur & Boden, 2000; Enns & Brodeur, 1989), children appeared to experience more awareness for stimuli appearing at fixation than stimuli appearing in the periphery whereas frequencies of awareness reports of fixation and peripheral critical stimuli were equal for adults. One possible explanation for this effect in awareness is that children are less able to disengage attention from fixation. This prediction could be tested by varying the extent to which the initial fixation display cues attention to the fixation or the periphery, (perhaps in a similar way to Experiment 10, Chapter 3) or by varying the spatial distribution of attention required by a task by presenting targets at different fixation/peripheral position combinations.

Alternative accounts

Future research into effects of age on awareness should consider age-differences in target response speed and susceptibility to backward masking during deployment selective attention. For example, there may have been longer delays between critical stimulus presentation and questioning of awareness for younger children as a result of their slower target RTs (e.g. Kail, 1991). Combined with age-related variations in language parsing ability and comprehension (e.g. Trueswell et al, 1999), the elapsed time interval before the awareness enquiry may have disproportionately increased the chances of rapid forgetting (e.g. Wolfe, 1999) for children. Furthermore, age-related differences in effects of attention on backward masking and the extent of visual integration across successive displays (e.g. Kovács et al, 1999) might have influenced reported awareness in the current study. Such factors must therefore be measured and controlled in future studies which directly probe awareness across different age groups of children.

6.2 Future research

Effects of load on other measures of awareness

There are several interesting directions for future research arising from results presented in this thesis. For the simple goal of deepening current understanding of the role of perceptual load in awareness, it would be useful to examine effects of load on awareness within other paradigms. The present experiments examined the effects of increasing task load on reported inattentional blindness during tasks using static displays. An extension of the current manipulation to the sustained inattentional blindness paradigm would strengthen the theoretical claim that similar mechanisms underlie these two types of inattentional blindness. For example, it is plausible that different mechanisms are operating in these two kinds of inattentional blindness since the sustained paradigm involves significant selection and inhibition within the attended task via the explicit ignoring of distracters whereas the current paradigm does not.

Effects of working memory load

Evidence has indicated that increasing working memory load leads to greater distracter interference during a concurrent selective attention task (Lavie, 2000; Lavie, Hirst, de Fockert & Viding, 2004). Such research finds larger compatibility effects during trials in which participants hold six numbers in memory compared to one or no numbers in memory. Consequently, it has been proposed that disrupting cognitive control functions by loading for example, working memory, reduces the ability to reject irrelevant information (the load theory of selective attention and cognitive control; Lavie et al, 2005). Contrasting effects of perceptual load with effects of working memory load on inattentional blindness should extend the scope of this theory into awareness. In particular, whereas higher perceptual load should reduce rates of awareness, higher working memory load should actually increase rates of awareness for a task-irrelevant object due to poorer control over selection.

Effects of aging in older adults

Another issue which merits further investigation is the effect of aging in older adults on awareness. The present results demonstrating awareness developing early in life reflect findings obtained via indirect measures regarding the development of attention. Since an analogous decline in processing capacity (as indicated by distracter effects on RTs) has also been found in adults later in life (Maylor & Lavie, 1998), it would be informative to establish whether such aging effects are accompanied by a concomitant decline in awareness (i.e. for older adults compared with younger adults). If awareness shows the same pattern of development and regression across the life-span as ability to ignore distracters, then awareness rates should decrease with age (over e.g. 60 years).

Cross-modal effects in awareness

Finally, it would be interesting to explore the possible cross-modal interactions between attention and awareness. For example, visual awareness may be influenced by increasing perceptual load within the visual domain but not within the auditory domain. Conversely, raising the perceptual demands of an auditory task may reduce reported visual awareness. Results from such research would elucidate the nature of the "general" attentional resource, indicating whether processing for awareness occurs in a strict modality-specific manner, or whether the resource is essentially "general" and therefore modality-free.

6.3 Implications for real life

Aside from their theoretical contributions, the current results have several potentially significant implications for daily life. In simple terms, observers fail to notice the appearance of clearly visible but unexpected objects (including shapes, letters, and musical instruments), if they are performing a perceptually-demanding task at the same time. It is easy to imagine that such conditions occur frequently in everyday life. It would therefore be advantageous to raise public awareness of the role of perceptual load in their ability to detect unexpected stimuli in general, so that they may seek to avoid certain actions which would enhance their safety. For instance, motorists should be encouraged to ignore extraneous visual information whilst on the roads, such as reading billboard advertisements or observing particular makes of cars. A perhaps less practical suggestion which follows logically from the present findings might be for high-risk road users such as motorcyclists to display biologically salient stimuli (e.g. an image of a face) on their vehicle or person (e.g. jackets, helmets). Since such images have been shown to escape inattentional blindness even under conditions of close attention, this modification, although possibly proving less popular due to potential social embarrassment, should enhance their visibility to other road-users. These describe just two possible real-life applications of the present research. It is clear that an examination of the impact of perceptual load on awareness in other everyday tasks would be beneficial for predicting when awareness is likely to breakdown, and in turn, for suggesting practical methods for overcoming such oversights.

This thesis identifies situations in which effects of perceptual load are visible within just a few trials (sometimes six or seven). It is possible then, that paradigms established here be used as a tool for screening participants for attention deficits. For example, participants could be classified as either "large capacity" or "small capacity" individuals depending on whether they report awareness for critical stimuli under conditions of high perceptual load (e.g. where awareness usually reaches 50%). Moreover, such brief methods of testing might be useful as a clinical diagnostic tool for certain types of developmental or attentional disorder.

6.4 Conclusions

In summary, this thesis has established the critical role of perceptual load in determining explicit awareness as measured in inattentional blindness paradigms. Rates of awareness for unexpected stimuli are reduced by increases in task-relevant perceptual load, with the exception of upright faces which reach awareness under any level of perceptual load. The current work also demonstrates that awareness is unaffected by the retinal position of critical stimuli, marking a departure from existing findings derived from indirect measures. Finally, I have shown that awareness increases with age over childhood, possibly as a result of a developing capacity for awareness. This thesis underlines the close relationship between attention and awareness, whilst providing a significant contribution to our existing understanding of inattentional blindness.

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Appendix

Critical stimulus and foils in the forced-choice guessing tasks.