Attended but unseen: Visual attention is not sufficient for visual awareness.

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The rights of our subjects were fully protected, following the procedures laid out by the relevant local ethical committee. All gave informed consent before participating in the studies reported here.

Attended but unseen: Visual attention is not sufficient for visual awareness.

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Abstract.

Does any one psychological process give rise to visual awareness? One candidate is selective attention – when we attend to something it seems we always see it. But if attention can selectively enhance our response to an unseen stimulus then attention cannot be a sufficient precondition for awareness. Kentridge, Heywood & Weiskrantz (1999, 2004) demonstrated just such a dissociation in the blindsight subject GY. Here we test whether the dissociation generalizes to the normal population. We presented observers with pairs of coloured discs, each masked by the subsequent presentation of a coloured annulus. The discs acted as primes, speeding discrimination of the colour of the annulus when they matched in colour and slowing it when they differed. We show that the location of attention modulated the size of this priming effect. However, the primes were rendered invisible by metacontrast-masking and remained unseen despite being attended. Visual attention could therefore facilitate processing of an invisible and cannot, therefore, be a sufficient precondition for visual awareness.

Keywords: Attention Vision Consciousness Masking

1. General Introduction

What makes us aware of the world we see? Introspection suggests that when we selectively attend to part of the visual scene we become aware of objects in that region. This was noted by early empirical Psychologists (James, 1890; Wundt, 1912) who proposed a causal link between visual attention and awareness which remains part of many contemporary theories of visual awareness (e.g. Baars' (1998) global workspace theory). The ability to select part of the visual world for enhanced processing makes adaptive sense. But need it be the case that all stimuli which benefit from this selective processing advantage necessarily reach awareness? Are visual attention and visual awareness really aspects of a single process or are there circumstances where one acts without giving rise to the other?

Lamme (2003) has argued that phenomenal awareness might be independent of attention. Many stimuli might elicit phenomenal experience (akin to iconic memory), only those to which we attend engage access consciousness - capable of engaging working memory. Attention may not, therefore, be *necessary* for awareness per se.

Recent evidence suggests that allocation of visual attention to a stimulus may not always be *sufficient* to render that stimulus consciously visible to the observer. In such circumstances the role of attention may be evident by virtue of a selective advantage in behavioural responses to attended stimuli despite the fact that those stimuli are not acknowledged.

Two of us, working in collaboration with Larry Weiskrantz (Kentridge, Heywood & Weiskrantz,1999, 2004) discovered the first evidence for just such an effect in a patient, GY, who has the neurological condition of 'blindsight' (Weiskrantz, 1986). Patients with 'blindsight' demonstrate preserved visual abilities in the absence of acknowledged awareness. They can, for example, guess whether a visual stimulus is presented in the first or second of two temporal intervals with remarkable accuracy despite denying that they see anything at all (e.g. Kentridge, Heywood & Weiskrantz, 1997). The condition arises as consequence of damage to primary visual cortex or its immediate afferents when more anterior visual areas are spared. It is thought that residual visual function is mediated by visual pathways which bypass the route from the lateral geniculate nucleus to striate cortex such as those from the superior colliculus or pulvinar (Cowey & Stoerig, 1991).

Using the classical Posner cueing paradigm (Posner, 1980) we were able to show that, as with normal observers, spatial cues speeded detection or discrimination of targets subsequently appearing in the cued location, compared with those appearing elsewhere. However, as is characteristic of 'blindsight', the patient steadfastly denied seeing the cued-targets. Given that the cue-dependent reaction-time advantage is an index of spatial attention we concluded that spatial attention is unlikely to a sufficient precondition for visual awareness. However, the demonstration of a similar dissociation in normal observers would add weight to the generality of this conclusion.

2. Experiment 1

In order to test whether attention is sufficient for awareness in normal observers we combined the Posner paradigm with a means of rendering stimuli invisible to normal observers - metacontrast-masking (Breitmeyer, 1984). Metacontrast-masked stimuli have been shown, despite their invisibility, to act as effective primes in subsequent visual discrimination tasks (Schmidt, 2000; Breitmeyer, Ro & Singhal, 2004). By presenting two different masked primes simultaneously, the effects of attentional cueing can be determined by comparing the efficacy of primes in cued and uncued locations.

Pairs of red and green discs, the primes, were presented, rapidly followed by masking annuli, which were both either red or green and served as the discriminanda. The speed at which participants signal the colour of a target annulus will be determined by whether the annulus is of a congruent or incongruent colour to the unseen prime. A symbolic spatial cue (an arrow) was used to direct attention to one or other of the targets. Since both targets were identical in colour, if the cue has an effect on discrimination reaction time it can only have done so by differentially affecting the processing of the unseen primes.

2.1 Method

2.1.1 Participants

Four participants (one male, three female, aged between 18 and 25) who were naïve as to the purpose of the experiment, but otherwise experienced observers, were tested.

2.1.2 Stimuli and apparatus

The visual display consisted of a Taxan Ergovision 885LR 14" colour monitor driven at 100Hz, with a resolution of 800x600 pixels, by a Cambridge Research Systems VSG2/5 stimulus generator and gamma corrected using a Cambridge Research Systems ColorCal colourimeter. The display used a P22 short-persistence phosphor to avoid potential display artefacts.

Stimuli were composed of metacontrast-masked 0.8^{O} discs which served as primes. These primes were masked by subsequently presented annuli. These masking annuli surrounded the discs (their inner diameter matched the outer diameter of the discs, 0.8^{O}, their outer diameter was 1.6^{O}) and were the targets to which subjects were asked to respond. Discs and Annuli were either a very desaturated red or green (~ 4.6% in cone-contrast) with co-ordinates in CIE 1976 u',v' colour space of 0.196, 0.477 and 0.226, 0.477, respectively. They were presented against a grey background (u', 0.211; v', 0.477). The stimuli and background were equiluminant ($20cdm^{-2}$). The red and green stimuli were equally salient to the extent that they deviated from grey by +/-0.015 in u',v' space which is a reasonable approximation of a linear discrimination space. By using low contrast stimuli with a brief 40ms interval between disc and annulus, potential problems with phosphor persistence were eliminated (see García-Pérez & Peli, 2001).

The two possible stimulus locations were centred 1.6^{O} above and below fixation (a black central disc with a diameter of 0.16^{O} present throughout the experiment). Arrowheads, which acted as cues for spatial attention, were black, centred around fixation with a width of 0.4^{O} and a height of 0.2^{O}.

2.1.3 Design and procedure

Participants were seated 57cm from the display in a dark room. A trial consisted of the presentation of a central cue, followed by a pair of primes embedded in the subsequently displayed annular targets. Participants were asked to indicate, as rapidly as possible while maintaining accuracy, the colour of the annuli by pressing one of two buttons on a button box. Reaction times (RTs) from annulus onset to response were collected. Participants were instructed to maintain fixation throughout. Fixation was monitored with an infrared video camera mounted above the monitor on which the experiment was presented. The stimulus sequence is illustrated in Figure 1a.

INSERT FIGURE 1 ABOUT HERE

As there are two identical targets in the cued and uncued locations the subject might ignore the ostensibly uninformative spatial cues. To ensure that subjects do indeed use the cues, we embedded the critical dual target trials described above within a much larger number of single target trials in which the symbolic cue indicated the likely location of the upcoming target with 80% accuracy (see figure 1b). Participants were informed that on some trials two targets would be presented but both targets would

always be the same colour as one another. They were also told that each trial would start with the presentation of a centrally located arrow which was a good, but not perfect, predictor of the location of the target on single target trials. No mention was made to the subjects of the fact that the experiment also involved priming or that all targets were preceded by primes.

Testing was conducted in 10 blocks, each of 280 trials. Within each block there were 56 double-target trials, 28 in which the cue pointed to the location of a congruent prime and 28 in which it pointed to an incongruent prime. Single targets were presented in the remaining 224 trials, in 196 of which the target location was correctly indicated by the cue (valid) and in 28 the cue was misleading (invalid). We treat the first 5 blocks as practice and only analyse the final 5 blocks for each subject. Separate analyses were conducted for single and dual target trials for each subject. Outliers (RTs>2 s.d. from the mean) and errors were discarded from all analyses.

A final methodological point to address is the question of how awareness, a subjective phenomenon, should be measured. One option is to use psychophysical methods such as signal detection analyses or two-alternate forced choice procedures in order to determine whether observers are, in fact, detecting apparently invisible stimuli. Such approaches might, however, only inform us as to whether the subject has access to information about stimuli, not whether those stimuli reach awareness. It is clear that we need to obtain a direct subjective report from our subjects whether or not other approaches are also taken. There is, however, a danger that when one simply asks a subject about their experiences the experimenter's expectations might influence the subjects' reports. We therefore adopted a protocol in which the initial questions asked of the subject were wholly non-directive and were followed up by questions successively increasing in direct reference to the experience under investigation. We therefore assess the subjects' cued and uncued recall of experience in queries which could reasonably be seen as both suggesting the likely absence and likely presence of possibly unseen stimuli.

2.1.4 Results and Discussion

Reaction-times for correct responses from the single target trials are shown in figure 2. Data were analysed by Analyses of Variance with the Factors of Cue Validity and Prime Congruency. The clear effect of Cue Validity is evident for all subjects (all F ratios > 39 with all dfs > 1,1000, maximum $p<10^{-9}$). The effects of Prime Congruency and its interaction with Cue Validity are not consistent across subjects. Prime Congruency fails to reach significance for subject IS and the Prime Congruency x Cue Validity interaction fails to reach significance for both IS and BJ. It appears, nevertheless, that there is a consistent effect of priming for validly cued, but not invalidly cued, trials across subjects. This is confirmed by analyses of simple main effect of priming for cued and uncued trials. Priming has non-significant effects on uncued trials for all subjects (all Fs<1) but highly significant effects on cued trials (all Fs > 33 with all dfs > 1,890, maximum p<0.0005).

INSERT FIGURE 2 ABOUT HERE

The key results, the reaction-times from the dual target trials are shown in figure 3. There is a consistent highly significant effect of cueing across all four subjects (Fs =

13.64, 7.26, 7.34 and 24.16 with 1 and 259, 257, 261 and 257 df respectively, $p<0.0005$, $p<0.005$, $0<0.0005$, $p<0.00001$ respectively). The average error rate across all subjects was less than 1.6%, TN made the most errors with a rate of 2.3%. The error rates for incongruent trials were higher than those for congruent trials for all subjects.

INSERT FIGURE 3 ABOUT HERE

Following the completion of testing subjects were systematically and individually debriefed. First, each was asked to describe everything they had seen on the display during the experiment. None mentioned the prime. The subjects were asked if they had any idea of the purpose of the experiment. They mentioned a number of possibilities (e.g. a study into carry over effects from preceding trials) but none suggested anything related to priming, subliminal stimuli or masking. They were then asked whether they might have seen anything else in addition to the fixation crosses, cues and rings (targets) that they had just described. Again, all four subjects maintained that they had seen nothing else displayed. They were then asked directly whether they had seen any coloured discs at the locations of the annuli centres just prior to the appearance of the annuli and again they denied seeing any primes. Finally, they were shown examples of the stimulus sequences slowed down by a factor of 10 so that the primes were now clearly visible. The subjects registered astonishment that such primes had been present throughout the thousands of trials they had just completed.

The conclusion we draw is that in normal observers, just as in GY, spatial attention can selectively facilitate the processing of unseen stimuli without those stimuli eliciting awareness. Attention cannot be a sufficient precondition for awareness.

3. Experiment 2

There is one clear drawback to the debriefing procedure we used to assess subjects' awareness of the masked primes. The debrief took place a short time *after* subjects had completed the experiment. It is therefore possible that they may have had a fleeting experience of the primes which had faded from memory by the time they were interviewed. One key advantage, therefore, of methods in which subjects are assessed on a trial by trial basis is that demands on memory are much lower. One might, for example, test whether subjects can discriminate between the presence and absence of primes explicitly in a signal detection or a two-alternate forced choice (2AFC) paradigm, as opposed to measuring their indirect effects via priming (see e.g. Dehaene et al,1998, for example, who use both debriefing interviews and an explicit detection task test to assess awareness). Although a forced-choice task does not explicitly test awareness, when performance is at chance it is reasonable to assume that it is extremely unlikely that a subject is having any experience of the stimuli whose presence or absence he or she cannot discriminate. On the other hand, if the subject can make an explicit discrimination it does not necessarily follow that that the subject is having a visual experience (blindsight subjects certainly deny having visual experiences while nevertheless performing visual 2AFC tasks with high levels of accuracy, see e.g. Kentridge, Heywood & Weiskrantz, 1997). Our second experiment uses the same stimuli as those employed in

experiment 1 but now in a 2AFC task designed to assess subjects' ability to detect the presence of primes immediately after they are presented on each trial.

3.1 Method

3.1.1 Participants

The participants were those who had taken part in experiment 1.

3.1.2 Stimuli and apparatus

The apparatus was the same as that employed in experiment 1. The stimuli were identical to those used in experiment 1 apart from the manner in which they were presented, as described in the following *design and procedure* section.

3.1.3 Design and procedure

Following debrief, in which the nature of the cues had been demonstrated to them, our subjects were presented with stimuli similar to those they had seen in experiment 1. There were two key differences. First, in each trial two entire stimulus sequences (fixation, cue, SOA, prime, gap, mask) were seen with a brief tone indicating the start of the second sequence. In either the first or the second presentation no prime (or primes for dual target trials) was presented. The stimulus sequence in each interval was drawn randomly and independently from the original set. Interval 1 and 2 stimuli were therefore not usually identical – this ensures that the attentional cues remain informative in both intervals of the prime detection task. The second difference was that the subjects' task was no longer mask-colour discrimination but rather a temporal 2AFC in which they were asked to indicate whether primes were present in the first or second interval.

Testing was conducted in 5 blocks, each of 280 trials (1,400 trials, 2,800 trial sequences). The proportions of single and double target sequences and of validly- and invalidly-cued single target trials in the first intervals and second intervals of each block was unchanged from experiment 1. The order in which trials were presented in intervals 1 and 2 were randomised separately in each block.

3.1.4 Results and discussion

The most critical tests to make are of discrimination in double-target trials. Accuracy and 95% binomial confidence intervals are shown for each subject in each condition for double-target trials in figure 4. It can be seen that all subjects' discriminations in all conditions do not differ from chance (all binomial $p>0.05$).

INSERT FIGURE 4 ABOUT HERE

It might be argued that by concentrating solely on double-target trials we are discarding data from single-target trials which could valuably be used to test subjects' awareness (or at least discrimination) of primes (even though the equivalent trials in experiment 1 were not suited to testing the effects of attention). We therefore pooled data from all single- and double-target trials for each subject in order to maximise statistical power. The means and 95% binomial confidence intervals are shown in figure 5. Again,

discrimination performance does not differ from chance for any subject (all binomial $p>0.05$) even though we are now using 1,400 trials per subject.

INSERT FIGURE 4 ABOUT HERE

The results of this second experiment are consistent with the reports of our subjects during the interview phase of experiment 1. It is clear that, despite focussing their attention on locations in which primes appeared, masking was sufficiently effective to prevent those primes eliciting conscious visual experience. Attention is known to decreases the effectiveness of metacontrast masking (Boyer & Ro, 2007), however, our de-saturated, equiluminant colour stimuli have masked so well that even when attended they remained unseen.

4. General Discussion

The results from dual-target trials in experiment 1, which directly test our hypothesis, clearly indicate that spatial attention was modulating the effectiveness of priming. Although the interpretation of *single* target trials is clouded by the fact that attention is highly likely to modulate target processing as well as prime processing, such trials can still tell us something about the relationship between attention and awareness. The pattern of results again appears consistent with an attentional effect on prime processing because priming only had an effect at attended locations. These effects cannot be attributed to speed-error trade-offs since error rates were always higher for the slower incongruent priming condition. We can conclude that spatial attention, although clearly conferring a selective processing advantage on primes presented at a cued-location, did not engender visual awareness of those primes. This absence of awareness is evident both in the interview phase of experiment 1 and in the results of experiment 2. Hence spatial attention cannot be a sufficient condition for visual awareness and, moreover, visual attention and visual awareness cannot depend upon identical underlying neural processes.

Although our results might seem surprising they can be seen as a combination of two well-accepted phenomena. First, masked stimuli which are undetected by observers have repeatedly shown to be effective primes. Second, attention has been shown to modulate priming in many ways (e.g. Logan (1980) who demonstrates effects of attention on Stroop-based tasks, Tipper and Cranston (1985) who showed that attention modulated negative-priming, amongst many others). Lachter, Forster & Ruthruff (2004) report an experiment in which the effectiveness of masked positive primes was modulated by spatial attention, using a lexical decision task to measure performance and interruption masks to manipulate awareness. As the authors point out, however, their "participants are certainly aware that something appears before the target. Even under these conditions, however, they are not consistently aware of what the prime is" (p. 896). In contrast, masking in our experiment did not merely prevent participants from discriminating the nature of the primes (red or green in our case). Instead, our subjects were completely unaware of the existence of primes and attention did not raise those primes into awareness.

Following our findings with GY, other authors have found conditions in which attention facilitates behavioural tasks without eliciting awareness of target stimuli in

normal observers. Kanai, Tsuchiya & Verstraten (2006) report an elegant experiment in which they used continuous flash suppression where a rapidly changing field of stimuli presented in one eye prevents stimuli presented in the other eye from reaching awareness. They found that feature-based attention, as evidenced by a modulation of the tilt after effect, modulated processing of masked stimuli. They did, not, however, find evidence that *spatial* attention could affect the processing of unseen stimuli. This result is at odds with the data we present here. There may, however, be a relatively simple explanation of this apparent contradiction. It is possible that the visual transients in the flash-suppression mask automatically capture spatial attention thereby interfering with the subjects' attempts to voluntarily maintain attention at one location. In the feature-based variant of their task the items to which subjects must voluntarily attend are not in locations covered by the flash-suppression mask and may hence be less affected by it.

Sumner, Tsai, Yu & Nachev (2006) have also demonstrated that attention can have significant behavioural effects without engaging awareness. They exploit the fact that stimuli which prime a specific motor response produce a negative priming effect (they slow responding) when the stimuli are perceptually weak (e.g. very low contrast), only producing a normal, positive, priming effect when they are strong. This negative compatibility effect is effector-specific, that is, primes that are associated with one particular means of responding (e.g. button pressing) will not inhibit responses made with other effectors (e.g. eye-movements). Sumner et al use this effect to distinguish two distinct effects of attention: first, attention may strengthen the perceptual strength of a stimulus; second, attention may strengthen the sensorimotor processing associated with the stimulus. Attention may well act in both ways. The question Sumner et al address is whether the effects of attention which do not engage awareness are sensorimotor. They showed that, with their experimental procedure, spatial attention significantly slowed responses in cued, as opposed to uncued, locations. That is, attention enhanced the sensorimotor-specific negative-compatibility effect. This then is evidence that attention affects sensorimotor processes independently of perceptual ones. As Sumner et al note (and, indeed, demonstrate experimentally), it does not, however, imply that attention acts only on sensorimotor processing to the exclusion of perceptual enhancement. Our results show attention facilitating *positive* effects of unseen primes. There are, of course, many procedural differences between our experiment and that of Sumner et al. For example, in our experiment the relationship between stimuli and response (red → press left, green → press right) might be seen as more spatially arbitrary than that used by Sumner et al (left-pointing arrow → press left, right-pointing arrow → press right). Critically, however, metacontrast-masked colour primes appears to act at an early sensory stage of processing (Breitmeyer, Ro & Singhal, 2004) and so are much less likely to be exerting their primary effect by influencing response programming. In any case, there is not necessarily a contradiction here. Attention may facilitate either perceptual or sensorimotor processes and, on the basis of our result here, either type facilitation can occur without necessary concomitant awareness.

There are, then, many lines of evidence, including the results presented here, suggesting that attention, be it spatial or feature-based, can modulate the processing of stimuli without those stimuli necessarily entering awareness. The fact that attention can be selective for space or for features and that it can enhance sensorimotor links or perceptual processing, all without concomitant awareness, suggests that far from being

intimately linked, the neural processes underlying attention and underlying visual awareness must be quite distinct. It is clear that, rather than being isolated to a single neuropsychological case, as might have been thought following our work with Larry Weiskrantz on patient GY, these dissociations generalise to the normal population.

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Figure Legends

Figure 1. (a) A dual target trial. In this example the congruent prime location is cued. (b) Single target trials with validly cued congruent and incongruent primes are shown in upper and lower panels on the left while examples of invalidly cued trials are shown on the right.

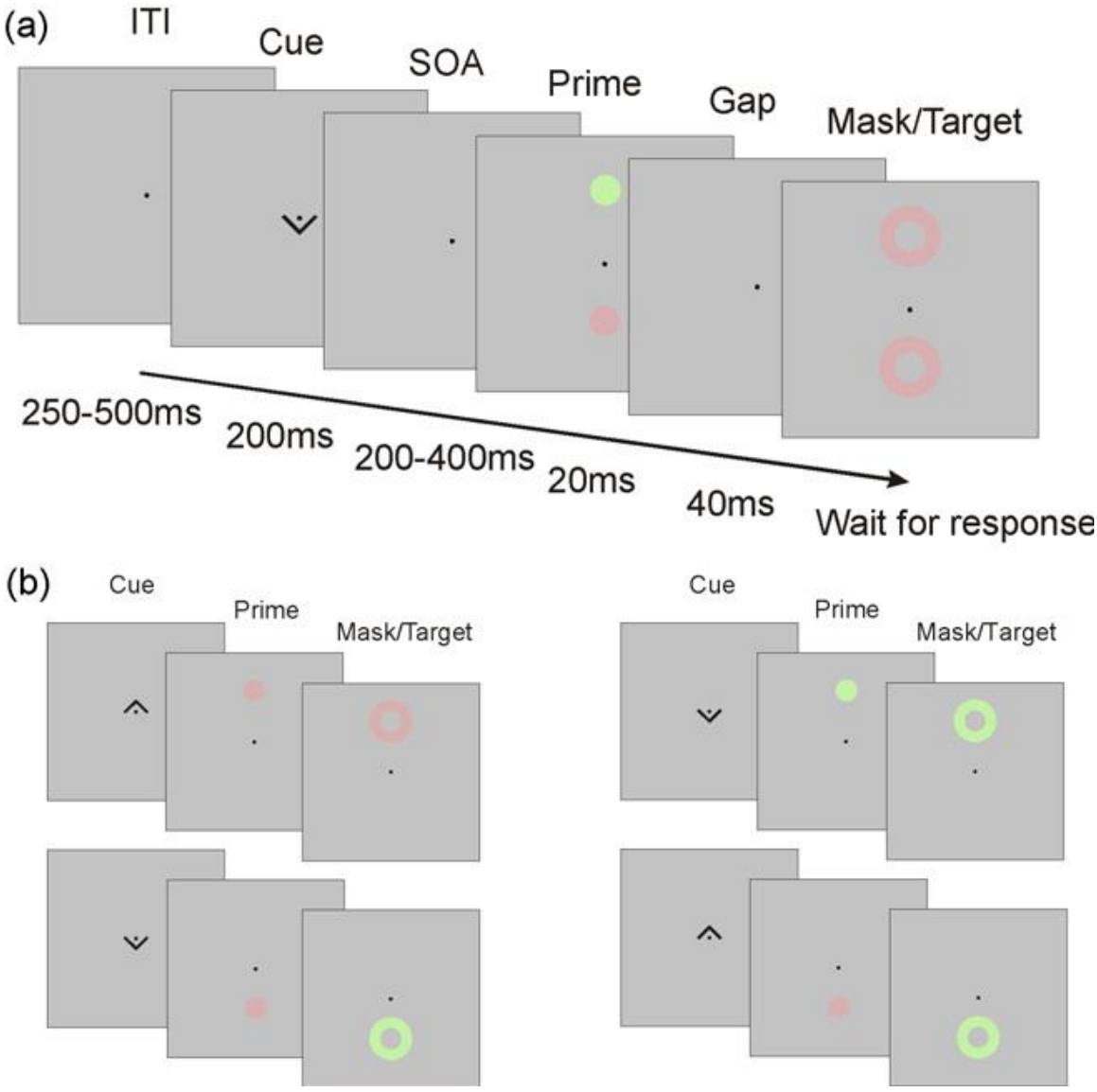
Figure 2. Reaction times to single target stimuli for each subject (error bars are +/- sem).

Figure 3. Reaction times to dual target stimuli for each subject (error bars are +/- sem).

Figure 4. Proportion of double-target trials for each subject in which they correctly identify in which of two 2AFC intervals primes are present. Error bars are 95% binomial confidence intervals.

Figure 5. Proportions of all trials for each subject in which they correctly identify in which of two 2AFC intervals primes are present. Error bars are 95% binomial confidence intervals. Note magnified scale.

Figure 1.


(a)
ITI
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250-500ms
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(b)
Cue
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Mask/Target
Cue
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Mask/Target

Figure 2

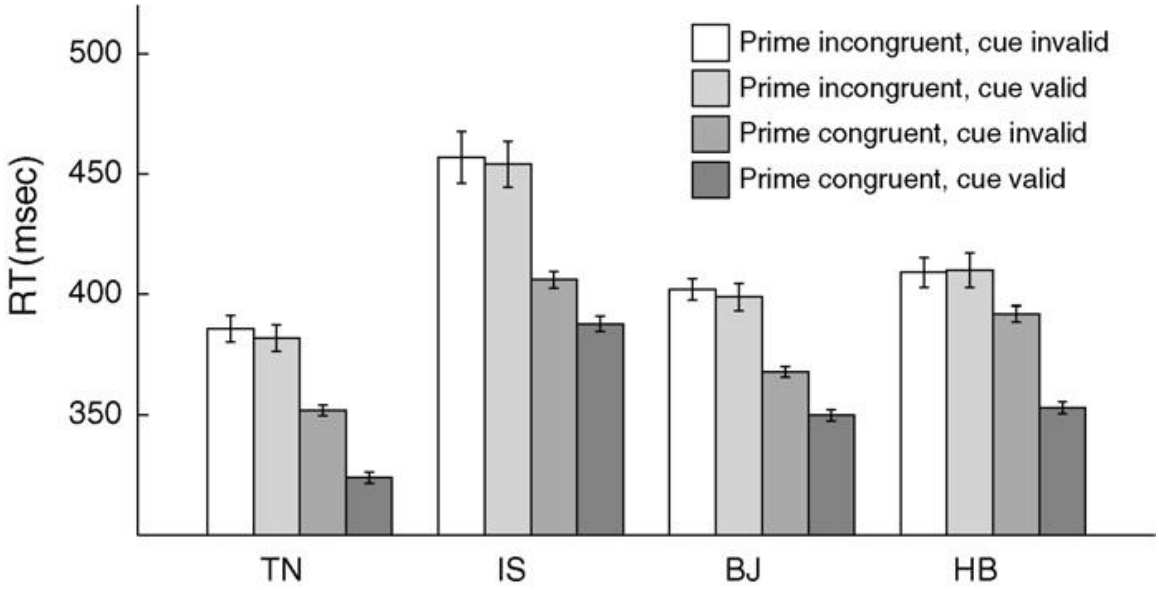


Figure 3

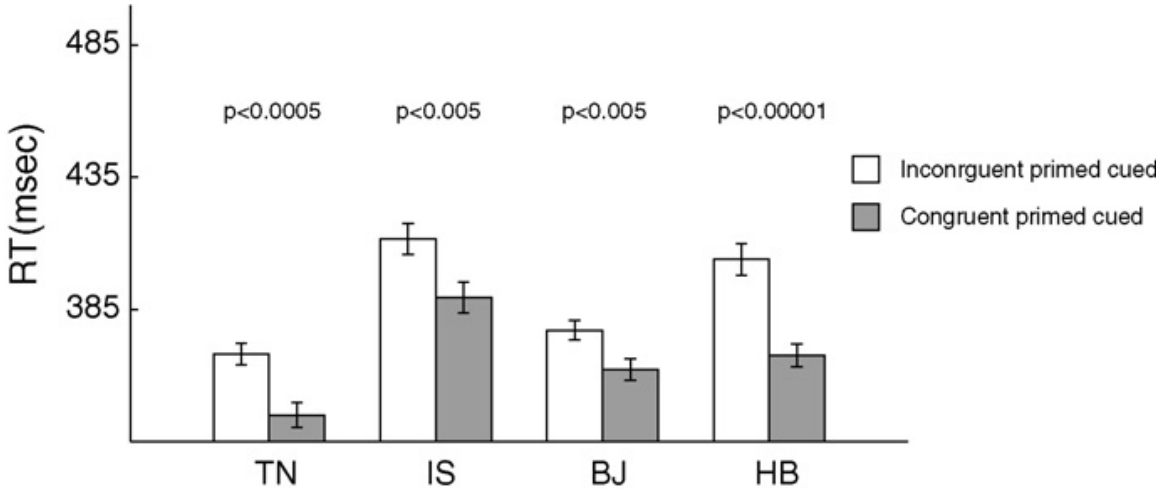
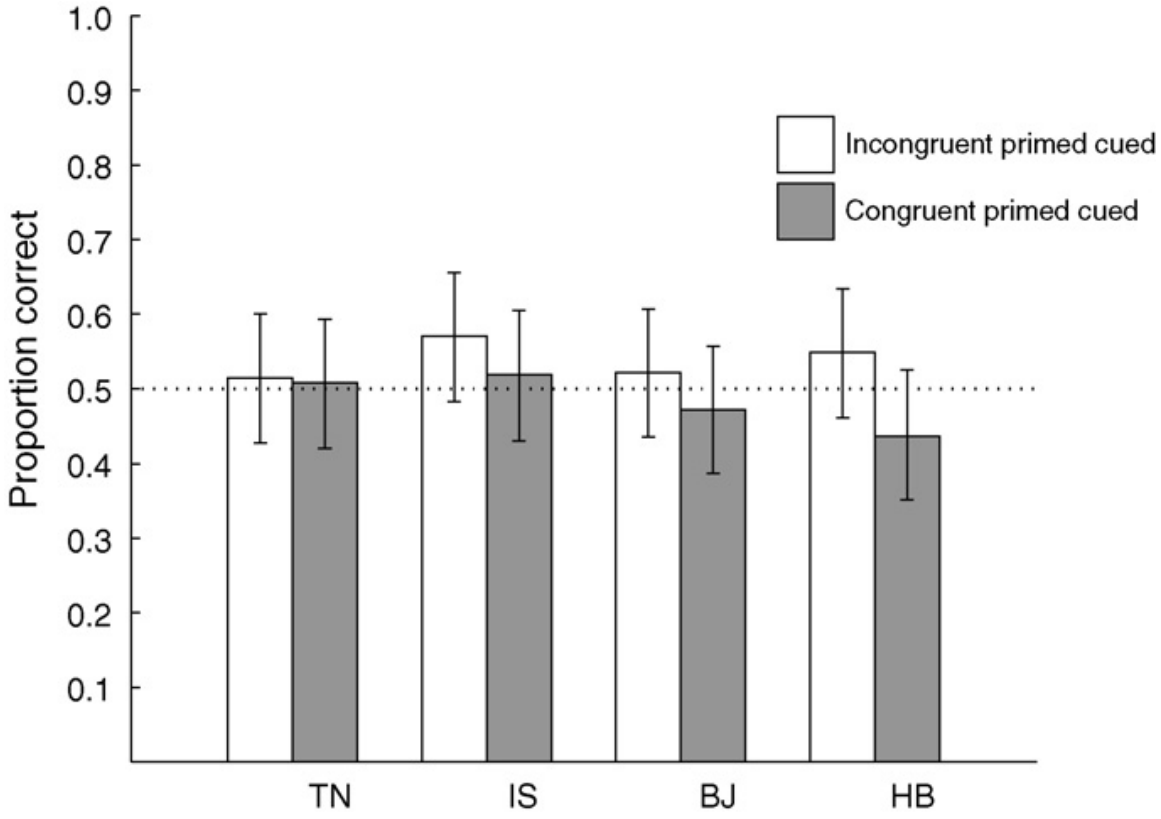


Figure 4


1.0
0.9
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Proportion correct
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Congruent primed cued
TN
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BJ
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Figure 5