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DOI:
10.3758/s13414-011-0181-z

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Document Version
Peer reviewed version

Citation for published version (Harvard):
Zhao, Y, Heinke, D, Ivanoff, J, Klein, RM & Humphreys, G 2011, 'Two components in IOR: evidence for response bias and perceptual processing delays using the SAT methodology.', *Attention, perception & psychophysics*, vol. 73, no. 7, pp. 2143-2159. https://doi.org/10.3758/s13414-011-0181-z

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Publisher Rights Statement:
The final publication is available at Springer via http://dx.doi.org/10.3758/s13414-011-0181-z

Checked July 2015

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Two components in IOR: Evidence for response bias and perceptual processing delays using SAT methodology

Abstract

Inhibition of return (IOR) occurs when reaction times (RTs) are slowed to respond to a target that appears at a previously attended location. We used the speed-accuracy trade-off (SAT) procedure to obtain conjoint measures of IOR on sensitivity and processing speed by varying the validity of a cue preceding the target. The results showed that IOR is associated both with delays in processing speed and shifts in response criteria. When the target was briefly presented, the results supported a criterion shift account of IOR. However, when the target was presented until response the evidence indicated that, in addition to a response bias effect, there was an increase in the minimal time required for information about the target to accumulate above chance level. A hybrid account of IOR is suggested in which there are effects on both response bias and perceptual processing.

Introduction

The visual environment contains multiple stimuli which cannot be responded to at once. As a consequence, attentional mechanisms are required to select the behaviorally relevant stimuli and to filter out stimuli less relevant to our goals. One classical experimental approach used to study visual attention is to use spatial cueing to bias attention to or away from a target (Posner & Cohen, 1984). In this procedure participants typically see a spatial cue either to the left or right side of fixation followed by a target either at the same location as the cue or on the opposite side. Participants are asked to press a key as soon as they detect the target. When there are relatively short time intervals (SOA) between the cue and the target, reaction times (RTs) are faster when the target and the cue are at the same location compared to when these stimuli appear on opposite sides. However, when the time interval between the cue and target is increased, this facilitatory effect of cueing is usually reversed: Participants are slower to respond when the target and cue appear at the same location compared to when they appear on opposite sides. Posner, Rafal, Choate and Vaughan (1985) termed this the inhibition of return (IOR) effect.

One (standard) interpretation of these results is that the early facilitation effect reflects the fast, reflexive orienting of attention towards the sudden appearance of the cue, which leads to more efficient processing of targets at that location (Folk, Remington, & Johnston, 1992; Posner, 1980; Posner & Cohen, 1984; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984). However, the nature of the later IOR effect remains unclear, with arguments being made both for IOR reflecting impaired perceptual processing (e.g. Cheal et al., 1998; Handy et al., 1999; Lupianez, Milan, Tornay, Madrid, & Tudela, 1997; Prime & Ward, 2004) and for it reflecting a change in response criteria to stimuli at the cued location (e.g. Ivanoff & Klein 2001, 2003, 2004, 2006; Klein & Taylor, 1994). In this paper we aim to examine these two aspects of IOR using speed-accuracy trade-off (SAT) methodology.

To assess IOR we take a signal detection theory (SDT) approach. SDT separates processing of stimuli into two stages: a perceptual coding stage and a decision stage (Green & Swets, 1966; Swets, Green, Getty, & Swets, 1978). Crucially the particpant's sensitivity to the stimulus can be measured with the *d'* metric, and the bias for responding in a particular direction may be determined with *c*, the decision criterion metric (Macmillan & Creelman, 2005). Both measurements are influenced by several factors, including the quality of the stimuli and the length of time available for stimulus classification. Especially important for this paper is the fact that the timing of the response to a stimulus reflects the monotonically increasing quality of perceptual encoding based on continued accumulation of information about the target, leading to the well-established SAT function (Reed, 1973; Wickelgren, 1977). Figure 1 illustrates three hypothetical SAT functions that might underlie the IOR effect. Within the framework of SDT, the IOR effect can be explained in at least two ways. One possibility is that IOR influences perceptual coding, with perceptual sensitivity to the target being impaired. For example, the maximal amount of information that can accrue from the time-limited presentation of the target may be less at regions affected by IOR (Figure 1A). Alternatively, it may take longer to accumulate information about the target at the previously cued location (Figure 1B). This is the attentional/perceptual account of IOR (cf. Ivanoff & Klein, 2006; Handy, et al. 1999; ReuterLorenz, Jha, & Rosenquist, 1996). A second possibility is that IOR occurs because the criterion for the decision process is raised at the previously cued location - the criterion-shift account (Ivanoff & Klein, 2001, 2003, 2004, 2006) (see Figure 1C). Crucially these two accounts predict different effects of IOR on performance accuracy, even if similar effects are predicted on RTs. The criterion shift account holds that there is no difference in the accumulation of information at the cued and uncued locations, but cueing generally slows RT when a decision criterion is applied (it is applied later to targets at cued locations). As the decision criterion is applied later, there should be more perceptual information available when a decision is made (at least when the perceptual information remains available for report). It follows that there should be higher accuracy at the cued location compared to the uncued location. In contrast the attentional/perceptual account suggests that accuracy should be lower at the cued location since information accrual is delayed, or the rate of accrual is slowed, at the cued location. Importantly, there is support for both accounts in the literature. We first will review the studies supporting the attentional/perceptual account.

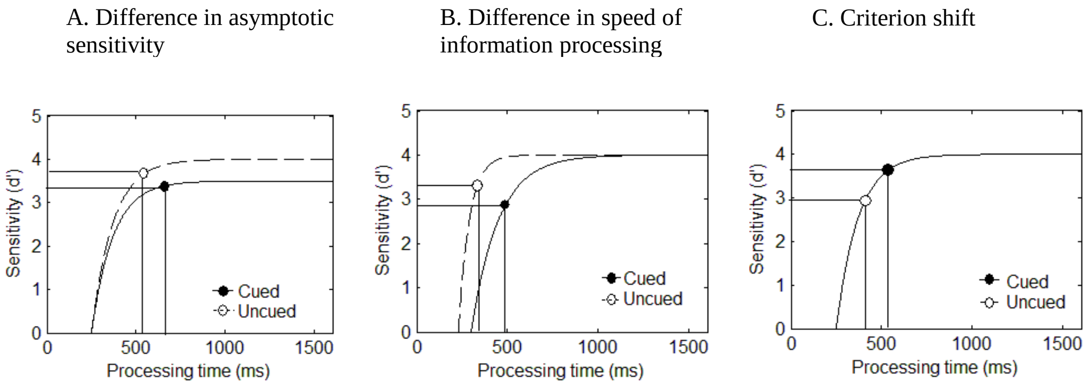
Lupianez et al. (1997) investigated IOR in a discrimination task. They found that there were both delayed RTs and reduced accuracy at cued locations compared to uncued locations across a range of SOAs from 700 to 1300 ms. Cheal et al. (1998) and Handy et al. (1999) also found decreased accuracy along with delayed RTs when the cue shared the same location as the target. However, these studies used either masking or short target presentations which may lead to a rapid loss of stimulus information. If response selection is delayed while stimulus information decays, performance may be less accurate under IOR conditions simply because of greater decay of stimulus-based evidence over a longer period of time (see Ivanoff & Klein, 2001, 2006, for a similar argument). This argument is supported by Handy et al.'s (1999) study where *d'* was reported to decrease with longer RTs. In this study for which participants were instructed to emphasis accuracy they tended to respond more slowly and, interestingly, also with decreased accuracy.

Support for the criterion shift account of IOR comes from a series of studies by Ivanoff, Klein and Taylor (e.g., Ivanoff & Klein 2001, 2003, 2004, 2006; Klein & Taylor, 1994). These studies reported that there was a lower false alarm rate along with longer RTs for targets appearing at cued relative to uncued locations in both go-nogo and discriminantion tasks. These authors argued that lower false alarms imply more a conservative response criterion and therefore constitutes evidence for a criterion-shift account of IOR. Although lower false alarms alone do not provide conclusive evidence for a criterion shift, as false alarms need to be considered together with the hit rate to properly measure criterion levels, *c* scores in these studies were highly related to false alarms as generally no misses was found. It is noteworthy that, in these studies, targets were presented until response, thereby avoiding effects of stimulus decay on performance – unlike studies supporting the perceptual account.

The present paper aims to go beyond the above studies by fully measuring the SAT function so as to derive the parameter estimates for the intercept, slope, and asymptotes, as suggested by Wickelgren (1977). This approach enables the time course of information accrual to be plotted while, at the same time, allowing the experimenter to control the relations between the speed and accuracy of responses. Importantly, the procedure also allows us to determine the time course of target processing for limited and unlimited presentation times together, since this procedure produces false alarms together with hits at a reasonable rate for both. Importantly, in the case of limited target presentation time the procedure allows us to determine whether effects of information decay contribute to performance. Finally we also manipulated the luminance of the cues to test generality and robustness of our findings with respect to cue luminance.

The SAT-method has previously been applied in a variety of areas in cognitive psychology, including attentional cueing (Carrasco & McElree, 2001; Giordano, McElree & Carrasco, 2009), and memory (Reed, 1973). These studies show that the relationship between processing time and accuracy can be best described with the so-called SAT function. The SAT function assumes that response accuracy increases with processing time in an exponential fashion (see Figure 1 for illustrations and the Results section of Experiment 1 for the mathematical formula). The function has three parameters. The intercept parameter indexes the point in time at which the increase begins and accuracy departs from chance level. The sensitivity asymptote specifies the maximal possible accuracy. Finally, the “rate parameter” describes the growth rate of accuracy over time. The combination of the intercept and rate parameters can be interpreted as describing the speed of information processing (e.g., Giordano, McElree, & Carrasco, 2009). Note there are alternative models such as the Linear Ballistic Accumulation (LBA) model proposed by Brown and Heathcote (2008) which can also successfully accommodate decision making and choice response time (e.g. Farrell, Ludwig, Ellis & Gilchrist, 2009). In this model, evidence for alternative responses is independently accumulated in a linear manner, at different rates. Each accumulator begins with a starting amount of evidence and a response is made when the first accumulator reaches the threshold. However, by fitting an SAT-function here, we are able to compare our results to the results from similar studies using this method (e.g. Carrasco & McElree, 2001; Ivanoff & Klein, 2006).

Carrasco and McElree (2001) applied the SAT-method to an investigation of the effect of spatial cueing on visual search. They found that cueing not only improved asymptotic sensitivity but also accelerated the rate of information processing speed at the cued location (at least at short cue-target SOAs). McCormick and Francis (2005) also found that spatial cueing improved processing speed at short SOAs. In contrast to these studies on early facilitatory cueing, Ivanoff and Klein (2006) explored IOR using of the SAT-procedure. They examined sensitivity as a function of response time in both go/no-go and discrimination tasks using a time window procedure (Carrasco & McElree, 2001; Ivanoff & Klein, 2006; Wickelgren, 1977). Participants were required to respond within a 210 ms time window 120 ms, 240 ms, 360 ms or 480 ms after target presentation. In both tasks, IOR was observed in RTs across all but the longest time intervals between the cue and the target (480 ms). This effect on RTs was accompanied by a reduced *d'* at the cued locations for all but the shortest time interval (120 ms). No effect of a criterion shift was found apart from at the shortest time interval, when the criterion was higher for targets at cued relative to uncued locations. Together, these findings support the perceptual as well as the criterion shift account of IOR. The authors suggested that, early-on in target processing when the quality of stimulus evidence is poor, IOR is initially implemented as a criterion shift which biases participants against responding to targets at cued locations. However, later in time, when the quality of stimulus evidence improves, IOR appears to act upon perception, reducing sensitivity to cued targets and slowing RTs. The design of Ivanoff and Klein's (2006) study did not allow them to fit a SAT function as they used only four intervals between target presentation and the response window. It is possible however that their effect on perceptual sensitivity could arise for at least two reasons – an effect on the asymptotic level of sensitivity at cued and uncued locations or an effect on the time course of the build-up of perceptual information (see Figure. 1A and 1B for an illustration). The design of the current experiments overcomes this limitation by using 7 time intervals ranging from 90 ms to 1350 ms, to enable SAT functions to be plotted and asymptote and rate effects to be distinguished. In addition, Ivanoff and Klein (2006) used only unlimited target presentation times, yet different effects may emerge with short and prolonged target exposures. Here we will apply the time window procedure to both unlimited and limited target presentations to explore whether differences in target exposure contribute to the conflicting results found in the IOR literature. We used limited target presentation in the first experiment and fitted a single SAT function for the cued and uncued conditions (Figure. 1C). In Experiment 2 unlimited target presentations were used and there was a delay in information processing for the cued compared to the uncued target (Figure. 1B). In addition, both experiments showed a more conservative criterion at the cued than the uncued location.


A. Difference in asymptotic sensitivity

B. Difference in speed of information processing

C. Criterion shift

Figure 1. Hypothetical SAT function: *d'* sensitivity as a function of processing time. A) expected curves if IOR impairs only on the asymptote sensitivity reached by a stimulus. The functions maintain the same intercept and the rate of information processing, but differ in asymptote. B) expected curves if IOR affects the rate of information processing and the starting point at which stimulus information accumulates above chance. C) expected curves if IOR generates a criterion shift only. The figures show that the RT advantage for uncued over cued locations can be

associated with changes in sensitivity (A), the speed or the starting point of information processing (B), or a criterion shift (C). Note that RTs and/or *d'* measures are determined by the balance of speed and accuracy which participants adopt.

Experiment 1: Brief target presentation

In Experiment 1 a brief target presentation was used. With brief target presentations, Lupianez et al. (1997), Cheal et al. (1998) and Handy et al. (1999) have all found evidence indicating an effect of IOR on perception, since accuracy increased at cued compared to uncued locations. However, their studies did not control for speed-accuracy trade-offs nor did they determine the SAT function to assess the precise effect of IOR on performance. Our experimental procedure follows Ivanoff and Klein's (2006) second experiment, the main differences being that Ivanoff and Klein (2006) used an unlimited target presentation and 4 response windows. Here we limit the presentation of the target and use 7 response windows so that we are able to fit a complete SAT function. We also manipulated target luminance. Hunt and Kingstone (2003) and Reuter-Lorenz, Jha and Rosenquist (1996) have reported that reductions in target luminance increase IOR. Target luminance was manipulated as a between subject factor to test generality of our findings and to assess if there were differential effects of this factor across the SAT function.

Methods

Participants

Seventeen postgraduates (eight were tested with the bright target and nine with the dim target), ten females and seven males, aged from 22 to 40 years, with a mean age of 28.5 years participated. Participants were from the Psychology Department, Dalhousie University and they were naive as to the purpose of the study. The participants were paid 25 Canadian dollars and took part in approximately two sessions of 70 minutes each which were completed on different days within the same week. All participants reported normal or corrected-to-normal vision. All except three were right handed.

Apparatus

Stimulus presentation and data collection were performed using E-Prime 1.2. Stimuli were presented on a 17-inch view Sonic PT775 monitor controlled by a personal computer and responses were polled from the standard keyboard.

Stimuli

The stimulus display (see Figure 2) consisted of a fixation circle (68.86 cd/m^2) subtending 0.6˚ in diameter and 0.07˚ thick, presented at the centre of the screen (background 0.82 cd/m^2), and two outline boxes with asterisks (2.5 cd/m^2) in the centre of boxes, aligned horizontally to the left and right of the fixation cross. The distance between the fixation circle and the centre of each box was 7.1˚. Each box had a 0.15˚ thick frame and subtended 3.3˚ in height and 3.0˚ in width. The asterisk was made up from an overlapping × and +, the + was 2.3˚ in length and 0.2˚ thick and the × was 3.4˚ in length and 0.15˚ thick, with both elements containing with the same number of pixels. The cue comprised a luminance increase of the box outline to 123.69 cd/m^2 for the bright cue and to 23.30 cd/m^2 for the dim cue, each lasting 80 ms. The cue back to fixation comprised a thickening of the fixation circle to 0.15° for 100 ms. The target was a luminance increase of either the + or the × to 123.69 cd/m^2 (the bright target) or to 23.30 cd/m^2 (the dim target) for 80 ms.

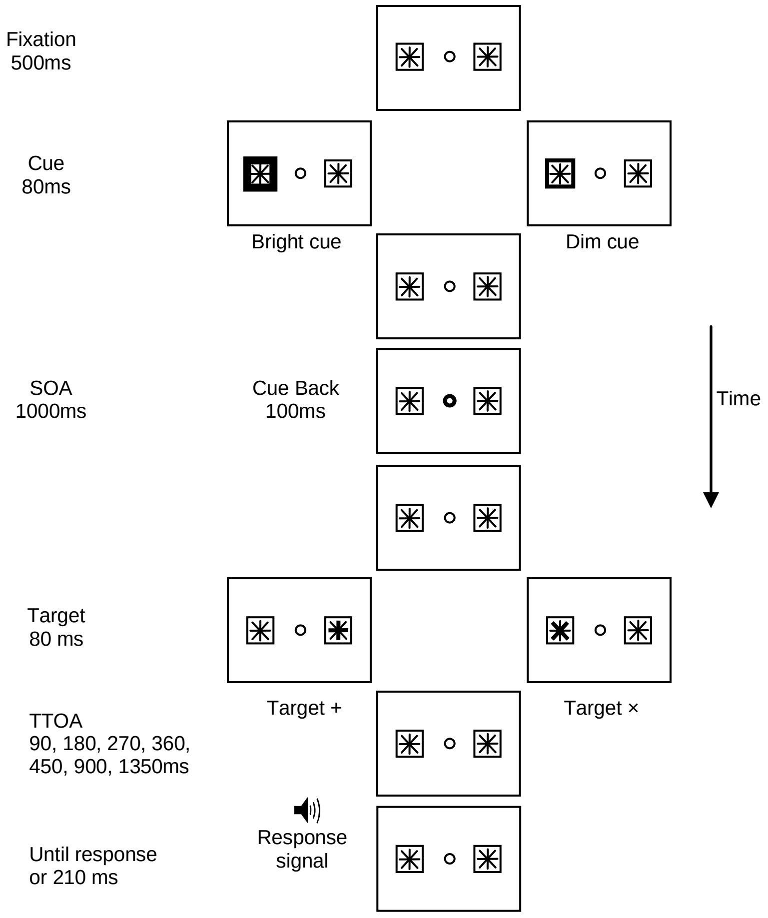


Figure 2. The trial sequence used in Experiment 1.

Procedure

The experiment was conducted in a quiet, dimly lit room. Participants were given both written and oral instructions for the task. Participants were individually tested sitting at a distance of approximately 57 cm from the computer screen. Response times (RT) and response accuracy were recorded by the computer. The participants were instructed to maintain fixation throughout the experiment and not to make any eye movements. They were also told that cues were uninformative as to the locations of the targets.

The trial sequence is shown in Figure 2. Each trial began with a blank 500 ms intertrial interval, not shown in Figure 2. Following this, a display consisting of a central fixation circle and two peripheral boxes with asterisks in the middle was presented for 500 ms. Subsequently one of the peripheral boxes was cued by increasing the luminance of the outline of the box for 80 ms. This increase was experienced as a flash. The cue comprised two levels of luminance changes. After the cue was removed, the fixation circle and the two boxes with asterisks were presented alone for 170 ms. A return cue was presented by enlarging the fixation circle for 100 ms to ensure that attention does not remain at the cued location. The fixation circle and two boxes with asterisks were then presented alone for 650 ms. Finally, the target was presented with a luminance increase of the + or the × in the left or right boxes. Target presentation time was 80 ms and comprised two levels of luminance change. The targets, the + or ×, appeared with equal frequency.

One of seven target-tone onset asynchronies (TTOAs) (90, 180, 270, 360, 450, 900, 1350 ms) was presented in separate blocks, for each day. Whether the TTOAs are blocked or mixed appears to have little effect on the SAT function (Miller, Sproesser, & Ulrich, 2008). The order of the TTOAs was randomised. The tone (high pitch) signalled a 210 ms response window in which participants were instructed to make the appropriate response. Half participants were instructed to make a keypress with the index fingers of the left hand on the Z key and the middle finger on the A key and the other half were instructed to use their right index finger on the M key and middle finger on the K key. Within each group, half were also instructed to press index finger whenever + was presented and to press the middle finger whenever × was presented or vice versa. Detection time for the target was measured from the target onset to response. If no response was made within the response window, an error tone (low pitch) was given at the end of each response window to inform participants; this provided no information about whether the responses were correct.

After the instructions had been understood, the participants were administered practice trials until they were able to perform the task correctly. The responses for these trials were not recorded.

Design

The experiment consisted of a 2 (Cue luminance: bright/dim) × 2 (Cue: cued/uncued) × 7 (TTOA: 90/180/270/360/450/900/1350 ms) × 2 (Target luminance: bright/dim) mixed design with target as a between-subject factor. The experiment consisted of 1792 trials in total, which were divided by 14 blocks and the first 16 trials of each block were excluded from analyses. Within each block, the trials were randomised with respect to trial type, and equally divided with respect to cue luminance, cue, SOA and target location. Each of the experimental conditions contained 56 trials, with 28 trials using target + and 28 trials with target ×.

Data analysis

Sensitivity was calculated by:

$$d' = z(H) - z(F) \tag{1}$$

Where *z(H)* is the z-score for correct responses to + (hits) and *z(F)* is the z-score for incorrect responses to × (false alarm). Extreme values of hits and false alarms were treated by subtracting or adding 0.5 respectively ('Log-linear' transformation, Snodgrass & Corwin, 1988).

The Criterion was given by:

$$c = -[z(H) + z(F)]/2 \tag{2}$$

The criterion value in a discrimination task only indicates bias toward a particular response, either + or ×. To determine additional evidence for a criterion shift, we used the following indirect measures: anticipations, response frequencies and misses (see Ivanoff & Klein, 2006). Anticipations are the percentages of responses after target onsets but before the response signal. Response frequency refers to the percentage of responses within the response window (including correct and wrong responses). Misses are responses made either after the response window or a failure to respond on a trial (time limit: 500 ms after the response). A more conservative criterion is reflected by an increase of misses, and a decrease of anticipations. The IOR-effect on RTs was measured based on the tone-response time (tone-RT) analysis. The tone-RT is the time from the response signal (tone) to the response when a correct key press occurred within the response window.

The dependent variables were analyzed using ANOVAs with the Greenhouse-Geisser correction applied when the Mauchly's test of Sphericity was significant.

Results

The hit rate (response rate within the response window) was 79.05% on average with a minimum of 68.62%. The accuracy rate of hits was 84.75% on average with a minimum of 75.87%. Figure 4 shows that *d'* increases with increasing processing time. Hence, despite our use of a brief target presentation, information about the target increased rather than decayed as the TTOA was increased. Since the time course of *d'* is very similar to other experiments employing the SAT-methodology (e.g. Carrasco & McElree, 2001) we fitted the SAT-function as suggested by Wickelgren (1977).

Fit of SAT function

We used the following mathematical description of the SAT-function to fit the data of *d*' for each TTOA condition and average processing time (TTOA plus RTs for correct responses) for that condition (Liu & Smith, 2009; Wickelgren, 1977):

$$d'(t) = \begin{cases} \lambda(1-e^{-(t-\delta)/\beta}), t > \delta \\ 0 \qquad\quad , t \le \delta \end{cases} \tag{3}$$

where λ is the asymptotic parameter reflecting the accuracy with maximal processing time; $1/\beta$ describes the rate at which accuracy grows from chance ($d' = 0$) to asymptote; and δ is an intercept parameter indexing the discrete point in time when accuracy departs from chance.

We used a hierarchical model-testing scheme to find the most parsimonious SAT-model for each participant (Carrasco & McElree, 2001; Giordano, McElree, & Carrasco, 2009; Liu & Smith, 2009). The model selection procedure began with the full model, where each condition was modeled with a unique set of parameters. To find the simplest model, we used the G^2 statistic (the difference in deviance values between two nested models; Liu & Smith, 2009). The maximum likelihood criterion was used to fit the models with Matlab's fminsearch (Liu & Smith, 2009). In addition the resulting model was characterized with the adjusted-R^2 (Dosher, Han, & Lu, 2004):

$$adj\ R^2 = 1 - \frac{\sum_{i=1}^{n} (d_i - \hat{d_i})^2 / (n-k)}{\sum_{i=1}^{n} (d_i - \bar{d})^2 / (n-1)} \tag{4}$$

Where d_i is the observed *d'* values, $\hat{d}_i$ is the predicted *d'* values, $\bar{d}$ is the mean of *d'*, *n* is the number of data points and *k* is the number of free parameters.

To analyze the results across all participants, the parameters for each participant were entered into three separate three-way within-participants ANOVAs (Liu & Smith, 2009).

The final models produced an average adjusted-R^2 value of 0.930 across participants, with a minimum of 0.858. The parameters of asymptote, slope and intercept in the final model for each participant were entered into three separate 2 × 2 × 2 ANOVAs with cue luminance (bright or dim), cue (cued or uncued) as within-subject factors and target luminance (bright or dim) as a between-subject factor. Figure 3 shows the mean of the three sets of parameters[1]. There were no significant effects of any factor for any of the parameters (*asymptote*: cue (F (1, 15) = 0.20, p = 0.66); *intercept*: cue (F (1, 15) = 1.04, p = 0.32); 1/slope: cue (F (1, 15) < 0.001, p = 0.99). Figure 4 illustrates the mean of the curve fitting procedure for d' for each participant as a function of processing time, cue luminance and cue. The mean data points for each condition are also shown. The pattern of the curve in Figure 4 is consistent with pattern C in Figure 1.

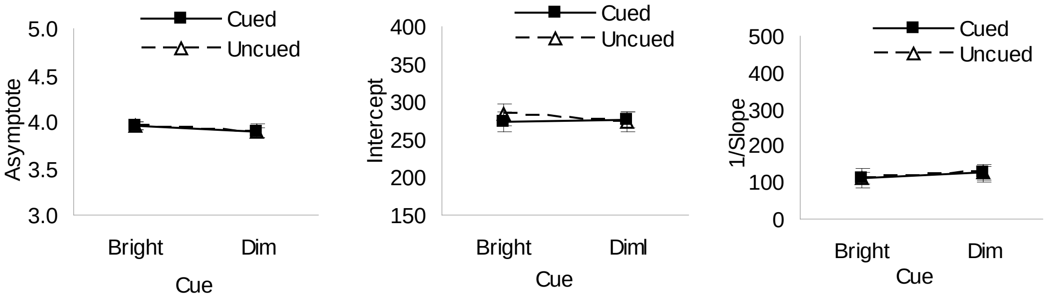


Figure 3. Mean parameters in Experiment 1. a) asymptote. b) intercept. c) 1/slope.

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[1] The between-subject factor target luminance was merged in the figure (the same holds for the other figures and tables in this experiment) as there was no major effect of target luminance. This makes the figures here consistent with the figures and tables in Experiment 2 where target luminance was not manipulated.

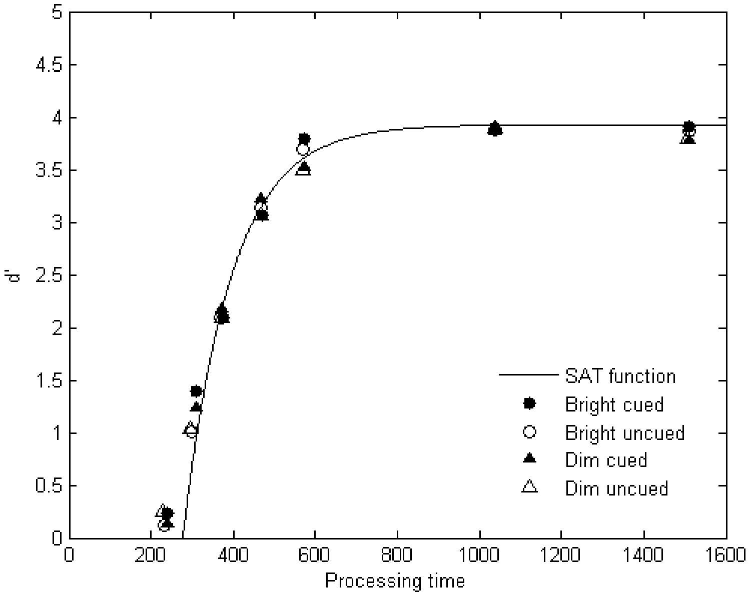

Figure 4. Average sensitivity as a function of processing time for 4 conditions. Smooth functions show the average of the best fitting model based on 3 parameters of equation 1. The marked crosses show the mean data point for each condition across participants. Note the curve was fitted for each individual but not for the mean data.

Tone-RT

The mean tone-RTs for each condition are shown in Table 1. The tone-RTs were entered into a 2 × 2 × 7 × 2 ANOVA with cue luminance (bright or dim), cue (cued or uncued), TTOA (90, 180, 270, 360, 450, 900 or 1350ms) as within-subjects factors and target luminance (bright or dim) as a between-subjects factor. The main effect of cue was significant, F (1, 15) = 52.69, $p < 0.001$. RTs were 4.74 ms faster in the uncued condition than in the cued condition. There was a cue × TTOA interaction (F (6, 90) = 5.48, $p < 0.001$) reflecting greater IOR at early TTOAs. The main effect of TTOA was significant, F (6, 90) = 25.19, $p < 0.001$, indicating decreasing then increasing (a U-shape function) RTs across the TTOAs. There was also a significant cue luminance × target luminance interaction (F (1, 15) = 4.77, $p < 0.05$) (Figure 5). When the target was dim, RT was slowed following the bright cue (131.28 ms) relative to the dim cue (129.10 ms), however the data went in the opposite direction when the target was bright (bright cue: 125.85 ms; dim cue: 126.51 ms). None of the other main effects or interactions reached significance (all *ps* > 0.1).

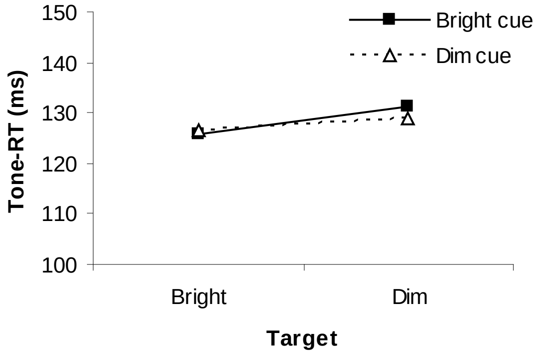

Figure 5. The significant cue luminance × target luminance interaction of tone-RT.

	Conditions		TTOA (ms)						
			90	180	270	360	450	900	1350
Tone-RTs (ms) for correct responses	Bright cue	Cued	**150.5**	**131.1**	**105.2**	110.6	122.9	139.7	159.2
		Uncued	**142.3**	**117.5**	**98.7**	107.7	119.6	138.6	158.6
	Dim cue	Cued	**148.5**	**128.8**	**102.8**	107.9	124.1	138.9	159.3
		Uncued	**140.3**	**115.1**	**100.1**	106.5	120.0	139.8	158.2
d'	Bright cue	Cued	0.24	**1.40**	2.10	3.07	**3.79**	3.89	3.91
		Uncued	0.12	**1.01**	2.10	3.13	**3.70**	3.88	3.87
	Dim cue	Cued	0.14	**1.24**	2.18	3.22	**3.52**	3.86	3.78
		Uncued	0.25	**1.04**	2.10	3.06	**3.49**	3.90	3.79
Anticipations (%)	Bright cue	Cued	1.68	0.95	**1.47**	10.92	9.77	10.19	7.46
		Uncued	1.58	1.05	**4.31**	11.45	10.92	10.71	7.88
	Dim cue	Cued	1.89	0.53	**2.63**	10.40	10.50	10.19	9.03

		Uncued	2.52	1.26	**5.46**	12.39	11.03	8.51	9.66
Response frequencies (%)	Bright cue	Cued	**72.58**	81.30	**89.18**	78.36	76.16	79.83	75.21
		Uncued	**79.31**	83.93	**86.76**	77.73	77.21	78.47	74.47
	Dim cue	Cued	**70.06**	81.72	**87.92**	77.73	78.89	78.68	74.16
		Uncued	**77.00**	83.72	**85.50**	77.31	74.89	81.41	73.84
Misses (%)	Bright cue	Cued	**22.58**	**15.55**	7.35	9.56	**13.66**	9.77	17.02
		Uncued	**17.23**	**11.97**	6.72	9.87	**11.45**	10.29	17.23
	Dim cue	Cued	**25.21**	**15.97**	8.30	10.82	**9.98**	11.03	16.28
		Uncued	**17.33**	**12.39**	7.35	8.72	**13.13**	9.77	16.07
Criterion	Bright cue	Cued	0.12	0.16	-0.01	0.02	-0.05	0.02	0.01
		Uncued	0.05	0.03	0.06	0.07	0.01	-0.05	-0.04
	Dim cue	Cued	0.15	0.11	0.02	0.09	-0.02	-0.03	-0.04
		Uncued	0.02	0.13	0.08	0.10	0.07	-0.05	0.03

Table 1. Mean tone RTs, *d'*, percentage for anticipations, percentage for response frequencies percentage for misses and criterion for each condition in Experiment 1. The columns in bold font indicate that an ANOVA for the respective TTOA found significant effects (see text for details). Note the criterion value in a discrimination task only indicates a bias towards a particular response. Here a positive criterion value indicates a response bias towards + and negative value indicates a bias towards ×.

We conducted separate ANOVAs with cue luminance and cue as factors at each TTOA[2]. Figure 6 shows the mean IOR (positive values indicate IOR) for each combination of cue luminance and TTOA (the between-subject factor of target luminance

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[2] To explore further the significant cue × TTOA interaction, separate ANOVAs were performed at each TTOA. Moreover in earlier research, Ivanoff and Klein (2006) showed that tone-RT, *d'*, anticipation, response frequency and miss measures behave differently at contrasting TTOAs, which they used as evidence of early criterion shifts and late perceptual effects of IOR as a function of the TTOA. Therefore, we performed separate ANOVAs at each TTOA for all these measurements for all experiments (even though some of the interactions were not significant) in order to examine whether these findings were replicated in the current study.

was merged for all the figures). There were significant IOR effects at TTOA 90 ms [magnitude 8.21 ms] (*F* (1, 16) = 19.45, *p* < 0.001); TTOA 180 ms [magnitude 13.67 ms] (*F* (1, 16) = 31.22, *p* < 0.001) and TTOA 270ms [magnitude 4.61 ms] (*F* (1, 16) = 7.07, *p* < 0.05).

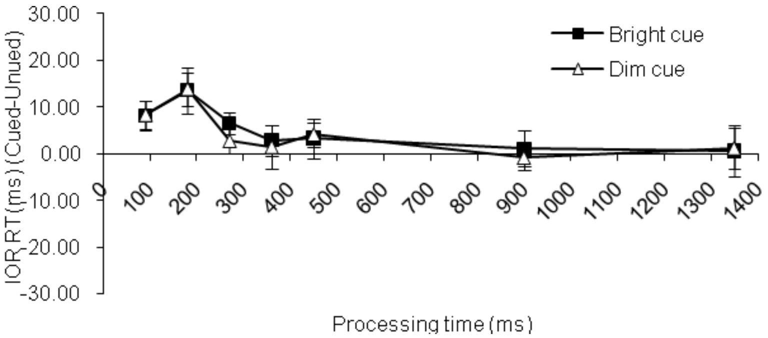

Figure 6. IOR on RTs in Experiment 1. Positive values indicate IOR on RT.

Sensitivity (d')

Table 1 shows *d'* for each condition. From the fitted SAT-curve it is clear that *d'* reached ceiling before TTOA 900 ms. We therefore omitted TTOAs 900 ms and 1350 ms from the analyses. The same analysis was conducted in Experiment 2 here. The main effect of cue was significant (*F* (1, 15) = 7.38, *p* < 0.05); *d'* was 0.09 higher for targets at the cued than the uncued location. There was also a significant TTOA main effect (*F* (4, 60) = 150.48, *p* < 0.001); *d'* increased as TTOA increased from 90 ms to 450 ms. None of the other main effects were reliable and there were no interactions (all *ps* > 0.1).

Figure 7 shows the mean IOR in *d'* for each combination of cue luminance and SOA (a positive value indicates a lower *d'* at the cued location). Separate ANOVAs on cue luminance × cue were performed at each TTOA. There was a significant main effect of cue at TTOA 180 ms (F (1, 16) = 6.67, $p < 0.05$), d' was 0.30 higher for cued trials than uncued trials. There was a significant main effect of cue luminance at TTOA 450 ms (F (1, 16) = 7.61, $p < 0.05$); d' was 0.24 higher for the bright cue than the dim cue.

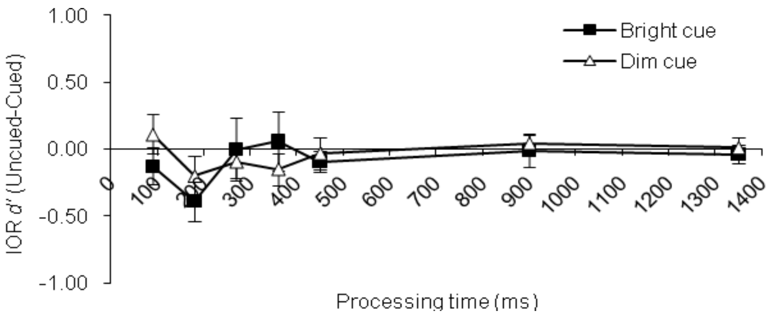

Figure 7. IOR on d' in Experiment 1. Positive values indicated lower d' at the cued location.

Anticipations

Anticipations (responses after target onsets but before the response signal) for each condition, presented as percentages, are shown in Table 1. The main effect of cue was significant (F (1, 15) = 5.01, $p < 0.05$); anticipations were 0.78% lower for targets at the cued than the uncued location. The main effect of TTOA was significant (F (2.92, 43.86) = 15.34, $p < 0.001$); anticipations increased as the TTOA lengthened and were constant after a TTOA of 360 ms. Finally the cue luminance × cue × target luminance interaction was also significant (F (1, 15) = 5.00, $p < 0.05$). Anticipations were lower for targets at the cued than the uncued location when the cue and target luminance were both dim, but not with the other luminance combinations. None of the other main effects were reliable and there were no interactions (all $ps > 0.08$).

Separate ANOVAs with the factors cue luminance and cue, at each TTOA, showed a significant cue main effect at TTOA 270 ms (F (1, 16) = 16.29, $p < 0.001$).

There were 2.84% fewer anticipations made to the cued than to the uncued location in this case.

Response frequency

Table 1 shows the response frequencies (both correct and incorrect responses within the response window) as percentages in each condition. The main effect of TTOA was significant (F (3.08, 46.16) = 6.65, $p < 0.001$). The response frequency was higher at TTOA 270 ms than at the other TTOAs. The cue × TTOA interaction was also significant (F (6, 90) = 4.94, $p < 0.001$). No other main effects or interactions were significant (all $ps > 0.1$).

Separate ANOVAs with the factors cue luminance and cue were conducted for each TTOA. There was a significant main effect of cue at TTOA 90 ms (F (1, 16) = 11.48, $p < 0.01$); 6.83% fewer responses were made to targets at the cued relative to the uncued location. There were also main effects of cue at TTOA 270 ms (F (1, 16) = 4.64, $p < 0.05$); there were 2.42% more responses to targets at the cued relative to the uncued location.

Misses

The percentages of misses (responses after the response window or a failure to respond on a trial) are provided in Table 1. The main effect of cue was significant (F (1, 15) = 13.04, $p < 0.01$), with 1.68% more misses to targets at cued than uncued locations. The main effect of TTOA was significant (F (3.01, 45.16) = 11.60, $p < 0.001$), with misses decreasing and then increasing as TTOA increased. In addition, the cue × TTOA interaction was significant (F (3.57, 53.56) = 4.92, $p < 0.01$) as was the cue × TTOA × target luminance interaction (F (6, 90) = 2.96, $p < 0.05$). None of the other main effects or interactions reached significance (all *ps* > 0.1).

Separate ANOVAs with the factors cue luminance and cue at each TTOA revealed the following. There were more misses at TTOA 90 ms (F (1, 16) = 12.07, $p < 0.01$) and TTOA 180 ms (F (1, 16) = 6.97, $p < 0.05$) to targets at cued compared with uncued locations [effect sizes 6.62% and 3. 57%]. There was also a cue luminance × cue interaction at TTOA 450 ms (F (1, 16) = 5.72, $p < 0.05$). More misses were made to targets at cued than uncued locations when the cues were bright, however this effect was reversed when the cues were dim.

Criterion (c)

Table 1 shows the criterion measure for each condition. Criterion values reflect bias toward a particular response. The main effect of TTOA was significant (F (3.75, 56.28) = 3.03, $p < 0.05$) with c decreasing (from positive to negative values) as TTOA increased. There was a slightly greater bias to the + than the × at early TTOAs but this was reversed at late TTOAs. None other main effects or interactions reached significance (all *ps* > 0.1).

Discussion

The results showed that the quality of target information as measured with *d'* increased with increasing processing time (at longer TTOAs). This accrual of target information took place despite the brief target presentation, providing no evidence for target decay being a critical factor in this study. This time course for *d'* is similar to previous experimental findings with the SAT-methodology (e.g. Carrasco & McElree, 2001). Nevertheless, our curve fitting procedure did not reveal significantly different parameters across the different experimental conditions, instead, all conditions followed the same SAT-function.

There was evidence for IOR in terms of RTs, especially for short TTOA intervals (TTOAs of 90, 180 and 270 ms). These results are largely consistent with findings by Ivanoff and Klein (2006), who also demonstrated an IOR-effect for early response windows. It also showed a significant overall effect of cueing on *d'*, with greater sensitivity for targets at cued relative to uncued locations. In the absence of any difference in the parameters of the SAT function, this pattern is consistent with the criterion shift account of IOR (see Figure 1C). Also note that the results were largely robust to changes in cue and target luminance.

Converging evidence for a criterion shift was also found from the analysis of anticipations, response frequency and misses. Participants tended to make fewer anticipations and more misses to targets at the cued location relative to those at uncued locations, particularly at short TTOAs. There were no cueing effects on response frequency measures. This pattern of responses indicates that participants were more conservative when responding to targets at cued relative to uncued locations. Finally, the manipulation of cue and target luminance had little impact on the results.

The present evidence for a criterion shift account of IOR contradicts at least one conclusion from Ivanoff and Klein's (2006), who found that *d'* was significantly decreased at the cued compared with the uncued location – a result consistent with a perceptual account of IOR. However, there is at least one major methodological difference between our study and that of Ivanoff and Klein. Our target appeared for 80 ms while their target was presented until the response. In the next experiment we will test whether this difference is responsible for the contrasting findings[3].

Experiment 2: Unlimited target presentation times

The second experiment investigated whether the target presentation duration was critical to the differences between our data and those of Ivanoff and Klein's (2006). In this case the target presentation time was unlimited, making our experiment essentially a replication of Ivanoff and Klein (2006) only with more TTOAs.

Methods

The Method was the same as for the first experiment, except where mentioned.

Participants

Ten volunteers, nine females and one male, aged from 18 to 28 years were recruited. The participants were naive as to the purpose of the study and none had taken

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[3] There was also another methodological difference compared to Ivanoff and Klein (2006). They used a target onset instead of a luminance change which may have been responsible for our partial failure to replicate their results. We tested this idea in a separate experiment but did not find a reliable difference between this experiment and Experiment 1.

part in previous experiment. All participants reported normal or correct-to-normal vision. All were right handed.

Stimuli

Since the effects in the previous experiment were immune to the difference in the two levels of cue luminance we decided to increase the cue thickness to 0.4°[4]. The luminance value remained the same as in Experiment 1 except the target luminance was always dim as Experiment 1 did not show an effect of target luminance. The target remained visible until a response was made or the response window had elapsed.

Results

The mean hit rate was 76.06% with a minimum of 67.73%. The accuracy rate of hits was 84.52% per participant on average with a minimum of 78.10%. The SAT function was fitted and the data were analysed as before.

SAT function

The average adjusted-R^2 across participants was 0.894, with a minimum of 0.767. Figure 8 shows the mean of the three sets of parameters. An ANOVA revealed a significant main effect of cue on the intercept parameter (F (1, 9) = 6.00, p = 0.037); the time at which information accumulation rose above chance was delayed 18.17ms for targets at the cued compared with the uncued location. None of other effects or

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[4] Initially this modification was tested in combination with the limited onset target presentation to examine further the generality and robustness of our findings. However we did not find an effect in that separate experiment. For consistency reasons, we maintained the larger cue size in the current experiment.

interactions were significant (*asymptote*: cue luminance (*F* (1, 9) = 0.00, *p* = 0.99); cue (*F* (1, 9) = 0.50, *p* = 0.50); interaction (*F* (1, 9) = 1.02, *p* = 0.34)); *intercept*: cue luminance (*F* (1, 9) = 1.86, *p* = 0.21); interaction (*F* (1, 9) = 1.86, *p* = 0.21)); *1/slope*: cue luminance (*F* (1, 9) = 2.15, *p* = 0.18); cue (*F* (1, 9) = 0.40, *p* = 0.54); interaction (*F* (1, 9) = 0.48, *p* = 0.51)). The mean curve fits and data points for each condition are presented in Figure 9. The pattern of the curves in Figure 9 is consistent with pattern B in Figure 1.

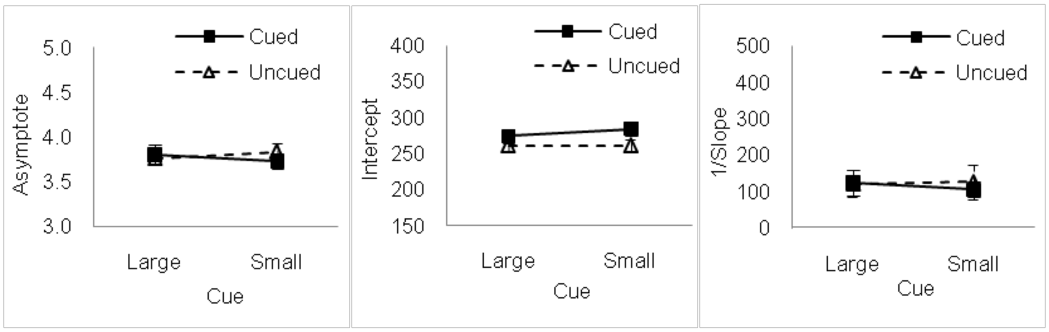

Figure 8 mean parameters in Experiment 2. a) asymptote. b) intercept. c) 1/slope.

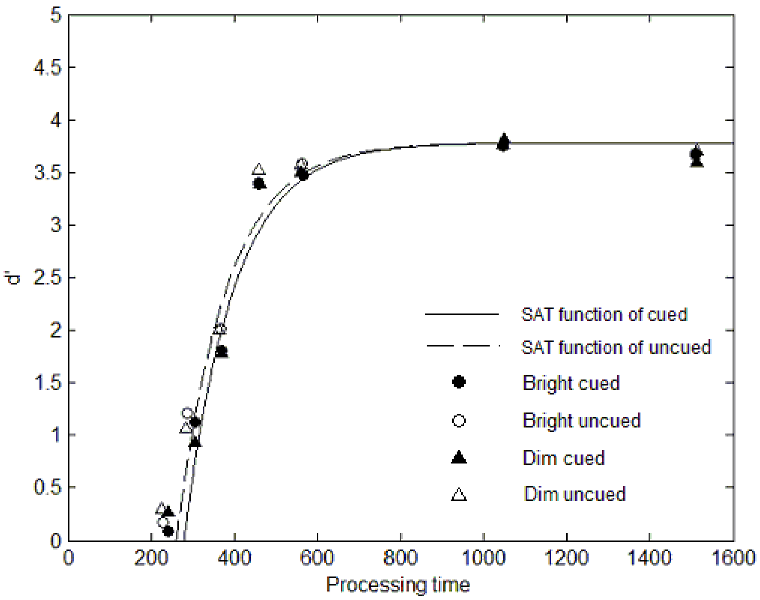

Figure 9. Average sensitivity as a function of processing time for the critical 4 conditions (bright cued, bright uncued, dim cued and dim uncued). The cued conditions have a greater intercept

than the uncued conditions, which reflects delayed starting points for information processing. This effect was identical for the bright and the dim cues.

Tone-RT

The main effect of cue was significant (*F* (1, 9) = 7.59, $p < 0.05$) (Table 2). RTs were 5.67 ms slower for targets at cued than uncued locations. The main effect of TTOA was significant (*F* (6, 54) = 33.41, $p < 0.001$); there was a U-shape function relating overall RT to TTOA. In addition, the cue × TTOA interaction was significant (*F* (6, 54) = 10.39, $p < 0.001$). IOR appeared at the earlier TTOAs and disappeared at later TTOAs (see Table 2). None of the other main effects or interactions reached significance (cue luminance × cue (*F* (1, 9) = 0.48, $p = 0.50$); cue luminance × cue × TTOA (*F* (6, 54) = 0.15, $p = 0.99$)).

	Conditions		TTOA (ms)						
			90	180	270	360	450	900	1350
Tone-RTs (ms) for correct responses	Bright cue	Cued	**150.3**	**126.7**	100.6	98.2	**117.3**	146.4	158.8
		Uncued	**138.1**	**106.9**	98.0	98.9	**113.9**	146.9	159.7
	Dim cue	Cued	**149.9**	**125.4**	99.4	101.2	**111.1**	148.3	161.5
		Uncued	**134.5**	**104.2**	95.1	99.6	**109.8**	147.1	162.9
d'	Bright cue	Cued	0.09	1.12	1.80	3.38	3.48	3.76	3.68
		Uncued	0.17	1.21	2.01	3.40	3.59	3.77	3.67
	Dim cue	Cued	0.27	0.93	1.78	3.39	3.50	3.82	3.59
		Uncued	0.30	1.07	2.00	3.52	3.57	3.76	3.70
Anticipations (%)	Bright cue	Cued	1.96	0.54	**3.04**	10.54	13.21	**10.36**	**8.57**
		Uncued	1.43	0.89	**7.86**	14.82	9.82	**9.82**	**8.93**
	Dim cue	Cued	1.43	1.07	**3.57**	12.50	13.39	**13.39**	**17.50**
		Uncued	1.79	1.96	**8.21**	14.64	14.11	**12.68**	**11.43**

Response frequencies (%)	Bright cue	Cued	**65.71**	80.18	85.36	82.14	75.54	74.82	**69.11**
		Uncued	**80.00**	85.00	81.07	78.04	79.82	73.04	**66.43**
	Dim cue	Cued	**66.07**	79.46	83.39	78.57	75.71	74.29	**59.11**
		Uncued	**78.39**	83.21	81.25	79.82	76.96	73.21	**63.93**
Misses (%)	Bright cue	Cued	**29.82**	**15.89**	9.11	6.43	10.89	**14.82**	21.07
		Uncued	**16.61**	**11.07**	10.18	6.43	10.18	**16.79**	23.93
	Dim cue	Cued	**28.93**	**15.54**	11.61	7.86	10.00	**11.96**	25.00
		Uncued	**17.50**	**12.86**	9.11	4.82	8.75	**14.11**	25.00
Criterion	Bright cue	Cued	0.01	0.06	0.01	-0.15	-0.04	-0.03	0.04
		Uncued	0.14	-0.02	0.05	-0.05	0.01	-0.04	0.00
	Dim cue	Cued	0.15	0.04	0.02	-0.06	-0.04	0.02	0.03
		Uncued	0.09	0.01	0.11	0.05	-0.02	0.07	-0.04

Table 2. Mean tone RTs, *d'*, percentage for anticipations, percentage for response frequencies percentage for misses and criterion measures for each condition in Experiment 2. The columns in bold font indicate that an ANOVA for the respective TTOA found significant effects (see text for details). Note the criterion value in a discrimination task only indicates a bias towards a particular response. Positive criterion values indicate a response bias towards + and negative value indicate a bias towards × here.

Figure 10 shows the mean IOR for all combinations of cue luminance and SOA. Separate ANOVAs with the factors of cue luminance and cue were performed at each TTOA. There were significant effects of cue at TTOAs 90 ms (F (1, 9) = 14.80, $p <$ 0.01) and 180 ms (F (1, 9) = 23.97, $p <$ 0.01) [magnitude of IOR effects: 13.82 and 20.48 ms]. There was a main effect of cue luminance at TTOA 450 ms (F (1, 9) = 7.58, $p <$ 0.05), with RTs slower after a bright than a dim cue (a 5.15 ms effect).

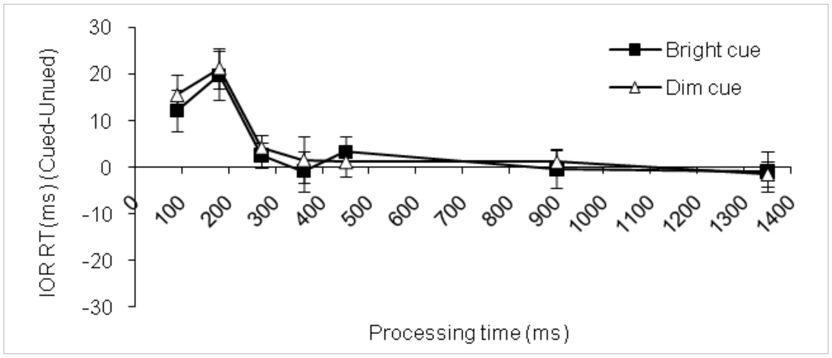

Figure 10. IOR on RTs in Experiment 2. Positive values indicate IOR.

Sensitivity (d')

Data from TTOAs 90 ms to 450 ms were entered into an ANOVA (Table 2). The main effect of TTOA was significant (*F* (4, 36) = 141.65, *p* < 0.001); *d'* increased as TTOA increased from TTOA 90 to 450 ms. No other main effect or interaction reached significance (cue (*F* (1, 9) = 2.64, *p* = 0.14); cue luminance × cue (*F* (1, 9) = 0.06, *p* = 0.81); cue × TTOA (*F* (4, 36) = 0.33, *p* = 0.85); cue luminance × cue × TTOA (*F* (4, 36) = 0.07, *p* = 0.99)).

Figure 11 shows the mean IOR in *d'* for each combination of cue luminance and SOA. Separate ANOVAs on cue luminance × cue were performed on each TTOA. There were no significant effects (the largest *F* was 2.59).

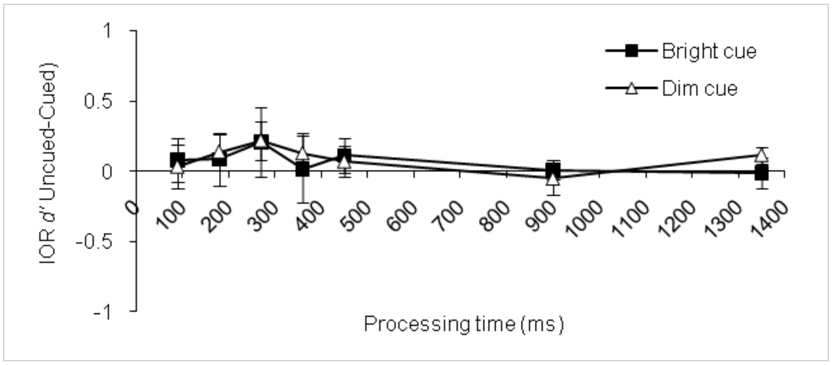

Figure 11. IOR on *d'* in Experiment 2. Positive values indicated lower *d'* at the cued location.

Anticipations

The anticipations for each condition are shown in Table 2. The main effect of cue luminance was significant (F (1, 9) = 9.34, $p < 0.05$), indicating 1.85% fewer anticipations in the bright than the dim cue trials. The main effect of TTOA was significant, F (2.07, 18.63) = 10.10, $p < 0.001$; anticipations increased and stayed constant as TTOA increased. The cue × TTOA interaction was also significant, F (6, 54) = 5.75, $p < 0.001$.

Separate ANOVAs with the factors cue luminance and cue were conducted at each TTOA. There were significant main effects of the cue at TTOA 270 ms and 1350ms (F (1, 9) = 13.73, $p < 0.01$, and (F (1, 9) = 7.62, $p < 0.02$); there were respectively 4.73% fewer anticipations to the cued than the uncued location at the short TTOA and a 2.86% reversed effect at thee long TTOA. There was also a reliable cue luminance effect at TTOA 900 ms (F (1, 9) = 9.79, $p < 0.05$) [2.95% fewer anticipations were made to the bright than the dim cue].

Response frequencies

The response frequencies are presented in Table 2. The main effect of cue luminance was significant (F (1, 9) = 26.54, $p < 0.01$); there were 1.63% more frequent responses in the bright cue trials than in the dim cue trials. The main effect of cue was significant (F (1, 9) = 10.29, $p < 0.05$); there were 2.19% fewer responses to targets falling at cued relative to uncued locations. The main effect of TTOA was significant (F

(6, 54) = 9.88, $p < 0.001$). Hits increased and then decreased as TTOA increased. The cue × TTOA interaction was also significant (F (6, 54) = 7.56, $p < 0.001$).

Separate ANOVAs with cue luminance and cue as factors at each TTOA showed a significant cue main effect at TTOA 90 ms (F (1, 9) = 17.07, $p < 0.01$); there were 13.30% fewer responses to targets at the cued location than to targets at the uncued location. There was also a main effect of cue luminance at TTOA 1350 ms (F (1, 9) = 7.93, $p < 0.05$); there were 6.25% more responses after bright than dim cues.

Misses

The percentages of misses are provided in Table 2. The main effect of cue luminance was significant (F (1, 9) = 26.54, $p < 0.01$); there were 0.02% more frequent misses to targets after a bright than after a dim cue. The main effect of cue was significant (F (1, 9) = 8.08, $p < 0.05$). There were 2.26% more frequent misses to targets at cued than uncued locations. The main effect of TTOA was significant (F (6, 54) = 19.43, $p < 0.001$). Misses first decreased and then increased as TTOA increased. The cue × TTOA interaction was also significant (F (6, 54) = 9.47, $p < 0.001$).

Separate ANOVAs with the factors cue luminance and cue at each TTOA showed significant main effects of cue at TTOA 90 ms and 180ms (F (1, 9) = 16.68, $p < 0.01$ and F (1, 9) = 5.44, $p < 0.05$) [12.32% and 3.75% more misses to cued than to uncued locations]. There was also a significant cue luminance main effect at TTOA 900 ms (F (1, 9) = 13.33, $p < 0.01$), with 2.77% more misses were made after bright than dim cues.

Criterion (c)

Table 2 shows the criterion measure for each condition. In this experiment, the cue main effect was unexpectedly significant (F (1, 9) = 25.16, $p < 0.05$). There was a slightly greater bias to the + than the × at the uncued location.

Discussion

The RT results were consistent with the first experiment in demonstrating IOR especially at the first two TTOAs.

Unlike the first experiment, the present experiment yielded two distinct SAT functions for cued and uncued trials. IOR delayed the point in time when the target information started to accumulate above chance (the intercept parameter). This is consistent with Ivanoff and Klein's (2006) Experiment 2 (Figure 5 in their paper). However in contrast to our results, their pattern, due in part to the limited number of TTOAs, could be attributed to either an intercept-effect or an effect on the asymptote of the sensitivity function. Our data, however, provide a clear indication for an effect of IOR on the dynamics of perceptual coding, indexed by the intercept parameter on the SAT-function.

In addition, the data from this experiment again point to a more conservative criterion being adopted for targets at the cued compared to the uncued location. This was reflected by fewer hits and more misses to targets falling on cued relative to uncued locations.

Given the apparent differences in the SAT function for Experiment 2 compared with the earlier experiment, a formal comparison was undertaken.

Comparison across experiments

SAT function

The parameters were analysed across two experiments with experiment as the between-subject factor. The ANOVA revealed a cue × experiment interaction for the *intercept* parameter (F (1, 25) = 6.71, $p < 0.05$). This interaction was driven by the main effect of the cue only being significant in Experiment 2 (a greater intercept for cued than uncued trials). Similar analyses on the other SAT parameters revealed no significant effects (all $ps > 0.1$).

Tone-RT

A mixed ANOVA was conducted to compare tone-RTs across experiments. There was a significant main effect of cue (F (1, 25) = 34.82, $p < 0.001$) (RTs for cued > uncued locations (5.21 ms effect)). There was a reliable TTOA effect (F (3.77, 94.21) = 52.31, $p < 0.001$). There was also an interaction of cue × TTOA (F (6, 150) = 15.73, $p < 0.001$). This interaction was driven by the decreased IOR effect as the TTOA lengthened.

Sensitivity (d')

A mixed ANOVA revealed a significant TTOA effect (F (4, 100) = 267.10, $p < 0.001$) and a significant interaction of cue × experiment (F (1, 25) = 9.12, $p < 0.01$) (see Figure 12). In Experiment 1 sensitivity increased at the cued relative to the uncued location, while the data went in the opposite direction in Experiment 2.

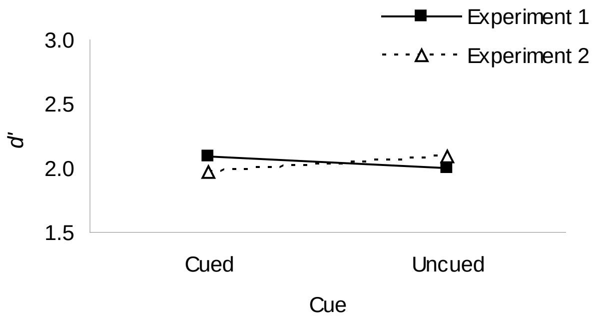

Figure 12. Average *d'* to the cued and the uncued targets in each experiment. In Experiment 1 cue increase the sensitivity at the cued location. However, in Experiment 2, there was no any significant difference between the cued and the uncued locations.

Anticipations

Only those effects involving cue or experiment are listed here (the same holds for the response frequency and miss data). The main effect of cue was significant (*F* (1, 25) = 7.23, $p < 0.05$) as was the cue × TTOA interaction (*F* (3.95, 98.81) = 6.91, $p < 0.001$). There were fewer anticipations made to targets at the cued than the uncued locations, especially at TTOAs 180, 270 and 360 ms. The cue luminance × experiment interaction was also significant (*F* (1, 25) = 4.95, $p < 0.05$), driven by the effect of cue luminance only being significant in Experiment 2 (see the separate analysis for this experiment). There were no other significant effects involving cue or experiment.

Response frequency

The main effect of the cue was significant (*F* (1, 25) = 14.81, $p < 0.001$) along with the cue × TTOA interaction (*F* (6, 150) = 12.10, $p < 0.001$). The response frequency was lower to targets at the cued relative to the uncued locations (especially at TTOAs 90 and 180 ms; however there was a reverse effect at TTOA 270 ms). There were no any significant effects involving either the cue or the experiment.

Misses

Both the main effect of the cue (*F* (1, 25) = 21.85, $p < 0.001$) and the cue × TTOA interaction were significant (*F* (6, 150) = 13.05, $p < 0.001$). There were more misses to targets at cued than at uncued locations (especially at TTOA 90 and 180 ms). In addition, the interaction of TTOA × experiment was significant (*F* (6, 150) = 3.07, $p < 0.01$). There were no significant effects involving cue or experiment.

Summary of the comparisons

Table 3 summarises the results of Experiments 1 and 2. The comparison of the SAT-parameters confirmed that Experiments 1 and 2 differ in terms of their SAT-functions for cued and uncued trials. In Experiments 1, for which a brief target exposure was used, there was no reliable effect of the cue on parameters of the SAT function, and all the other evidence pointed to an effect of IOR on the response criterion adopted (while perceptual sensitivity tended to be higher at cued locations, response time was slower, the rate of anticipatory responses was lower and misses were greater). In contrast, Experiment 2 showed an effect of the cue on the intercept of the SAT function (while sensitivity did not show any significant change, response times were slower), suggesting that IOR delayed perceptual processing in this case. In addition, there was evidence of conservative responses (the response frequency was lower and misses were greater at cued than uncued locations) as found too for Experiment 1. The data indicate that, with short target exposures, IOR affects the response criterion adopted. With longer exposure, some effects on perceptual processing emerge, in addition to effects on the response criterion.

	Experiment 1: brief target	**Experiment 2: unlimited target**
Parameters of SAT-function	Not significant on any parameters	Intercept parameter: cued > uncued *
	Cross experiments: intercept parameter: cue × experiment *	
RT and *d’*	RT: cued > uncued **; *d’*: cued > uncued *	RT: cued > uncued *; *d’*: not significant
	Cross experiments: RT: cued > uncued **; *d’*: cue × experiment **	
Response categories (anticipation; response frequency; miss)	Anticipations: cued < uncued *; misses: cued > uncued **	Response frequencies: cued < uncued *; misses: cued > uncued *
	Anticipations: cued < uncued *; Responses frequency: cued < uncued **; misses: cued > uncued **	
Conclusion	Criterion shift	Criterion shift + attention/perceptual

Table 3. Summary of the results for Experiments 1 and 2. Significant at 0.05 *; 0.01**.

General Discussion

This paper reports two experiments that explore the IOR-effect using SAT-methodology. SAT-methodology allows the experimenter to jointly control reaction times and accuracy when participants respond to targets. The specific implementation of the SAT-methodology employed here follows the experimental procedure devised by Klein and Ivanhoff (2006) which entails setting response times via a response window.

Using the SAT methodology, the paper explored how IOR is implemented within the framework of the SDT. According to SDT IOR may operate at a stage of perceptual coding, decision, or both. Effects of IOR on perceptual coding are indicated by a decrease of sensitivity for targets falling at cued relative to uncued locations. In contrast evidence for increased sensitivity at the cued location is consistent with a criterion shift account. As noted in the Introduction, there is empirical support for both proposals in the literature. We compared effects with limited and unlimited target presentation times and showed that different effects emerged in these conditions (Table 3). With short exposures there was good evidence for IOR reflecting a change in the response criterion. On the other hand, Experiment 2 provided evidence for a change in the SAT function consistent with delayed perceptual processing at the cued location, in addition to a conservative criterion shift.

We also found that, across the experiments, there was a small but significant IOR-effect for the short TTOAs. It is possible that, when fast responses were required, participants may have used IOR to perform the task more efficiently, while, when they had more time to prepare a response, IOR offers less help to improve performance, especially when perceptual information has reached an asymptote. Experiment 2 essentially replicates Klein and Ivanoff’s (2006) findings while at the time enabling us to fit a SAT-function to the results. Finally note that all our results were unaffected by different levels of cue and target luminance indicating a degree of generality with respect to these factors.

Taken together, our experimental results suggest a hybrid account in which there is a criterion shift, present with both short and prolonged target exposures, plus an effect on attention/perception when target presentation is prolonged. Past research has suggested that IOR is realized in a combination of attentional and motor components. Abrams and Dobkin (1994) compared the time to make an eye movement instructed by either peripheral or central targets after a peripheral cue. IOR was found to be larger in the peripheral condition than in the central condition. They argued that, with a central cue, programming an eye movement evokes the motor component of IOR. In contrast, a peripheral cue enhances perception as well as cueing the eye movement, so that both perceptual/attentional and motor components are present – this then leads to the increased IOR-effect. Furthermore, Kingstone and Pratt (1999) investigated IOR in both stimulus localization and identification tasks and their results also support both attentional and motor accounts of IOR. Evidence for an attentional component came from the finding that IOR was obtained for both localization and identification, as Kingstone and Pratt argued that motor effects should be evident on stimulus localization not identification. These authors also obtained evidence for a contribution of an oculomotor response to IOR, with IOR increasing when eye movements were executed compared to when eye movements were withheld. Similarly, there may have been some contributions from microsaccades (see more details in Galfano, Betta, & Turatto, 2004; Betta, Galfano, & Turatto, 2007). The question remains, however, as to why both components of IOR may have operated here when the target presentation time was unlimited, while, with a limited presentation time, participants relied only on a criterion shift. Here, we can only speculate. When the target is presented indefinitely, there is opportunity for accrual sensitivity to reach its peak, even with a delayed starting point (after the target presentation). In contrast, when the target presentation time is brief, any delay may result in an unrecoverable loss of target information. As a consequence, when participants know that the stimulus will be briefly presented, they may be able to compensate for an initial intercept disadvantage from IOR For example, compensation may come in the form of earlier sampling of perceptual evidence relative to when the target information is available for much longer, and this overcomes the effect of the perceptual component of IOR. Therefore the attentional/perceptual IOR is only revealed when the target presentation time is long. Further research could investigate IOR when the target presentation times are unpredictable or participants have biased expectations to the target presentation, to assess if a strategic change in perceptual processing is possible.

This explanation of our results is based on the assumption that the perceptual impairment operates in addition to the motor effect. In contrast, work by Taylor and Klein (2000), Hunt and Kingstone (2003) and recently by Chica, Taylor, Lupianez & Klein (2010) suggests that there are two different “flavours” of IOR that are generated under different circumstances (two components of IOR are isolated): an attention/perceptual IOR (impaired processing at the peripheral locations) is generated when the oculomotor system is tonically inhibited, while a motor IOR (motoric bias in responding) is generated when the oculomotor system is activated. This hypothesis is based on a series of experiments in Taylor and Klein (2000) using a combination of peripheral and central cues and targets. Participants were required to either ignore the cues, make manual responses to the cues or saccadic response to the cues. To the targets, participants had to make either manual or saccadic responses. Taylor and Klein found that, when no eye movements were made to either the cue or the target, IOR only occurred for manual responses to peripheral targets and not to central targets. Under the latter condition, there is no motoric component linked to an eye movement and no attentional/perceptual component as the target appeared at fixation rather than at the location signalled by the cue. However, even without eye movements (and no motor component) there was IOR to peripheral targets, consistent with an attentional/perceptual IOR when the oculomotor system was tonically inhibited, while the motor component contributed when eye movements were made. Importantly, when eye movements were made, the IOR effect to central targets (the motor component alone) was at least as large as that to peripheral targets (the attentional/perceptual and motor components), offering no support to the additive components view. The idea that there are two "flavours" of IOR depending on whether an eye movement occurs might be used to account for why the mechanism underlying the IOR effect (motor/criterion versus perception/attention) might vary with target duration[5]. Although participants were instructed not to make eye movements, eye movements were not monitored and may have been made unknowingly. These speculations have to be explored in further experiments by using eye tracking.

In any case, our results indicate that target exposure is an important factor determining the locus at which IOR affects processing. Interestingly, unlike Handy et al. (1999), who showed that accuracy decreases at longer RTs, we found that target

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5. When the targets were briefly presented, participants may not even have noticed the incorrect eye movements, and, thus, the oculomotor system would not be strongly inhibited. Therefore, a pure motor/criterion effect was observed. However with the prolonged target presentation, when eye movements were made, participants were able to see the target and became aware of their failure to follow the instructions. This may have initiated a period during which the oculomotor system would have been inhibited resulting in a perceptual/attentional IOR. However, eventually, participants stopped inhibiting eye movements, e.g. due to fatigue and, subsequently, reinstated the motor IOR. Therefore, it is possible that the evidence for both perceptual processing delay and criterion shift results from a mixture of states across trials.

information continued to improve even after the target disappeared (with short exposures, in Experiment 1). Although this appears to be inconsistent with the assumption that, with short target exposures, information about the target decays (e.g. Klein & Ivanoff, 2006), it must be kept in mind that we did not mask the targets after their brief presentation. Moreover the asymptote and rate parameter of the SAT-functions did not differ across the two experiments, suggesting that the briefly presented target provided the same perceptual information as targets given prolonged exposure. Hence, it is possible that 80ms was long enough to initiate early visual processing sufficiently to ensure that information accrual continued beyond the presentation time. We note here that Handy et al. (1999) presented a mask after exposing the target, and this would have disrupted information acquisition. A second apparently discrepant finding here, relative to the literature, is that studies with brief target presentation times (Lupianez et al., 1997; Cheal et al., 1998; Handy et al., 1999) have found support for attentional/perceptual accounts of IOR - directly contradicting our findings. However, as pointed out, the accuracy measured in these studies might have been affected by the decay of target information which was not apparent here.

In sum, the data presented here point to there being different factors involved in IOR: IOR reflects a criterion shift with both brief and longer stimulus exposures whereas, with longer exposures, there are also effects on attention/perception. The SAT procedure provides a powerful tool for pulling these different effects apart.

Acknowledgment

The authors would like to thank the Experimental Psychology Society (EPS) for funding Y. Zhao's five weeks visit to R. Klein's laboratory. Some of the research presented was made possible by NSERC Discovery Grants to R. Klein and to J. Ivanoff.

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