On the Information Processing Dynamics of Inhibition of Return

by

Jason Ivanoff

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Research Supervisor:

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Abstract

The detection of a target occurs expeditiously when it is closely preceded by an uninformative cue that had occupied the same location as the target. However, as the time interval between the cue and target increases, the detection of targets at cued locations is delayed. This latter effect is known as inhibition of return (IOR), referring to a mechanism that is believed to promote search to novel locations by inhibiting attention from returning to a recently visited location (Posner & Cohen, 1984). Although the name of the effect implies a putative mechanism, the inhibition of attention, there are three other prominent explanations for the IOR effect. The slowed time to detect targets at the cued location may be the result of a raised criterion to respond to the target's location (criterion-shift account), the inhibition of responding to the target (inhibited response account), or a temporary disconnection between stimulus and response stages of processing (stimulus-response disconnection account). The goal of the present investigation was to assess these accounts of the IOR effect. Experiments 1-3 examined the effects of IOR on the speed-accuracy tradeoff function. Whether IOR improved or reduced the sensitivity to the target depended on the context of the task. However, the results consistently showed that responding was more conservative for targets appearing at the cued location when response speed was stressed. In Experiments 4 and 5, the IOR effect was assessed in conjunction with non-spatial expectancies. The resulting interaction between the IOR effect with a non-spatial expectancy suggests that the IOR effect is, in part, a criterion-shift. The results are discussed within an integrated framework that posits that IOR has multiple effects on information processing. Moreover, there are particular task contexts that have a strong influence on the manifestation of the IOR effect.

List of Abbreviations

IOR	inhibition of return
RT	reaction time
SAT	speed-accuracy trade-off
S-R	stimulus-response
CTOA	cue-target onset asynchrony
TTOA	target-tone onset asynchrony
d'	measure of sensitivity
c	measure of criterion

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Chapter 1: Introduction to Inhibition of Return

What is inhibition of return?

Sir Isaac Newton's third law states that for every action there is an equal and opposite reaction. Although this law generally refers to the events following the collision of two objects, it may be an appropriate analogy for some mental events. For instance, Posner and Cohen (1984) - using a peripheral cueing paradigm - examined the timecourse of exogenous orienting. Participants in their experiments were presented with a non-informative visual "cue" (a brightening of a peripheral box) and they were instructed to ignore it because it did not provide relevant information concerning the location of the impending target. Following this, participants were instructed to indicate that they detected a visual target by depressing a key. Although responses to cued targets were faster than responses to uncued targets when the cue-target onset asynchrony (CTOA) was less than about 300ms, indicative of attentional facilitation, responses were slower to cued targets than to uncued targets when the CTOA was greater than 300ms. This slowing of responses to cued targets, later called inhibition of return (IOR; Posner, Cohen, Rafal, & Vaughan, 1985), was thought to reflect attention being inhibited from returning to a recently visited location. This biphasic pattern of results is analogous to the concept behind Newton's third law: for every action (attentional facilitation) there is an opposite reaction (IOR). The analogy falls apart in that the early, attentional effect of the cue is not necessarily related to the later IOR effect. Although the term IOR may be a misnomer, because it assumes a particular hypothesis that is just one of many that may account for the IOR effect, it has stuck and IOR has been the subject of extensive investigation (see Klein, 2000, and Taylor & Klein, 1998, for recent reviews of the IOR effect).

Taylor and Klein (1998) made an important distinction between *causes* of the IOR effect and the *effects* of the IOR mechanism. Hereafter, for the sake of clarity, I will use the term *IOR* to reflect the mechanism that causes the increase in *cued* reaction time (RT) relative to *uncued* RT. When I refer to this difference in performance, I will call it the *IOR effect*.

The goal of the present investigation is to further understand the underlying mechanism responsible for the slower RTs to cued targets than to uncued targets in a peripheral cueing task. The current investigation will focus on the IOR effect under conditions similar to those used by Posner and Cohen (1984). This kind of task has been dubbed a *cue-target* task. The IOR effect, or at least something resembling it, has been studied in *target-target* tasks (i.e., where a response is made to the cue; e.g., Maylor, 1985; Taylor & Klein, 2000; Terry, Valdes, & Neil, 1994) and search tasks (i.e., where the "cue" is a distractor in a search display; e.g., Klein, 1988; Klein & MacInnes, 1999; Müller & von Mühlenen, 2000; Takeda & Yagi, 2000). To date, there has not been one study that has confirmed - beyond a doubt - that the "IOR effects" in these paradigms are the result of the same underlying mechanism. I will limit the focus of the current work to cue-target tasks where IOR was originally discovered.

Why is there an IOR effect?

There are four general proposals concerning the effect of IOR on information processing: (1) the inhibited-attention account, (2) the criterion-shift account, (3) the inhibited response account, and (4) the stimulus-response (S-R) disconnection account. These four proposals are not necessarily mutually exclusive, however, and there are varying degrees of preexisting support for each one. The information processing dynamics of these accounts are illustrated in Figure 1. In Figure 1 it is presumed that the target remains present until the response is made. I have assumed that processing between perceptual and response-based stages is discrete (Mouret & Hasbroucq, 2000; Sternberg, 1969), while acknowledging that continuous processing may occur between other stages (McClelland, 1979; Miller, 1988).

The inhibited-attention hypothesis

The *inhibited-attention account* (Posner et al., 1985) is perhaps the most widely adopted interpretation of the IOR effect. Shortly following the onset of the cue, attention is attracted to, and is temporarily engaged at, its location. Following a relatively long interval (about 300ms in Posner & Cohen's, 1984, work), attention leaves this location as there is no reason for it to remain. When attention leaves the cued location, a hypothetical inhibitory marker or tag (i.e., IOR) is left behind that discourages attention from returning (Klein, 1988). IOR thus delays spatial attention from returning to a recently visited location, and it is the slowed reorienting of attention that gives rise to the performance difference on cued and uncued trials (Posner et al., 1985).

Posner and Cohen (1984) made the important observation that IOR was related to the conditions that produce *exogenous* orienting of attention but not *endogenous* orienting. Exogenous attention is thought to be fast and potentially

Figure 1. (Next page). An illustration of the four accounts of the inhibition of return (IOR) effect. The processing of the target is assumed to proceed discretely through perceptual and response preparation stages. The processing of uncued targets serves as a baseline measure of performance. The inhibited attention (IA) proposal presumes that responses to cued targets are slowed because IOR delays the onset of the perceptual stage. The delay is represented by the dots from target onset to the onset of perceptual processing. It has also been presumed that IOR impairs the perceptual processing of the cued target in some way. The impairment is represented by the hashed portion of the perceptual stage. The criterion-shift (CS) proposal holds that the response processing of cued targets is prolonged due to the raised criterion. The inhibited response (IR) proposal holds that responding to cued targets is inhibited (i.e., delayed). An additional assumption is made in that inhibiting response preparation allows more time for the accumulation of information at the perceptual stage. Lastly, the stimulus-response disconnection (DIS) proposal holds that there is a delay between the translation of perceptual information to response information. During this delay, it is presumed that the outcome from the perceptual stage passively decays.

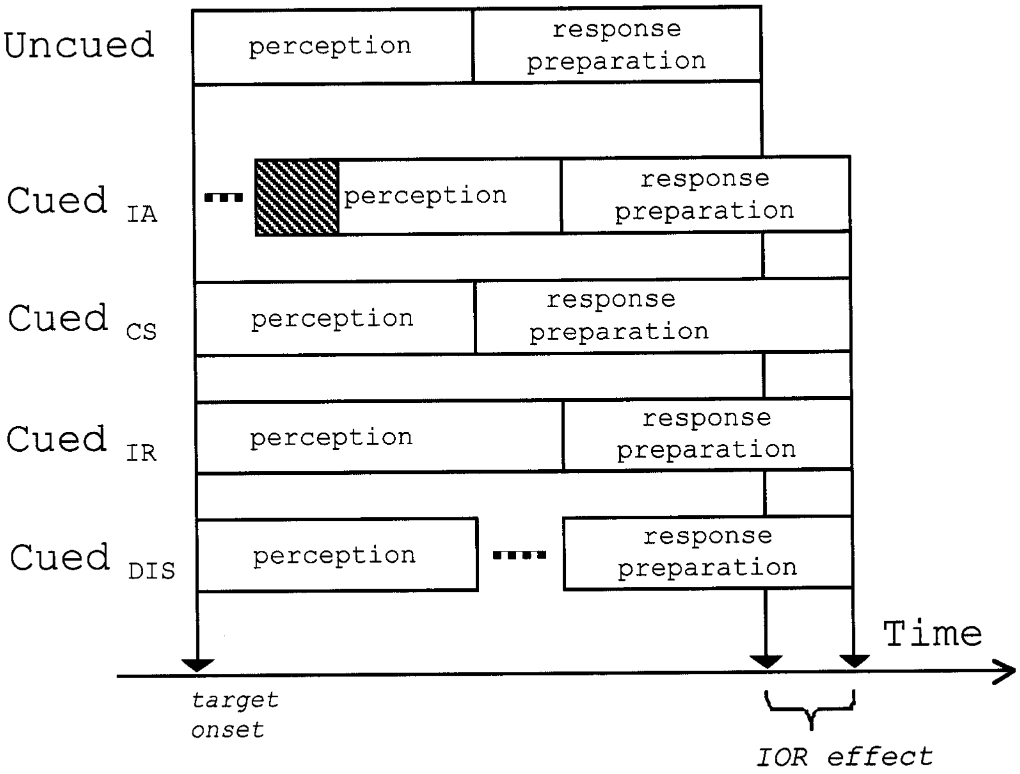
Uncued
perception
response preparation
Cued IA
perception
response preparation
Cued CS
perception
response preparation
Cued IR
perception
response preparation
Cued DIS
perception
response preparation
Time
target onset
IOR effect

Figure 1.

involuntary under certain conditions, whereas endogenous attention is slow and voluntary (Posner, 1980). Exogenous attention is evoked when an uninformative (i.e., with respect to the location of the forthcoming target) peripheral cue is presented. Endogenous attention is elicited when a symbolic cue predicts the location of the impending target. Posner and Cohen, and many others, have observed the IOR effect when a peripheral cue, which initially summons exogenous attention, is quickly followed by a central cue (or some kind of transient change at fixation). The purpose of the second, central cue is to remove exogenous attention from the periphery. When the first cue is central and predicts where the target will occur, but is followed by a central signal that nullifies the predictive validity of the first cue (and should, therefore, remove endogenous attention), the IOR effect is not observed (Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989). Thus, if attention is inhibited it must be of the exogenous mode.

There is more to Posner and Cohen's (1984) hypothesis than just inhibition of attention, however. They argued that attention is not directly responsible for the IOR effect: "inhibition does not arise from attentional orienting but from the energy change present at the cued location" (p. 539). Thus, "attention is not a sufficient condition for the inhibition effect" (p. 541). In some regard, they had foreshadowed work later done by Rafal et al. (1989) suggesting that IOR (i.e., the mechanism) is an oculomotor, but not an attentional process. However, the original idea of an "energy change" is too vague to be of any theoretical use. Rafal et al. (1989) showed that an oculomotor program directed towards the cued location was necessary to generate IOR. Nevertheless, although the IOR mechanism may be oculomotor in nature, they still believed that the IOR effect was due to the inhibited return of attention to the cued location.

Posner and Cohen (1984) also suggested that the IOR effect and the early attentional effect are independent. The implication of this independence is that "if attention is not drawn away from the cued location, no *net* inhibition is found" (Posner & Cohen, 1984, p. 541, italics added; see also Klein, 2000). Thus, IOR can be present and may affect performance even when cued RTs are not slower than uncued RTs (Taylor & Klein, 1998, 2000).

Considering that attention is a mechanism presupposed to operate on perception, and that conscious perception requires attention (Mack & Rock, 1998; see also Posner, 1980) it is a considerable challenge to differentiate the effects of IOR on perception (e.g., Handy, Jha, & Mangun, 1999) from the effects of IOR on attention. Thus, for the goals of the current work, I will include the idea that IOR inhibits perception under the guise of the inhibited attention account all the while recognizing that they are not necessarily the same.

The inhibited attention proposal is depicted in Figure 1 as a delay in the onset of the perceptual stage, reflecting the delay of the shift of attention to cued targets. It is also depicted with a darkened portion of the perceptual stage, reflecting the possibility for impoverished processing during said stage. As just indicated, I will surmise that the inhibited attention proposal assumes either or both mechanisms may be operating, and Figure 1 illustrates both ideas.

The criterion-shift hypothesis

Another account of IOR holds that it is the result of a criterion shift (Klein & Taylor, 1994). It is worth citing the original proposal because it is often misinterpreted. According to Klein and Taylor (1994):

> "IOR is a reluctance to respond to an event at the inhibited location; in other words, IOR is more closely associated with responding than with attention... In essence, there is a criterion shift for responding that something has happened at a particular location. Unlike the allocation of attention in cueing paradigms … this shift does *not* affect the processing efficiency of information coming from the attended location. If it did, all choice tasks would show evidence of IOR. Its effect is only seen in simple detection or localization responses, because the criterion is changed for 'responses to' stimuli from a particular location." (pp. 142-143).

The history and the reaction to this hypothesis is worth mentioning. At the time of this publication (1994) there had not been any evidence of an IOR effect in tasks for which a non-spatial target discrimination was to be made. More importantly, several studies (see Klein and Taylor, 1994) had failed to find an IOR effect when a non-spatial discrimination task was used. Klein and Taylor (1994) described an unpublished experiment by Pontefract and Klein that used CTOAs of 100 ms and 500 ms. The task was to press one of two keys (i.e., choice-RT task) to indicate whether a target (a five-dot stimulus) expanded or contracted. At both CTOAs, there was only a facilitation effect. With a detection task, however, IOR was present at the 500 ms CTOA. Klein and Taylor (1994) proposed the *criterion-shift* account of IOR based on this evidence (no IOR in non-spatial choice-RT tasks). I will refer to this as a criterion-shift account, rather than the misnomer *response-bias or response-inhibition account* because the former label seems to capture the spirit of the idea more than the other labels. I will discuss the inhibited response account shortly. In essence, the criterion-shift account of IOR proposes that it is a sort of pigeonholing mechanism (Broadbent, 1971) for which the criterion for targets appearing at the cued location is raised. The accumulation of evidence at the cued location is not impeded by IOR[1].

The criterion-shift account has received some interest. Most of the "attacks" on the criterion-shift hypothesis have been aimed at the main assumption of the proposal: that IOR is not present in choice-RT tasks. Indeed, following Klein and Taylor's proposal there have been numerous experiments showing that IOR appears in non-spatial choice-RT tasks (Cheal, Chastain, & Lyon, 1998; Pratt, 1995; Pratt & Abrams, 1999; Pratt, Kingstone, Khoe, 1997; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Lupiáñez & Milliken, 1999). Whereas this finding undermines Klein and Taylor's foundation for their proposal (i.e., that IOR should not occur in non-spatial discrimination tasks) it is not strong evidence against the criterion-shift account. Even in a discrimination task, there may still be a reluctance to respond to targets at the cued location.

Ivanoff and Klein (2001) serendipitously provided the first evidence in support of a criterion-shift. Using a go/no-go task, for which responses ought to be executed to "go" targets and withheld to "no-go" targets, they found that RTs (i.e., responses to go targets) were slower, and false

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[1] An inhibited response account of IOR, however, presumes that a response is spatially biased and that this spatial response is affected by IOR. Nowhere in the original proposal did Klein and Taylor (1994) argue that a spatial response is inhibited or that there is a bias to make a localization response away from the cue. For this reason, the criterion-shift and the inhibited response hypotheses will be treated as distinct.

alarms (i.e., responses to no-go targets) were less frequent, to cued targets than to uncued targets. This pattern is a kind of speed-accuracy tradeoff, exactly what one would expect given that a raised response threshold reduces erroneous responding by increasing RTs and reducing the deleterious effects of noise.

In Figure 1, the criterion-shift proposal is illustrated as the lengthening of the response preparation stage. The implication of this model is that there are fewer opportunities for errors because the response criterion has been extended. Extending the response criterion may reduce errors because the activation function will be based on a greater accumulation of signal information relative to noise (e.g., see Posner, 1975; Ratcliff, 2001, 1978). I have assumed that the criterion of the response preparation stage is raised, and not the criterion of the perceptual processing stage, in order to distinguish this theory from the inhibited response hypothesis.

The inhibited response hypothesis

Tassinari and his colleagues have posited a different type of response account of IOR (e.g., Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987). Specifically, they argued that IOR is due to the voluntary suppression of eye movements to a peripheral location. Suppressing eye movements to the cued location results in poor detection performance (e.g., Rafal et al., 1989). As IOR has been observed when a eye movement is made to the cue (Rafal et al., 1989; Taylor & Klein, 2000), this oculomotor version of the inhibited response proposal seems implausible.

The inhibited response proposal may be salvaged, however, if its application is limited to experimental designs for which a response is not made to the cue. A general version of this hypothesis presupposes that IOR may be due to the inhibition of making any response to the cue (e.g., see Harvey, 1980). In some situations, there is a prepotent tendency to respond toward the source of stimulation (Simon & Rudell, 1967). However, when a response is not needed, this prepotent spatial response tendency (whether it be manual, oculomotor, or otherwise) must be inhibited. The inhibition of the response to the cue is IOR. In partial support of this inhibited response hypothesis, Abrams and Dobkin (1994) found that a peripheral cue delayed the initiation of an endogenous saccade toward it. A similar effect was found by Taylor and Klein (2000).

Although the inhibited response proposal does not fare so well in its attempts to explain IOR in tasks for which responses are executed to the cue, it may be a reasonable explanation for the IOR effect in tasks for which responses to the cue are withheld. In Figure 1, the inhibited response proposal is represented by the delay in the onset of the response preparation stage. Although this is where the inhibited response proposal stops, I will make an additional assumption. I will assume that during the time that response preparation is delayed, the activation of the stimulus will continue so long as the target remains visible. Hence, in Figure 1, the continued activation of the stimulus is represented by a prolonged perception stage. It is certainly possible that those who proposed the inhibited response hypothesis (Tassinari et al., 1987) did not envision that the consequence of delaying (i.e., inhibiting) response preparation is that evidence at earlier stages can accumulate. This additional assumption is made, however, simply to distinguish the inhibited response proposal from the next proposal: the stimulus-response disconnection hypothesis.

The stimulus-response (S-R) disconnection hypothesis

Fuentes, Vivas, and Humphreys (1999) proposed that IOR slows responding by temporarily severing the connection between a stimulus and its associated response. In support of this *disconnection* hypothesis, Fuentes et al. examined the flanker effect (e.g., Eriksen & Eriksen, 1974) in the context of a cueing study with long CTOAs (so as to observe the IOR effect). The flanker effect refers to faster responding to central targets flanked by a stimulus that is compatible with the central target (i.e., whose identity is associated with a similar response) than to targets flanked by an incompatible stimulus (i.e., whose identity is associated with another response). A neutral flanker stimulus is one for which the flanker's identity is not associated with any particular response.

The novel aspect of Fuentes et al.'s (1999) cueing procedure was that the target (on choice-RT trials) did not appear at the cued or uncued location; it was always presented at center. Only the irrelevant flanker appeared at the cued and uncued location. Fuentes et al. observed a normal flanker effect when the flanker appeared at the uncued location: responses to targets with compatible flankers were faster than responses to targets with neutral flankers, which in turn were faster than responses to targets with incompatible flankers (compatible RT < neutral RT < incompatible RT). However, they observed a different pattern of results when the flanker appeared at the cued location. Here responding on compatible trials was actually slower than responding on incompatible or neutral trials, but the difference between responding on incompatible and neutral trials was not significant (i.e., compatible RT > neutral RT = incompatible RT).

According to the disconnection hypothesis, on trials with incompatible and neutral flankers, IOR had no effect on performance because the response associated with the flanker is not the one signaled by the central target. On trials with compatible flankers, however, IOR temporarily prevents the activation of the response that is associated with the flanker and signaled by the central target. Fuentes et al. argued that this finding suggests that IOR temporarily disconnects stimuli from their associated responses.

In another investigation, Vivas and Fuentes (2001) found that IOR reduced Stroop interference (see also Hartley & Kieley, 1995). The Stroop effect refers to slower responses when making a colour discrimination to a colour-word that is incompatible (e.g., the word "GREEN" typed in a red font) than to a colour-word that is compatible (e.g., the word "GREEN" typed in a green font) or to a non-word (e.g., "XXXX" typed in a green font). In these experiments, the colour-word and colour features were presented at cued and uncued locations. Vivas and Fuentes observed an IOR effect for neutral trials but the IOR effect for incongruent trials was absent (in their second experiment). According to Vivas and Fuentes, the lack of IOR is due to the "indirect consequence of responses being *facilitated* by the effect of an inhibitory mechanism that prevents the irrelevant dimension of the target from being competitive for response" (p. 319).

In Figure 1, the disconnection between stimulus and response is illustrated as a delay between the translation of the perceptual code and the response code. Unlike the inhibited response account, I will assume that perceptual information does not have the opportunity to accumulate during the disconnection. The current version of the S-R disconnection hypothesis does not make any claim concerning what is happening during the delay. If perceptual information is accumulating during the delay, then the dynamics of information processing is very similar to the presumed dynamics of the inhibited response theory. I will make the assumption that the perceptual information that is passed along to the response preparation stage is susceptible to passive decay during the disconnection. Thus, responding to cued targets will be based on less stimulus information than responding to uncued trials.

Response accuracy and IOR

The four accounts of the IOR effect all predict that responses to cued targets will be slower than responses to uncued targets. Behaviourally, there are at least two effective ways to assess the four hypotheses. First, clever systematic procedural changes to the standard paradigm (Posner & Cohen, 1984) may provide insight into the inner workings of IOR. For instance, the application of additive factors logic (Sternberg, 1969) can be informative with respect to the stage(s) affected by IOR. This technique will be discussed shortly. Second, measuring the effect of IOR on accuracy will provide valuable information concerning IOR's effect on information processing. For instance, knowing that IOR slows responding and yet improves accuracy[2] (i.e., a speed-accuracy tradeoff; Pachella, 1974) calls for a different interpretation of the effect than knowing that it slows responding and decreases accuracy. In the current work, I will use additive factors logic to assess the stage

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[2] Accuracy can be defined in many ways depending on the context of the task. For the purposes of this thesis, I will use the term accuracy as it relates to the quality of information. Hence, accuracy will increase as the quality of information increases (Posner, 1975). Obviously, there are some measures that seem to reflect accuracy (e.g., the proportion of instances where one fails to respond to a suprathreshold target) but may be due to factors unrelated (e.g., response inhibition), or indirectly related (e.g., a raised response criterion) to the quality of information. In the terminology of signal detection theory, accuracy is sensitivity (i.e., d').

at which IOR operates (in Chapter 3) and I will measure the effect of IOR on accuracy (in Chapter 2) to further knowledge concerning the nature of IOR's effect on information processing. For now, I will discuss the importance of measuring IOR with more than just RT.

How is an effect of IOR on accuracy informative with respect to the four theories of IOR? Broadbent (1958) argued that scientific progress would be expeditious if extant theories are split into two groups and evidence is sought that provides support for one group and against another. On the one hand, the inhibited response and the criterion-shift proposals predict that cued targets may be associated with slow responding and higher accuracy as more information is accumulated during the time that IOR delays responding. According to my interpretation of the inhibited response account, during the time that IOR delays response preparation, more information concerning the perceptual representation of the target is allowed to accumulate. Thus, the information passed from perceptual to response stages will be of a greater quality for cued targets than uncued targets. According to the criterion-shift hypothesis, however, a raised criterion will mean that response preparation will be less susceptible to internal random noise (see, e.g., Ratcliff, 1978), thereby giving rise to improved accuracy (even though perception, *per se*, is unaffected).

On the other hand, the prediction of the inhibited-attention hypothesis and the S-R disconnection hypothesis is that response speed must be slower - and accuracy must be lower - for cued, than uncued, targets. The inhibited attention proposal presumes that accuracy may be lower for cued targets because IOR may hinder the perceptual representation of the target (Handy, Jha, & Mangun, 1999). On the one hand, if IOR simply delays the shift of attention to the target, without impairing perception, then there may be an RT delay with or without any effect of IOR on accuracy. Once this delay is overcome, attention shifts to the target just as though there had been no delay. On the other hand, if IOR impairs the quality of the attention-shift (in some manner) then it will also hurt the perception of the target. The disconnection hypothesis also predicts that accuracy ought to be lowered by IOR or that accuracy will be unaffected by IOR. Whether accuracy is lowered or unaffected by IOR depends on whether one assumes that the perceptual quality of the stimulus is susceptible to passive decay during the S-R disconnection. Although passive decay was not incorporated into the original formulation of the theory, it is a reasonable supplement to the theory.

It is customary to report error rates along with RTs when assessing performance. In detection tasks, which are also called simple-RT tasks or Donders' a-tasks, a single key-press response is required whenever the target appears. On some trials, the target does not appear (i.e., "catch trials"). Accuracy is measured by counting misses (i.e., absent responses in the presence of a target) and false alarms (i.e., responses when the target is absent). False alarms, in the context of a simple-RT task, are uninformative because they cannot be attributed to the cued or uncued target conditions. Misses, however, can be attributed to cued and uncued conditions, but they may be too infrequent to be of any use. Thus, the simple-RT task does not provide much information beyond RT.

A go/no-go task is like the simple-RT task in that only one response is ever made. Unlike the simple-RT task, however, false alarms may be attributed to the cued and uncued conditions. Ivanoff and Klein (2001) discovered that RTs to cued targets were, overall, 14ms slower than RTs to uncued targets while false alarms were 3.4% more frequent for uncued targets than for cued targets. This is a speed-accuracy tradeoff. This finding was recently replicated by Taylor and Ivanoff (in press). It is perfectly consistent with the criterion-shift and the inhibited response theories.

Handy et al. (1999), using signal detection analysis in a go/no-go task, found that response bias was unaffected by IOR but d' (a measure of sensitivity) was 0.18 units lower at the cued location than at the uncued location. However, the difference was only statistically significant with a one-tailed t-test. Their finding was consistent with the inhibited attention or disconnection interpretation of the IOR effect.

Unlike simple-RT tasks, for which only one response is ever made, a choice-RT task entails at least two response alternatives. In choice-RT tasks (or discrimination tasks or Donders' b-tasks) at least two stimuli are assigned to two responses. Errors occur when the response to a stimulus is inappropriate according to instructions. There exists a few studies of IOR that have used choice-RT tasks for the sole purpose of measuring accuracy. Cheal and her colleagues (Cheal, Chastain, & Lyon, 1998; Cheal & Chastain, 1999) have used an identification task to examine accuracy effects of IOR. Their task was not quite like a choice-RT in that response time was not measured while accuracy was measured. It was, however, like a choice-RT task in that the task was to identify the target. To reduce accuracy below ceiling level, a post-target mask was used and distractor stimuli were presented at non-target locations. Cheal and Chastain (1999) found 3% more errors for the identification of targets at the cued location than for targets at an uncued location.

The use of a post-target mask complicates the interpretation of Handy et al.'s (1999) and Cheal and

Chastain's (1999) results. The problem with measuring accuracy under conditions where the target is masked is that the response may be based on a rapidly decaying function (Posner, 1975). The implication is that slow responding (due to a criterion-shift or an inhibited response) may be associated with poorer accuracy. Thus, it is possible to misinterpret a criterion-shift effect for a negative effect of IOR on perception when measuring accuracy under conditions for which the target is masked or presented briefly (see also Ivanoff & Klein, 2001). In support of this possibility, note that Handy et al.'s non-speeded task (Experiment 2) had slower RTs and lower sensitivity scores than the speeded task (Experiment 1). Thus, measuring accuracy under conditions where the target is masked or presented briefly may be less than ideal.

What does IOR do to discrimination performance under conditions where the target is not masked? Table 1 summarizes the results from choice-RT studies demonstrating an IOR effect with RTs and the corresponding measurement of the IOR effect with the error rate (percent errors). All of the experiments listed in Table 1 are cue-target paradigms (where responses are not made to the cue), single target tasks where only one target is presented on a given trial at the cued or uncued location, and tasks that involve a non-spatial discrimination of the target. One choice-RT study of IOR had to be excluded because the error rates were not reported (Chasteen & Pratt, 1999). As shown in Table 1, it is very rare to find a *significant* effect of IOR on accuracy (indicated with an asterisk in the table), and those studies that have shown an effect (cf. Lupiàñez et al., 1997) have used brief target displays, making these effects vulnerable to the criticism that information was decaying by the time the response was executed (Posner, 1975). Overall, there are

TABLE 1. Mean reaction time (ms) and error rate (%) for cueing effects from a sample of published choice-RT experiments.

Reference	Reaction Time			Errors		
	Uncued	Cued	IOR effect	Uncued	Cued	IOR effect
Lupiáñez et al. (1997)						
E2b	563	593	-31*	7.8	10.8	-3.0
E3b	574	608	-34*	8.2	9.0	-0.8
E4b	642	657	-15	12.4	18.9	-6.5*
E5b	608	633	-25*	0.8	3.8	-3.0*
Pratt et al. (1997)†	496	540	-44	11.8	14.4	-2.6
Kingstone & Pratt (1999)						
E1: Identity	468	494	-26*	6.0	8.3	-2.3
E2: Identity, move eyes	562	584	-22*	6.3	9.6	-3.3
E2: Identity, fixate	524	545	-21*	6.3	6.6	-0.3
Lupiáñez & Milliken (1999)						
E2a/b: 700ms CTOA	537	548	-11*	6.8	4.5	+2.3
E2a/b: 1000ms CTOA	543	554	-11*	5.3	5.3	0.0
Gibson & Amelio (2000)						
E1: Onset-onset	521	540	-19*	2.2	3.1	-0.9
E3: Onset-onset	532	552	-20*	2.3	2.4	-0.1
E3: fixate	439	453	-14*	7	6	+1
Lupiáñez et al. (2001)						
E1b: 700ms CTOA	493	510	-17	5.1	4.3	+0.8
E1b: 1000ms CTOA	512	524	-12	4.5	5.7	-1.2
Pratt & McAuliffe (2002)						
E2: Onset-Onset	502	541	-39*	2.3	2.3	0
E2: Combination-Onset	498	520	-22*	2.4	2.5	-0.1
E2: Onset-Colour	577	623	-46*	6.1	4.6	-1.5
E2: Combination-Colour	586	604	-18*	4.6	4.6	0
Taylor & Donnelly (2002)†						
E2: Identity Task	502	521	-19*	3.8	4.5	-0.7
E2: Orientation Task	576	601	-25*	5.8	5.5	+0.3

Notes:
E1 = Experiment 1; E2 = Experiment 2; etc.
CTOA = Cue-Target Onset Asynchrony
*Indicates that the difference score (IOR effect = uncued - cued) is significantly ($\alpha=0.05$) different from zero. No mark next to the IOR score indicates that the difference score was not significant or it was not explicitly indicated whether the difference score was significant.
† These averages are based on the IOR scores over similar conditions where cued RTs were slower than uncued RTs.

more studies demonstrating that IOR is associated with lower accuracy and slower responding than there are demonstrating that IOR is associated with higher accuracy and slower responding. Nevertheless, the existing evidence concerning IOR's effect on accuracy is far from impressive.

Speed-accuracy tradeoff functions

The difficulty with measuring accuracy is that it is often at ceiling levels when the target remains in view, creating little opportunity to observe an effect of IOR on accuracy. As just mentioned, the alternative techniques that lower accuracy, such as post-target masks or brief target displays, are susceptible to the criticism that responses may be based on decaying information. The implication of this possibility is that slow responding will naturally suffer greater decay of information and therefore the quality of information will be lower for slow responses than it will be for fast responses. Although this finding would seem to be consistent with an inhibited attention or S-R disconnection hypotheses, it is equally consistent with the criterion-shift or inhibited response hypotheses. An alternative approach is to assess accuracy as information is accumulating, not decaying. This can be done by looking at the speed-accuracy tradeoff (SAT) function.

It is well known that one can trade response speed for accuracy in a variety of paradigms (Carrasco & McElree, 2001; Dosher, 1976; Fitts, 1966; Meyer, Irwin, Osman, & Kounious, 1988; Osman, Lou, Muller-Gethmann, Rinkenauer, Mattes, & Ulrich, 2000; Pachella, 1974; Reed, 1973; Ruthruff, 1996; Wickelgren, 1977; Wood & Jennings, 1976). As Wickelgren (1977) pointed out some years ago,

"…the SAT function [has] the great potential to advance

> all areas of cognitive psychology... [T]he speed-accuracy tradeoff method is so superior to the traditional reaction time method, that many psychologists interested in studying the dynamics of information processing … ought, in many instances, to do speed-accuracy tradeoff studies instead of reaction time studies." (p. 68).

In spite of Wickelgren's proclamation, SAT methodology has been generally underused in contemporary experimental psychology (but see Carrasco & McElree, 2001; Meyer, Irwin, Osman, & Kounious, 1988; Osman, Lou, Muller-Gethmann, Rinkenauer, Mattes, & Ulrich, 2000; Ruthruff, 1996).

The SAT function is thought to reflect the accrual of information, or evidence, as a function of time (see Pachella, 1974). In a task where accuracy is emphasized, the criterion may be based on the quality of information. In an SAT task, where the speed of responding is emphasized, the criterion is based on time. Points along the SAT function are attained by lowering the time criterion thereby limiting the accrual of information. Figure 2 is an illustration of this idea. Note that the time- and information criteria are directly related such that fast responding (responding based on a lowered time criterion; C_t-Low) is equivalent to a lowered information criterion. The most important aspect of the SAT is that it permits an examination of accuracy at levels below ceiling where information is not decaying but rather is accumulating. Thus, it is sure to provide an unambiguous conclusion concerning the effect of IOR on target processing.

SAT functions can be produced in a variety of ways (see Wickelgren, 1977, for a complete review of the methodology). A prominent technique is to use a secondary stimulus (e.g., a tone) to signal that a response must be made within a short

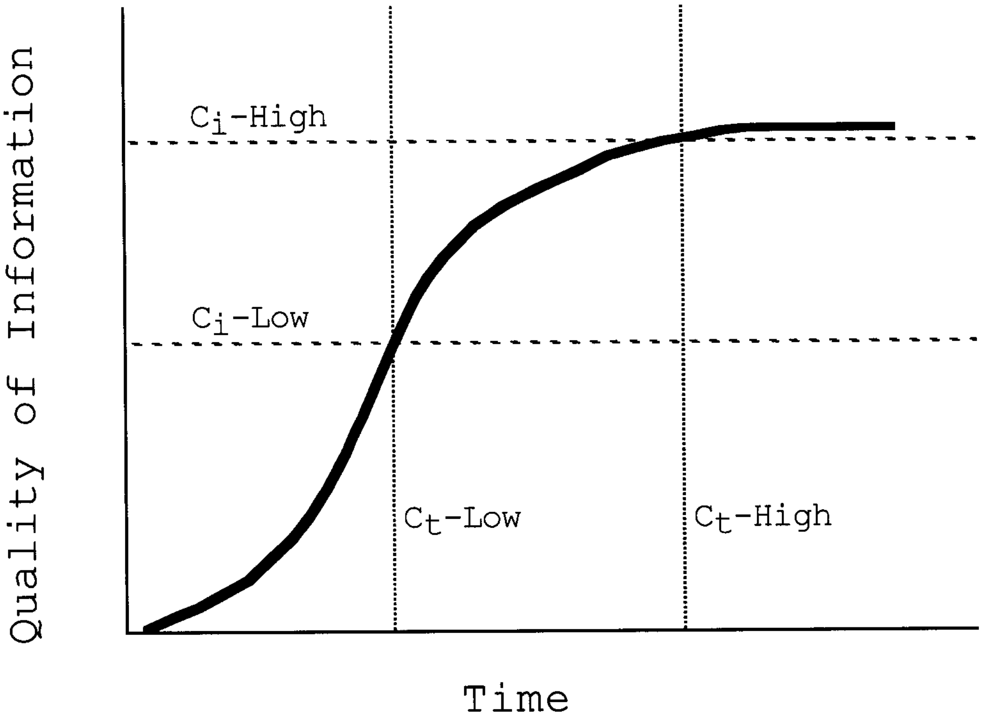

Figure 2. *The thick line reflects the accumulation of information as a function of time. Two different types of criteria, one based on time (C_t) and the other based on the quality of information (C_i), are illustrated at two different levels (High and Low). As the time (C_t) or information (C_i) criterion is lowered (from High to Low), response time will be decreased and responding will be based on less information.*

time window following its onset (e.g., see Carrasco & McElree, 2001). The interval between the target and the tone (i.e., the target-tone onset asynchrony; TTOA) can be long such that responding is based on high quality information (thereby giving rise to few errors) or extremely short such that it is based on low quality information (thereby giving rise to many errors). The TTOA directly adjusts the response criterion. Lowering the TTOA essentially lowers the criterion (e.g., Ratcliff, 1978). At each TTOA, the effect of some factor on tone-RT (i.e., the time from the onset of the tone to the depression of a key) may be eliminated because response time is controlled. Under such conditions, this factor ought to influence accuracy rather than tone-RT. Further details concerning SAT methodology are provided in Experiment 1.

Many theories of the SAT function generally agree that evidence accumulates with time, but they differ with respect to the underlying mechanics of information processing (Luce, 1986; Meyer et al., 1988; Nikolic & Gronlund, 2002; Pachella, 1974; Ratcliff, 1978, 1988). Some models hold that with extremely short TTOAs whatever little information is available is used to make a "best guess" response (e.g., Ratcliff, 1988). Considering the simple two-stage model illustrated in Figure 1, as TTOA decreases some portion of response preparation and/or perceptual processing may be clipped such that responding is more susceptible to internal noise and/or based on less information. Thus, decreasing the TTOA will result in an abridged perceptual or response processing stage. When these stages are prevented from running their full course, less stimulus information is transmitted through the system resulting in poor accuracy. Note, however, that some minimal amount of response preparation must occur, even when TTOA is very short, or else responses will never occur within the response window.

The purpose of using SATs to measure the effect of IOR on accuracy is to assess how IOR affects information accumulation when processing time is controlled. As previously mentioned, it is possible to eliminate two of the four theories of the IOR effect by examining the effect of IOR on accuracy. However, the predictions concerning the effect of IOR on accuracy differ under the constraints of an SAT task. How will IOR affect accuracy in an SAT task? The predictions for each theory are listed in Table 2 according to whether IOR affects tone-RTs. It is important to consider whether IOR affects tone-RTs because, according to the inhibited response and criterion-shift theories, if tone-RTs are affected by IOR, then there is the potential for there to be more information accrual at the cued location. If, however, IOR does not affect tone-RTs then there is no additional processing time available for cued targets and so IOR will have no effect on accuracy.

According to the inhibited attention account, IOR ought to reduce accuracy (i.e., accuracy ought to be lower for cued targets than for uncued targets) when tone-RTs are equated for cued and uncued targets. This prediction holds whether IOR affects attention, perception, or both. Moreover, given that Carrasco and McElree (2001) observed that attention increased the rate of information accrual, it seems reasonable to presume that inhibiting attention ought to decrease the rate of information accrual. Thus, the effect of IOR on accuracy ought to be larger for the later TTOAs than it would be for the earlier TTOAs. If RTs are not sufficiently controlled, such that IOR affects tone-RTs (rightmost column of Table 2), then the additional processing time for cued targets may reduce, or possibly eliminate, any effect of IOR on accuracy. In other words, if IOR slows

TABLE 2. The predicted effects of inhibition of return (IOR) on accuracy according to whether IOR slows tone reaction time (tone-RT) in a speed-accuracy tradeoff task.

Theory	Does IOR slow tone-RTs?	
	No	Yes
Inhibited attention	Decrease	Decrease or NE
Criterion-shift	NE	Increase
Inhibited response	NE	Increase
S-R disconnection	Decrease	Decrease or NE

Note:

NE = No effect.

S-R = Stimulus-Response.

tone-RTs it may compensate for the difference in cumulative evidence for cued and uncued targets. Critically, however, IOR ought not to improve accuracy.

If IOR raises the criterion, without affecting tone-RTs, then IOR ought to have no effect on accuracy[3]. The criterion-shift account purports that the IOR effect is merely the result of a shift along the SAT function. If, however, IOR slows tone-RTs, then this slowing ought to improve accuracy given the additional processing time available (at the response preparation stage) for cued targets.

Like the criterion-shift account, the inhibited response account also predicts that IOR will have no effect on accuracy when tone-RTs for cued and uncued targets are equated. It is presumed that the quality of perceptual information is better for cued targets than it is for uncued targets because delaying response preparation allows more perceptual information to accumulate. Thus, it is reasonable to predict that equating the processing time for cued and uncued targets, in the SAT paradigm, will eliminate the additional perceptual processing time on cued trials. Hence, if tone-RTs are slower for cued targets than for uncued targets, then this additional processing time will occur during the perceptual processing stage thereby improving the quality of information on cued trials. In other words, under the inhibited response account the IOR effect is a shift along the SAT function. Unlike the underlying processing dynamics assumed by the criterion-shift account, however, the inhibited response account assumes that the effect of IOR on improving accuracy is due to the additional perceptual processing time - not the additional

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[3] There is an obvious difficulty here in that evidence in favour of the criterion-shift account occurs when there is no evidence of IOR at all (i.e., when IOR does not affect tone-RTs and accuracy). This is also true of the inhibited response proposal. For this reason, it is obviously preferred that IOR slows tone-RTs.

processing time during response preparation.

The disconnection theory, like the inhibited attention theory, predicts that IOR will reduce accuracy if tone-RTs for cued and uncued targets are equated. Accuracy will be lower on cued trials because of the passive decay of information during the disconnection. An effect of IOR on tone-RTs will add processing time for cued targets which, in turn, may reduce or eliminate the detrimental effects of IOR on accuracy.

Additive factors logic and IOR

An appropriate measure of accuracy (i.e., accuracy as a function of time along the SAT function) has the potential to distinguish between two sets of theories concerning the effect of IOR on information processing. In order to further distinguish between theories of IOR's effect on information processing, I will use additive factors logic (Sternberg, 1969; see Sternberg, 1998, for a recent review) to isolate the stage(s) at which IOR is presumed to operate. The general tenet of additive factors logic is the following: two factors that operate on the same stage of processing will interact statistically. However, if these factors have effects on discrete stages information processing, then the effects will be *perfectly* additive. Thus, if there is a factor that is known to affect a late stage, for example, and if IOR affects the same late stage, then they will interact. If, however, IOR has only an early effect on information processing, then the IOR effect and this other factor will be additive.

A central tenet of the additive factors method is that stages are arranged serially and information transmission between stages is discrete. The applicability of additive factors logic becomes questionable if a purely continuous model of information processing is adopted (McClelland, 1979). However, two factors that have different effects on information processing can have additive effects under some circumstances in continuous models (e.g., Roberts & Sternberg, 1993). It is beyond the scope of the current investigation to fully discuss the evidence in favour of discrete versus continuous processing (see Miller, 1988; Sanders, 1990). As I mentioned earlier, I will assume that "stimulus" (i.e., perceptual processing in Figure 1) and "response" (response preparation in Figure 1) stages occur discretely (e.g., see Kornblum, Stevens, & Whipple, 1999; Mouret & Hasbrouq, 2000) while transmission between other sub-stages may be continuous.

There are many studies that have combined IOR effects with another factor. A short sample of these studies is presented in Table 3. An interaction is assumed when the IOR effects at one level of some factor is different from the IOR effect at the other level. It should be obvious from Table 3 that IOR interacts with many factors. Some of these factors have a late locus (e.g., the Simon effect; see Lu & Proctor, 1995, for a review of the Simon effect), but some of them have early effects too (e.g., target intensity).

That IOR seems to interact with a variety of factors poses a problem for the application of additive factors logic to IOR. For example, the multitude of interactive factors may be taken to mean that IOR has more than one effect on information processing (e.g., Kingstone & Pratt, 1999; Taylor & Klein, 2000). Alternatively, it is possible that the other factors (e.g., Stroop effect, target intensity effects) have more than one effect on information processing. This does not mean that additive factors logic is of little use in its application to the IOR effect. Rather, the point is that it

TABLE 3. A list of factors that interact and do not interact with the inhibition of return (IOR) effect.

Reference	Factor	Interacts with IOR?	IOR Effect (ms)*
Rafal et al. (1994)	Pro/Anti Saccades	No†	
Experiment 1	Pro-saccade		-18
(no saccade to cue)	Anti-saccade		-18
Hartley & Kieley (1995)	Stroop Effect	No‡	
	Congruent		-43
	Incongruent		-50
Reuter-Lorenz et al. (1996)	Target Intensity	Yes	
Experiment 4	Low		-46.1
	High		-13.6
Chasteen & Pratt (1999)	Word Frequency	Yes	
Experiment 1	Low Frequency		-119
	High Frequency		-60
	Non-words		-58
Fuentes et al. (1999)			
Experiment 2b	Semantic Priming	Yes	
	Related		-12
	Unrelated		+23
Experiment 4	Flanker Type	Yes	
	Compatible		-34
	Neutral		+6
	Incompatible		+21
Vivas & Fuentes (2001)	Stroop Effect	Yes	
	Congruent		-25
	Incongruent		-5
	Neutral		-43
Ivanoff et al. (2002)	Simon Effect	Yes	
	Corresponding		-15.1
	Noncorresponding		-25.9

Notes:

* In some cases, these numbers were approximated (with great care) from figures. IOR effect = Uncued RT - Cued RT.

† Unfortunately, Rafal et al. (1994) did not provide the cued and uncued RTs separately for the pro- and anti-saccade task. All that is known is that the interaction between cueing and task was not significant and that the IOR effect overall was 18ms.

‡ In a group of older adults, the IOR effect was significantly greater for congruent trials than it was for incongruent trials.

is absolutely necessary to use a factor that only operates on one stage of processing. Moreover, it is necessary to make a specific prediction concerning the interaction with IOR. Only under these conditions is it possible to assess the underlying effects of IOR.

Outline of thesis structure

The goal of the current investigation is to unearth the effect of IOR on information processing. Why are RTs slowed to detect and discriminate cued targets? In Chapter 2, three speed-accuracy analyses of the IOR effect will be presented. The goal of this chapter is to determine the effect of IOR on performance under conditions for which target information is accumulating. This chapter ought to provide a wealth of information concerning the effect of IOR on information processing in a cueing experiment beyond what is currently known from RT measurements. As pointed out earlier, the four theories of the IOR effect can be split into two groups based on the outcome (see Table 3 for a list of the predictions). Performance accuracy was measured under four levels of speed stress (i.e., four TTOAs). To foreshadow, accuracy was higher for cued targets than for uncued targets in a go/no-go task with asymmetric go/no-go frequencies. However, accuracy was lower for cued target than for uncued targets in a choice-RT task and a go/no-go task when targets were equiprobable (i.e., symmetric target frequencies). Moreover, responding was generally more conservative on cued trials than on uncued trials. These findings are difficult to reconcile with any one of the four theories of the IOR effect. However, they are not difficult to reconcile with the idea that IOR has more than just one effect on information processing.

The goal of Chapter 3 is to use additive factors logic to specifically assess the criterion-shift proposal of the IOR effect. The goal is to examine the IOR effect in the context of another factor, the S-R probability effect, that is thought to affect the response criterion (e.g., see Laming, 1968, who has explicitly modeled the S-R probability effect as an initial criterion-adjustment). In this context, assuming that the IOR effect is the result of a criterion-shift, one can generate a specific prediction concerning the interaction between IOR and the S-R probability effect. Specifically, Klein and Hansen (1990) demonstrated that endogenous attention interacts with the S-R probability effect. The details of their interaction, which I will discuss further in Chapter 3, were qualitatively reproduced by a logogen-type model that assumes endogenous attention is partially the result of a criterion-shift (see also Klein, 1994). In Chapter 3, a similar interaction was observed between IOR and the S-R probability effects, thereby providing further credibility to the criterion-shift account.

Finally, in Chapter 4, the findings are discussed in an integrated manner with respect to the four theories of the IOR effect. I will also discuss some of the results that did not quite fit with any current theory of the IOR effect.

Chapter 2: Speed-Accuracy Analyses of the IOR Effect

In this chapter, the effect of IOR on accuracy will be examined under different levels of speed stress using an SAT procedure. I will use four different intervals between the onsets of the target and the response signal tone (i.e., TTOA). The goal is not to measure a large number of points along the SAT function (i.e., TTOAs), but rather to look at how IOR affects accuracy when the emphasis is on fast rather than slow responding. This will provide a broad timecourse of the accumulation of target information.

In Experiment 1, the IOR effect is examined in the context of a *go/no-go* task (i.e., a Donders' c-task; Donders, 1969/1868; e.g., Ivanoff & Klein, 2001). A go target signals that a single key-press should be made and a no-go target signals that the response should be withheld. In Experiment 1, the go signal is a black square and the no-go signal is a checkerboard stimulus (i.e., small, alternating, black and white squares). The proportion of trials with a go target is 75%, no-go trials occur on 25% of the trials. In Experiment 2, a choice-RT task (i.e., Donders' b-task), is used to examine the effect of IOR on the accuracy of responding. Sometimes referred to as a discrimination task, in a choice-RT task a target is associated with its own unique response. One of the targets is a "+" stimulus with a ring around it and the other is an "X" with a ring around it. The + and X targets are equiprobable and require a key-press with the right or left index finger, respectively. In Experiment 3, the same stimuli from Experiment 2 are used in a go/no-go task. The + target signals that a response ought to be made (go target) and the X signals that the response ought to be withheld (no-go target). In this experiment, the ratio of go to no-targets is 1:1.

Go/no-go and choice-RT tasks were chosen because they measure accuracy in different ways. In a go/no-go task, accuracy is primarily measured by looking at how frequently responses are withheld to no-go targets (i.e., correct rejection). An error occurs when a response is made to a no-go target (i.e., false alarm; see Ivanoff & Klein, 2001; Taylor & Ivanoff, in press). In contrast, accuracy in a choice-RT task is reflected by the proportion of trials where the target was responded to with the appropriate key. In other words, an error occurs when the response to the target is inappropriate according to the instructed S-R assignments.

Experiment 1

The goal of Experiment 1 is to use an SAT procedure to examine the timecourse of IOR's effect on the accuracy of responding in a go/no-go task. An assessment of the effect of IOR on accuracy may falsify two of the four theories of the IOR effect. I will provide further details shortly. For now, it is important to discuss the methodology to appreciate how the dependent measures are derived. In the present experiment, an uninformative peripheral cue is presented briefly and precedes the onset of a change at fixation (intended to draw attention away from the first peripheral cue). After the change at fixation, a go or no-go target appears at the cued or uncued location. Following the presentation of a go target, a response signal (i.e., a brief tone) indicates that a response should be made immediately (i.e., within 210ms). If a no-go target is presented, the response signal can be ignored and the response ought to be withheld. By manipulating the target-tone onset asynchrony (i.e., the TTOA), the amount of information available at the time the response is made can be systematically manipulated.

To put it simply, as TTOA increases, the accrual of target information ought to lead to fewer erroneous responses.

In a go/no-go SAT task, several measures can be extracted. There are two measures derived from signal detection theory that are of particular interest (i.e., d' and c). Hits and false alarms may be influenced not only by the sensitivity (d') to the signal, but also by the criterion to respond (c). These measures were calculated using the formulas provided by Stanislaw and Todorov (1999; see also Brophy, 1986). The assumptions behind these calculations are that the underlying distributions of the internal activity associated with noise and the signal with noise (signal + noise) are normal and that the variances are equal. I will use d' as a measure of sensitivity and c[4] as a measure of the response criterion. c is defined as the distance between the point at which neither decision alternative is favored and the response criterion adopted by the observer. A positive c value indicates that responding is conservative (i.e., more signal evidence is required to make the design to respond) and a negative c value indicates that responding is liberal (i.e., less signal evidence is required to make the decision to respond).

As TTOA increases the quality of information improves and thus it is expected that d' will increase to an asymptotic level. Moreover, as TTOA decreases c may decrease (i.e., indicating that responding was liberal) due to the instruction to respond within the response window. If this occurred, liberal responding would be associated with low sensitivity at short TTOAs.

Along with d' and c, which are derived from hits and

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[4] c rather than ß (beta) will be used because there is some concern that ß is affected by changes in d' (Banks, 1970; Macmillan, 1993; Richardson, 1994). Moreover, whereas ß assumes that bias is based on a likelihood ratio of signal and noise at the criterion (c), c assumes that the "bias" is based on a particular level of internal activity.

false alarms, we can also look at *tone-RTs* (RT taken from the onset of the tone to response), *anticipations* (i.e., responses executed before the response window), and *misses* (i.e., responses executed after the response window). A tone-RT is like a typical RT except that the RT is taken from the onset of the tone, but is likely influenced by stimulus-controlled processes that precede the tone. An effect of IOR on tone-RTs may be used as a benchmark for the IOR effect. What I refer to as a *miss* and an *anticipation* are both "misses" in the sense that a response is not made during the response window. However, these response types are distinguished because they may be the consequence of different mechanisms. An anticipatory response may be the result of an inability to maintain response preparation at levels below threshold, perhaps because it is effortful to maintain a preparatory state (Näätenen, 1971). A miss may owe to the insufficient development of response preparation within the response window.

Predictions

What do the four theories of the IOR effect predict for each measure of the IOR effect? Table 2 lists the predicted effects of IOR on accuracy (i.e., sensitivity) in an SAT task under conditions where IOR does, and does not, affect tone-RTs. The four theories make additional predictions concerning the effect of IOR on other measures (i.e., anticipations, misses, and c). The details concerning the additional predictions are discussed below. There is no need to discuss the effects of IOR on hits and false alarms as these measures are not independent from the measures of sensitivity and criterion.

Recall that the inhibited attention account entails a delayed shift of attention and/or prolonged and impaired perceptual processing. Accordingly, IOR should not affect anticipations or the criterion (c) as there is no reason why inhibiting attention or impairing perception should affect premature responding or the response criterion, respectively. IOR may increase misses if there is an attempt to compensate for deficient evidence for cued targets by allowing more time to pass.

The criterion-shift account predicts that IOR will increase c, the criterion in signal detection theory. Recall that c reflects the degree to which responding is liberal or conservative. Whatever the nature of the IOR mechanism, if it invokes a criterion-shift, such that more evidence is needed to respond to cued targets, then it ought to increase c. This change in c is not necessarily related to sensitivity (d') or RT, it merely reflects the bias to respond. If IOR generates a reluctance to respond to targets (as suggested by Klein & Taylor, 1994), then IOR ought to increase c. Misses will be more frequent for cued targets than for uncued targets if IOR raises the response criterion. Anticipatory responses ought to be less frequent for cued targets as a raised criterion will entail fewer instances where response activation "slips" past the criterion due to noise.

The inhibited response theory predicts the same general pattern of performance as does the criterion-shift theory. Like the criterion-shift proposal, misses ought to be more frequent for cued trials than for uncued trials. However, the increase in misses would be due to response inhibition, rather than a heightened criterion. In addition, anticipations ought to be more frequent for uncued trials than for cued trials because the response inhibition would help prevent premature responding. Lastly, like the criterion-shift proposal, the inhibited response theory predicts that responding will be more conservative for cued targets than for uncued targets. In essence, the response inhibition for cued targets makes it less likely that a response will be made for cued targets. In other words, it will masquerade as a response bias. However, this prediction is not unlike Klein and Taylor's (1994) suggestion that IOR creates a reluctance to "respond to" targets at the cued location.

The disconnection hypothesis holds that the temporary disconnection of stimuli from their responses ought to result in more misses for cued targets because of the passive decay of stimulus information. Moreover, a disconnection may actually help to reduce the incidence of anticipations on cued trials because the disconnection may make it more difficult to respond prematurely. Like an inhibited response, the disconnection ought to decrease the likelihood of responding on cued trials. Thus, the criterion should be higher on cued trials than on uncued trials.

Methods

Participants, apparatus, and stimuli

Fourteen Dalhousie students participated in this experiment for course credit. The experiment was conducted on a 636 (seven subjects) and a 8500 (seven subjects) Macintosh computer. Participants were seated approximately 57cm from the computer monitor. Responses were taken from an ADB keyboard. Stimuli were presented in black on a white background. The placeholders were three squares, each measuring 1.5° x1.5° (visual angle). The distance from the outside of the central placeholder to the inside of the lateral placeholders was 6.2°. Inside the central placeholder was the fixation point. The fixation point was a hollow, black circle measuring 0.8° in diameter and it remained on the screen throughout the trial. The cue was a circle, 1.5° in diameter, with a "+" inside of it. The central fixation point enlarged briefly during the cue-target onset asynchrony (i.e., CTOA) to 1.2° and was created by doubling the original thickness. The "go" target was a black-filled square measuring 1.5°. The "no-go" target was a 1.5° checkerboard stimulus. The checkerboard pattern was a 10x10 grid that alternated between white and black. The tone was a brief 30ms "bip" presented via the computer's internal speaker. The feedback text was presented centrally, and alone, and it was in a large (48pt) arial font.

Procedure

The trial sequence is illustrated in Figure 3. The fixation point was presented alone with the three placeholders for 750ms. Following this, the cue was equally likely to be presented in the left or the right placeholder for 120ms. The cue was then removed and the three placeholders and the fixation point were presented briefly (30ms). The fixation point then enlarged for 60ms. After the 60ms, the fixation point returned to its original size and 255ms or 840ms elapsed, for CTOAs of 465ms and 1050ms, respectively. The CTOAs were equally likely to be presented and they were randomly presented within the same block of trials. After the interval, the target was presented to the left or to the right placeholder with equal probability. There was no correlation between the spatial position of the cue and that of the target. Go targets were presented on 75% of the trials and no-go targets were presented on 25% of the trials. Targets were presented until a response was made or the TTOA elapsed.

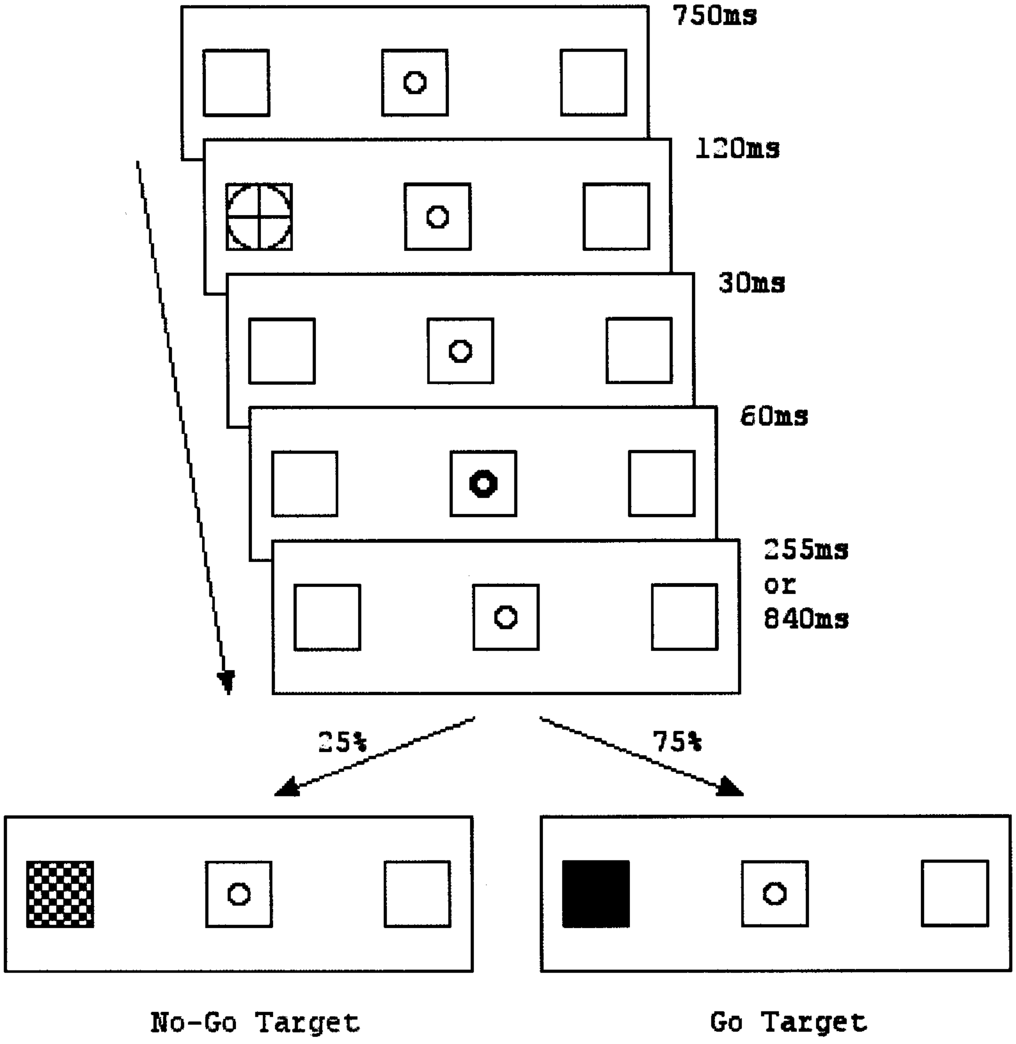

Figure 3. An illustration of the trial events for Experiment 1. Note that stimuli are not presented to scale. See text for full details.

There were four blocks of trials, one block for each of the four TTOAs (60ms, 120ms, 240ms, and 480ms). Whether the TTOAs were given in ascending or descending order was counterbalanced. The SAT methodology is illustrated in Figure 4. Following the presentation of the target, a tone was presented for 30ms. The onset of the tone provided a 210ms window in which all responses were to be made. Participants were not instructed to make their response *to* the tone. Rather, they were told to use the tone to *pace* their responses (e.g., as a musician would use a metronome). Following the completion of the trial (i.e., a response was made within or before the response window or the duration of the response window elapsed without a response), all the stimuli were removed and feedback was provided at centre for 450ms. If a response was made to the go target within 210ms of the tone, the word "HIT" was presented alone. If the response was not made within the 210ms, the message "MISS" was presented. If the response was made before the tone, the message "TOO SOON" was presented. No feedback was provided for no-go trials. The participants were instructed to try to get as many "HITS" as possible while avoiding responding to the go-no target.

There were 18 go trials and 6 no-go trials for every cell in the design. There were 2 CTOAs (465ms and 1050ms), 4 TTOAs (60ms, 120ms, 240ms, and 480ms), 2 cue locations (left and right), and 2 target locations (left and right), for a total of 576 trials.

Figure 4. (Next page). (A) An illustration of the speed-accuracy tradeoff (SAT) method. When the target is presented, there is a fixed amount of time within a block before the response signal is presented (target-tone onset asynchrony; TTOA). The onset of the response signal (i.e., the tone) is represented with a dotted arrow pointing downward. At the time the response signal is presented, there is an ensuing 210ms response window (represented by stippled rectangles in the figure). The participant's task is to respond to go targets during the response window and withhold responding to no-go targets. (B) An illustration showing the category of response types. If a response is made to a go target before the response window, it is an anticipation. Anticipatory responses to no-go targets are not considered because they are very rare. A correct response to a go target during the response window is a hit. A response to a no-go trial during the response window is a false alarm (FA). A failed response to a go target is a miss and a failed response to a no-go target is a correct rejection (CR). See text for more details.

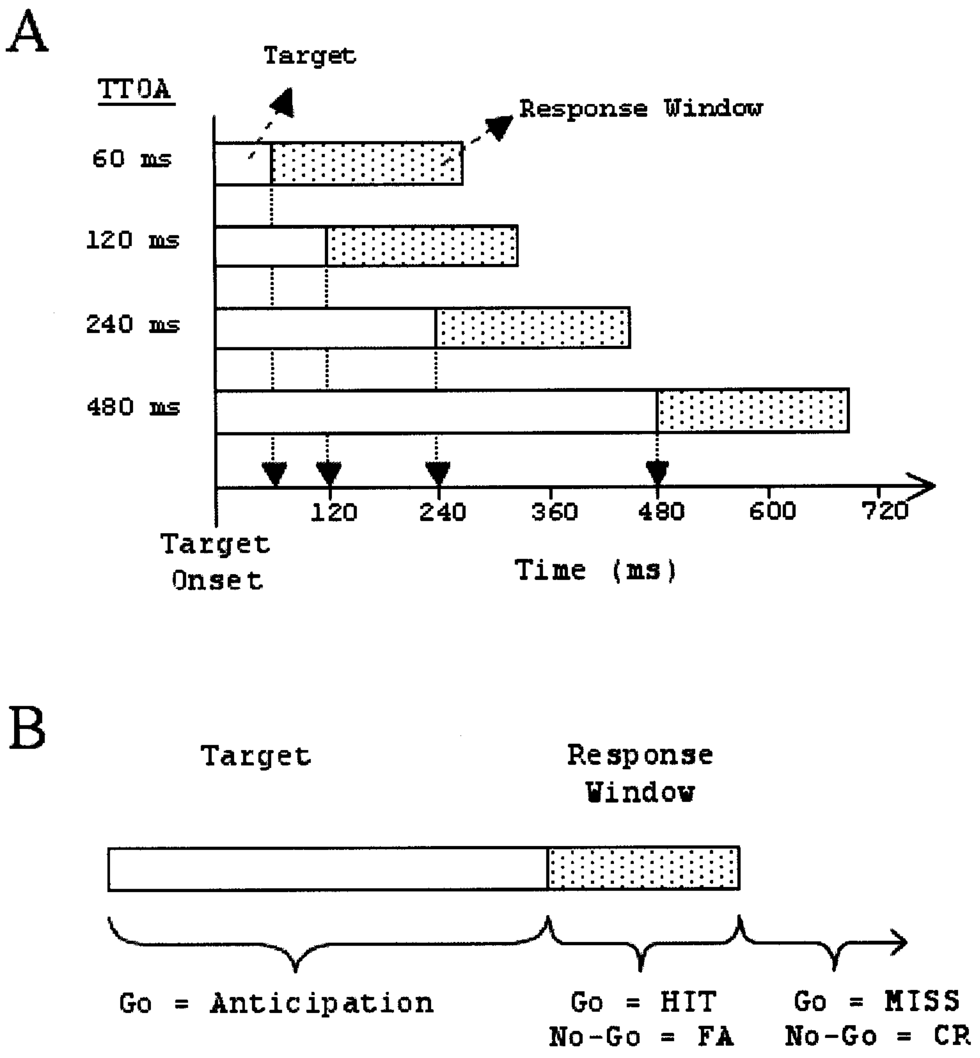
A
Target
TTOA
Response Window
60 ms
120 ms
240 ms
480 ms
120
240
360
480
600
720
Target Onset
Time (ms)
B
Target
Response Window
Go = Anticipation
Go = HIT
No-Go = FA
Go = MISS
No-Go = CR

Figure 4.

Results

The data from one participant were removed from the analysis because he/she made too few hits (i.e., responses to the go target). This participant's overall hit rate was 53.1%. The average hit rate of the remaining 13 participants was 83.4% (range: 70.5%-93.1%). Tone-RTs, false alarms, anticipations, misses, hits, d' and c were subjected to a 2 (cueing: cued and uncued) x 2 (CTOA: 465ms and 1050ms) x 4 (TTOA: 60ms, 120ms, 240ms, and 480ms) repeated measures analysis of variance (ANOVA).

Tone reaction time

Tone-RT is taken from the onset of the tone to the execution of the response. Only those tone-RTs to the go target that fell within the 210ms window following the tone were accepted into the analysis. The tone-RT distributions were non-normal at the extreme TTOAs. However, these RTs are still valid measures of processing time as they reveal whether one particular condition is generally faster than another condition. Tone-RTs are presented in Figure 5.

All main effects were significant: TTOA [$F(3,36)=41.33$, $p<0.0001$], CTOA [$F(1,12)=29.77$, $p<0.0005$], and cueing [$F(1,12)=48.04$, $p<0.0001$]. The interaction between TTOA and cueing was significant [$F(3,36)=16.13$, $p<0.0001$]. The IOR effects (uncued RT - cued RT) at the 120ms (M=-20ms) and 240ms (M=-21ms) TTOA were not significantly different from one another but they were both greater than the IOR effect at the 60ms (M=-7ms) TTOA and the 480ms (M=-2ms) TTOA. There was also an interaction between CTOA and cueing [$F(1,12)=8.76$, $p<0.05$]. The IOR effect was larger at the 465ms CTOA (M=-15ms) than at the 1050ms CTOA (M=-10ms).

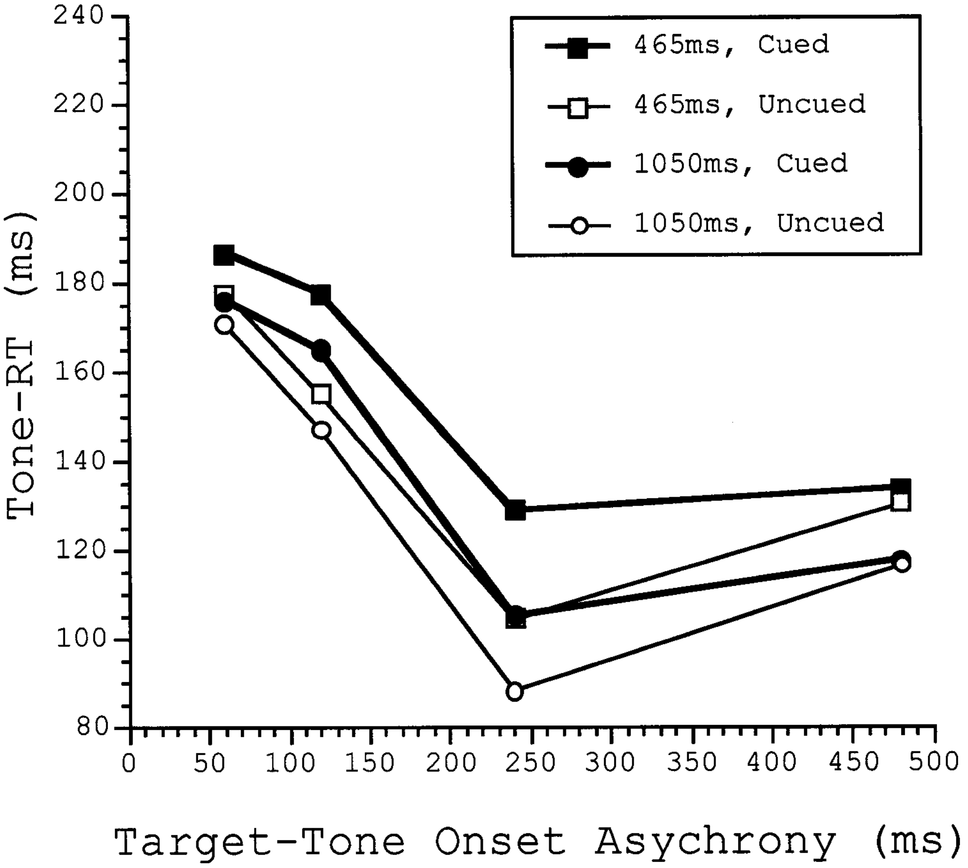

Figure 5. Tone-RT (tone reaction time, in ms) versus target-tone onset asynchrony as a function of cueing (cued and uncued) and cue-target onset asynchrony (465ms and 1050ms) in Experiment 1.

False alarms

A false alarm is defined as a response within the 210ms response-window following a no-go target. The total percentage of responses to no-go targets that were anticipations are quite low (less than 1%) and for this reason they will not be discussed. The percentage of false alarms (i.e., false alarms in response window ÷ total no-go trials x 100), plotted as a function of TTOA, is shown in Figure 6.

There was a significant main effect of TTOA [$F(3,12)=64.14$, $p<0.0001$], a marginal main effect of CTOA [$F(1,12)=4.69$, $p=0.051$], and a significant effect of cueing [$F(1,12)=47.39$, $p<0.0001$]. The cueing effect is due to more false alarms to the uncued targets than to the cued targets. The interaction between CTOA and cueing [$F(1,12)=6.45$, $p<0.05$] and the interaction between TTOA and cueing [$F(3,36)=13.35$, $p<0.0001$] were significant. Finally, the three-way interaction between TTOA, CTOA, and cueing was significant [$F(3,36)=5.12$, $p<0.005$]. This three-way interaction was analyzed by examining the cueing effect (uncued false alarm rate - cued false alarm rate) at each level of CTOA and TTOA. For the 465ms CTOA, the cueing effects were significant (except at the 480ms TTOA) and they decreased as TTOA increased (60ms: M=39.74%; 120ms: M=23.72%, 240ms: M=6.41%, 480ms: M=0.00%). For the 1050ms CTOA, there was a similar pattern of results, but the effects were generally smaller and marginally ($0.05<ps<0.10$) significant at all TTOAs, except 480ms where there was no cueing effect for all participants (60ms: M=16.03%; 120ms: M=10.90%, 240ms: M=7.05%, 480ms: M=0.00%).

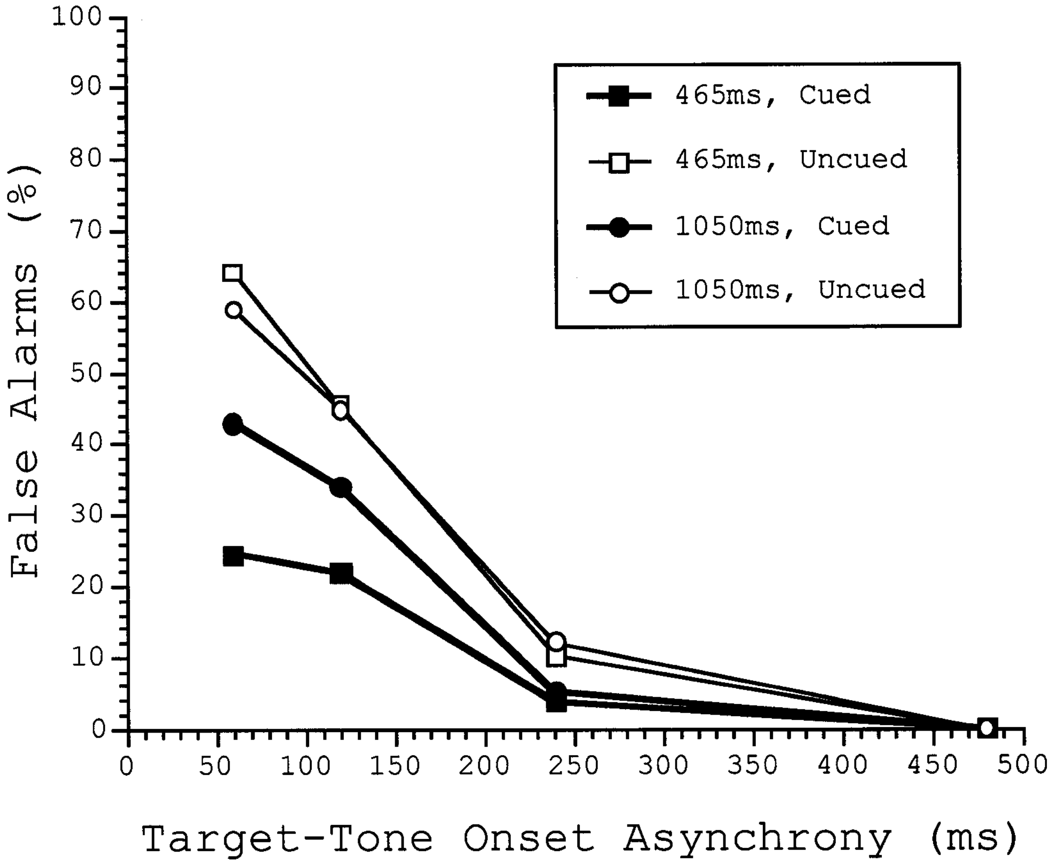

Figure 6. The percentage of false alarms (i.e., responses to the no-go target within the 210ms response window) versus target-tone onset asynchrony as a function of cueing (cued and uncued) and cue-target onset asynchrony (465ms and 1050ms) in Experiment 1.

Anticipations

An anticipation is defined as a response before the tone and after the go target. Anticipations are plotted against TTOA in Figure 7. There were three significant effects: TTOA [$F(3,36)=105.29$, $p<0.0001$], CTOA [$F(1,12)=12.52$, $p<0.005$], and TTOA x CTOA [$F(3,36)=3.43$, $p<0.05$]. At the 465ms CTOA, only at the 480ms TTOA was the percentage of anticipations significantly above zero [$M=10.90\%$; $t(12)=7.27$, $p<0.0001$]. At the 1050ms CTOA, the percentage of anticipations at 480ms [$M=16.24\%$; $t(12)=9.043$, $p<0.0001$], 240ms [$M=2.56\%$; $t(12)=2.98$, $p<0.05$], and 120ms [$M=0.78\%$; $t(12)=2.50$, $p<0.05$] TTOAs were significantly above zero. At the 60ms TTOA, anticipations were just marginally above zero [$M=1.07\%$; $t(12)=2.13$, $p=0.054$]

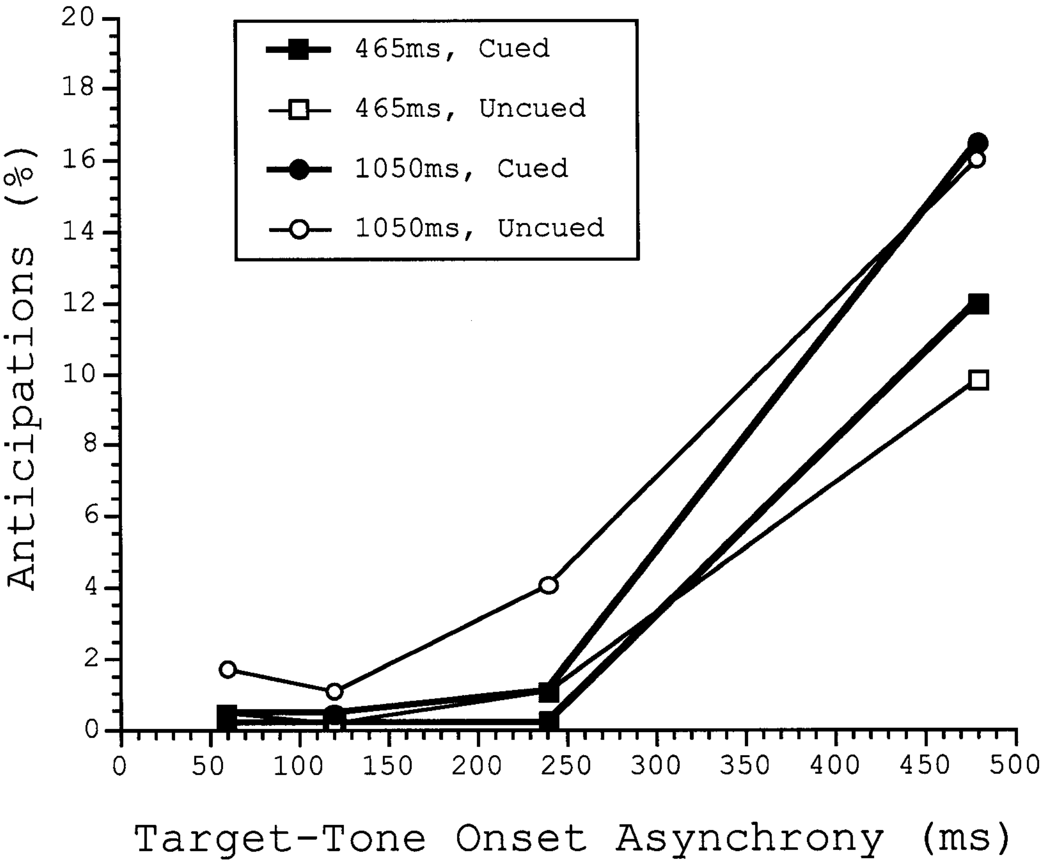

Figure 7. The percentage of anticipations (i.e., responses to go target before the onset of the tone) versus target-tone onset asynchrony (TTOA) as a function of cueing (cued and uncued) and cue-target onset asynchrony (465ms and 1050ms) in Experiment 1.

Hits

A hit is defined as a response within the 210ms window following the go target. Average hit rates (in %) are plotted against TTOA in Figure 8. The same analysis performed on the other measures was performed on the hit rate. The analysis showed that the main effect of TTOA [$F(3,36)=69.26$, $p<0.0001$] and cueing [$F(1,12)=44.51$, $p<0.0001$] were significant. The interactions between TTOA x CTOA [$F(3,36)=3.22$, $p<0.05$], TTOA x cueing [$F(3,36)=22.37$, $p<0.0001$], CTOA x cueing [$F(1,12)=19.95$, $p<0.001$], and TTOA x CTOA x cueing [$F(3,36)=3.33$, $p<0.05$] were significant. The three-way interaction was analyzed by examining cueing effects (uncued hit rate - cued hit rate) at each level of TTOA and CTOA. At the 465ms CTOA, there were significant cueing effects at the 60ms [M=27.35%, $t(12)=7.63$, $p<0.0001$] and 120ms [M=22.01%; $t(12)=6.08$, $p<0.0001$] TTOAs. The other cueing effects (at the 240ms and 480ms TTOAs) were not significant. At the 1050ms CTOA, only the cueing effect at the 60ms TTOA was significant [M=14.96%; $t(12)=3.63$, $p<0.005$], the cueing effects at the other TTOAs were non-significant.

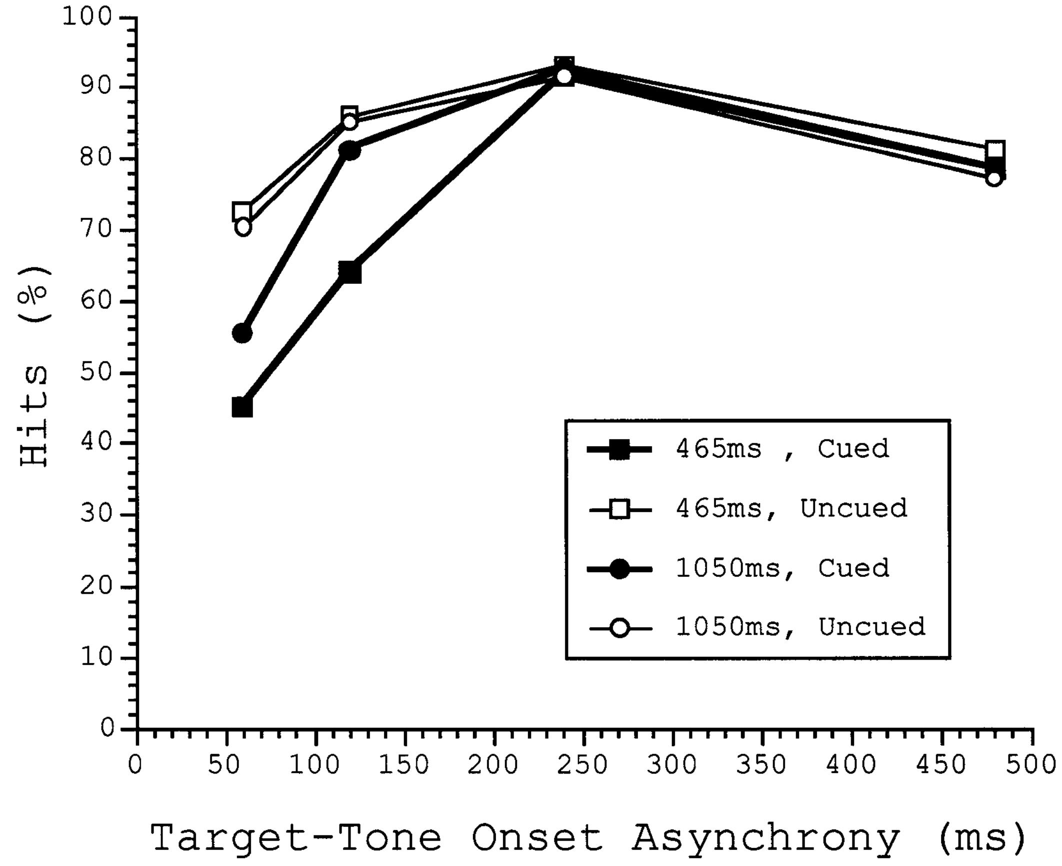

Figure 8. The percentage of hits (i.e., responses to the go target during the 210ms response window) versus target-tone onset asynchrony as a function of cueing (cued and uncued) and cue-target onset asynchrony (465ms and 1050ms) in Experiment 1.

Misses

A miss is defined as response that was not executed within (i.e., a hit) or before (i.e., an anticipation) the response window following a go target. The average miss rate (in %) versus TTOA is presented in Figure 9. The analysis of misses revealed the following significant effects: TTOA [$F(3,36)=109.38$, $p<0.0001$], CTOA [$F(1,12)=6.16$, $p<0.05$], cueing [$F(1,12)=38.58$, $p<0.0001$], TTOA x cueing [$F(3,36)=32.02$, $p<0.0001$], CTOA x cueing [$F(1,12)=25.23$, $p<0.0005$], and TTOA x CTOA x cueing [$F(3,36)=4.47$, $p<0.01$]. The three-way interaction was broken down by examining cueing effects (uncued misses - cued misses) at each CTOA and TTOA. For the 465ms CTOA, the cueing effect was significant at the 60ms TTOA [$M=-27.56\%$; $t(12)=7.42$, $p<0.0001$] and at the 12ms TTOA [$M=-22.01\%$; $t(12)=6.01$, $p<0.0001$]. The cueing effects at the other TTOAs were not significant. With the 1050ms TTOA, the only significant cueing effect was at the 60ms TTOA [$M=-16.24\%$; $t(12)=1.87$, $p<0.005$].

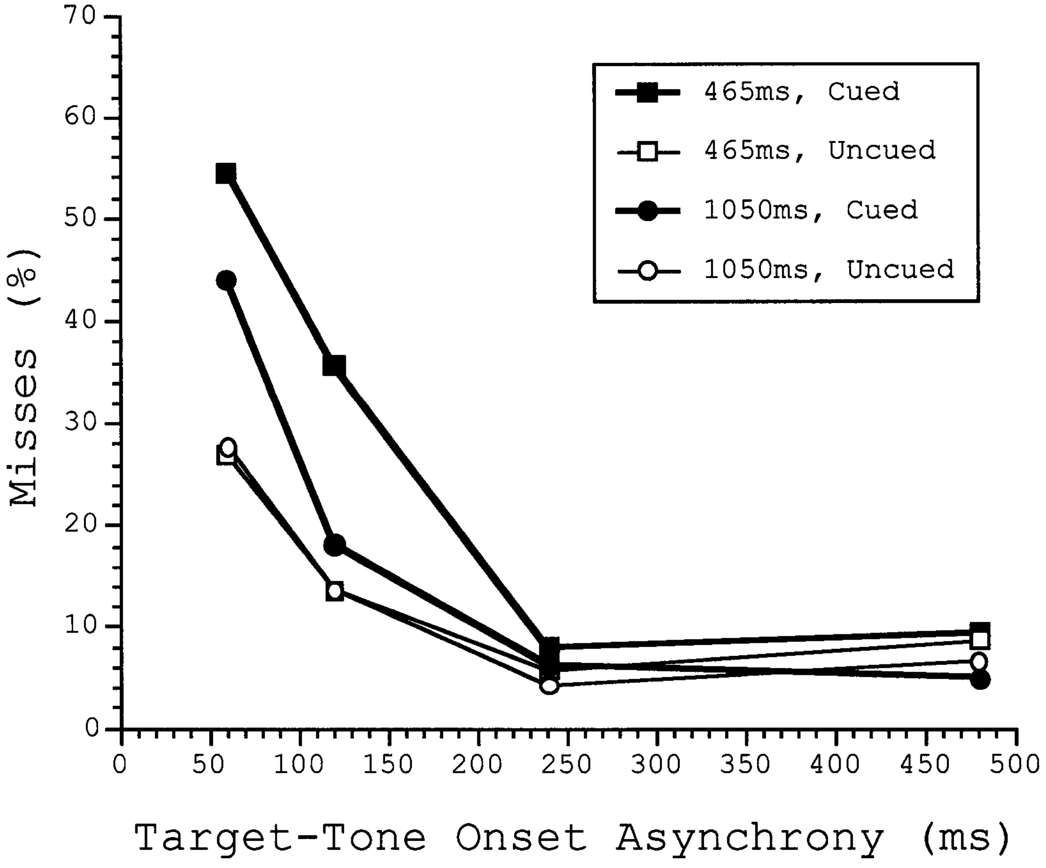

Figure 9. The percentage of misses (i.e., absent responding to the go target within or before the 210ms response window) versus target-tone onset asynchrony as a function of cueing (cued and uncued) and cue-target onset asynchrony (465ms and 1050ms) in Experiment 1.

Criterion (c)

c is a measure of the response criterion that does not seem to suffer from some of the pitfalls associated with ß (Brophy, 1986). A positive c value indicates a conservative response bias and a negative value indicates a liberal response bias. Because performance was occasionally at ceiling levels or floor levels, 100% hits or 0% false alarms, these cells were transformed to 99% or 1%, respectively. c scores were calculated with the transformed values (according to the formulas provided by Stanislaw & Todorov, 1999) and entered into the ANOVA. The c scores plotted against TTOA are presented in Figure 10.

The main effects of TTOA [$F(3,36)=37.87$, $p<0.0001$] and cueing [$F(1,12)=59.08$, $p<0.0001$] were significant. The criterion values increased as TTOA increased and there was generally more conservative responding to cued targets ($M=0.30$) than to uncued targets ($M=-0.07$). The interaction between cueing and TTOA was significant [$F(3,36)=21.32$, $p<0.0001$]. There was also a significant CTOA x cueing interaction [$F(1,12)=13.05$, $p<0.005$]. Lastly, the three-way interaction between TTOA, CTOA, and cueing was significant, $F(3,36)=3.92$, $p<0.05$. To break down this interaction, the c values were subjected to paired t-tests between cued and uncued conditions for each TTOA and CTOA. For the 1050ms CTOA, the only cued-uncued difference was with the 60ms TTOA where c was 0.47 units [$t(12)=3.88$, $p<0.005$] higher for cued targets than for uncued targets. For the 465ms CTOA, however, the only *non-significant* difference between cued and uncued trials was at the 480ms TTOA. At the 240ms TTOA, 120ms and 60ms TTOA, c values were 0.20 [$t(12)=2.85$, $p<0.05$], 0.85 [$t(12)=6.35$, $p<0.0001$], and 1.00 [$t(12)=9.09$, $p<0.0001$] higher for cued than for uncued trials.

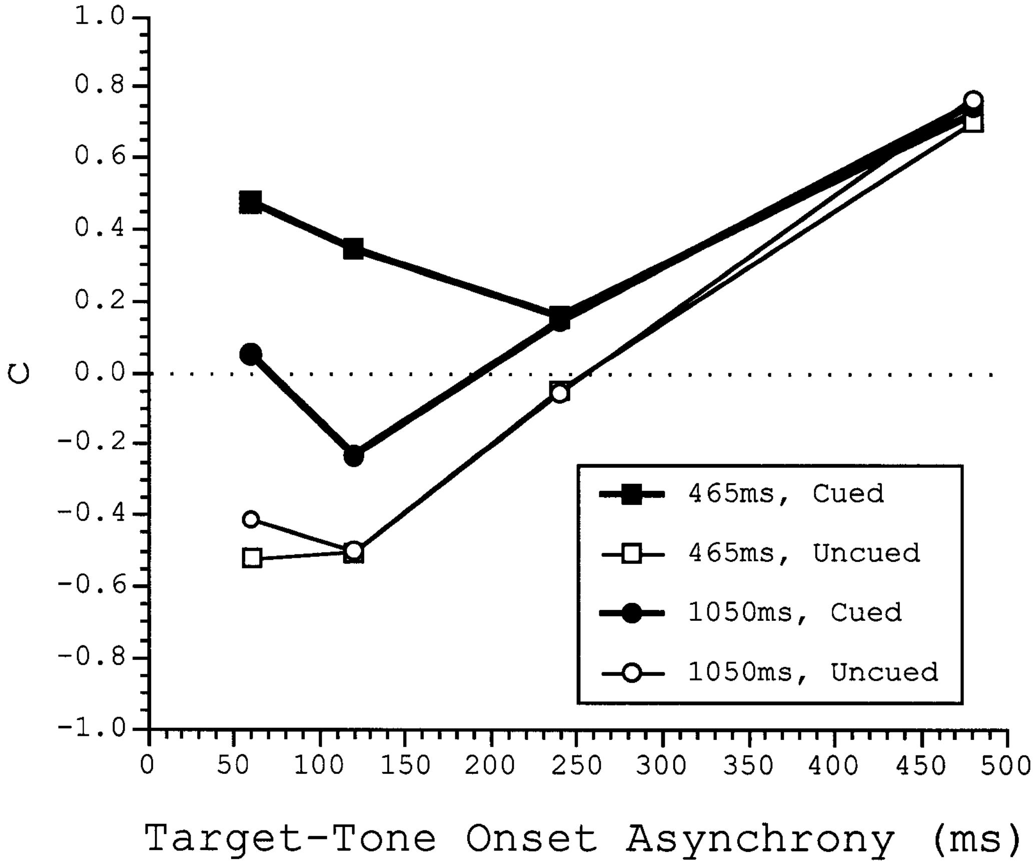

Figure 10. *The criterion (c) values versus target-tone onset asynchrony as a function of cueing (cued and uncued) and cue-target onset asynchrony (465ms and 1050ms) in Experiment 1. Positive values indicate a conservative criterion and negative values indicate a liberal criterion.*

Sensitivity (d')

d' is a measure of sensitivity and the d' values were calculated from the same transformed values of hits and false alarms used to calculate c. The calculation of d' was based on a single pair of hits and false alarms using the calculation provided by Brophy (1986; see also Stanislaw & Todorov, 1999). The mean d' values versus TTOA are presented in Figure 11.

The main effect of TTOA was significant [$F(3,36)=207.84$, $p<0.0001$], indicating that sensitivity increased dramatically as TTOA increased. The main effect of cueing was also significant [$F(1,12)=15.55$, $p<0.005$]. Generally, d' was higher for cued ($M=2.20$) than for uncued ($M=1.93$) targets. The interaction between TTOA and cueing was marginally significant [$F(3,36)=2.85$, $p=0.051$]. When the cueing effect (i.e., higher d' values for cued targets than for uncued targets) was examined at each level of TTOA, the cueing effect was only significant at the 240ms TTOA [$t(12)=3.21$, $p<0.01$], where sensitivity was higher for targets at the cued location ($M=3.56$) than for targets at the uncued location ($M=2.94$).

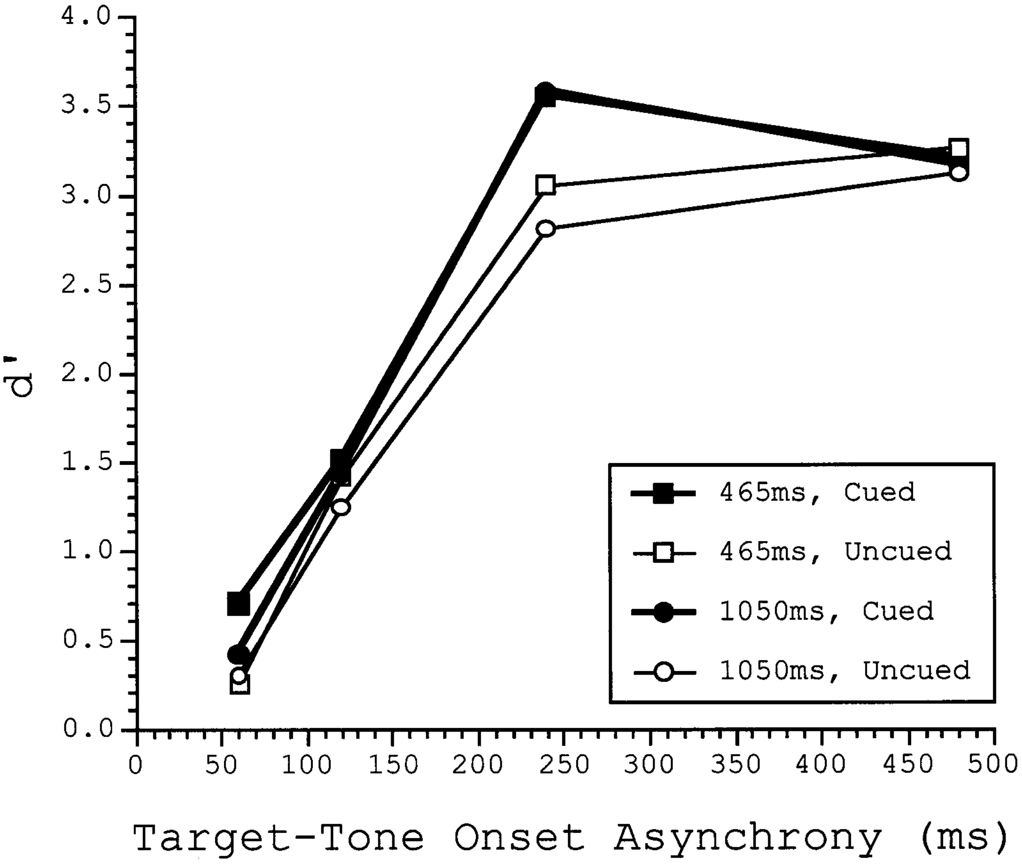

Figure 11. *d' versus target-tone onset asynchrony as a function of cueing (cued and uncued) and cue-target onset asynchrony (465ms and 1050ms) in Experiment 1.*

Discussion

The present SAT study of the IOR effect provided a wealth of new information concerning the time-course of IOR's effect on target processing in a go/no-go (Donders' c-reaction) task. Some of the results do not readily distinguish between the four theories of the IOR effect, and so do not merit much discussion. For instance, the miss rate was higher for cued targets than for uncued targets. All four theories predicted this result, albeit for different reasons. Although analyzed, hit rates and false alarm rates will not be described because they were used in the calculation of d' and c. Anticipations, sensitivity (d') and the criterion (c) will be discussed because they are particularly telling with respect to distinguishing between the four accounts of the IOR effect.

Sensitivity (d')

As shown in Table 2 in Chapter 1, the four theories were divided in their predictions concerning IOR's effect on sensitivity (i.e., accuracy). Before one can interpret d', it should be noted that there was an effect of IOR on tone-RT. The relationship between tone-RT and d' is illustrated in Figure 12. The origin of the vectors reflect the mean d' and tone-RT performance on uncued trials. The end of the vector (with the arrow) reflects the d' and tone-RT performance for cued trials. The gray vectors reflect the performance patterns for each participant and the black vectors are the means for the group. Vectors that point up and to the right are consistent with the criterion-shift or inhibited response interpretations of the IOR effect. Those vectors that point down and to the right are consistent with the inhibited attention and disconnection theories.

Figure 12. (Next page). Summary of the relationship between tone-RT (abscissa) and sensitivity (d'; ordinate) for each cue-target onset asynchrony (CTOA) and each target-tone onset asynchrony (TTOA) in Experiment 1. Each end of the vector is the mean tone-RT and d' values for uncued and cued trials. The vector points toward the values for cued targets. The gray vectors are those belonging to individual participants and the dark black vector is the average.

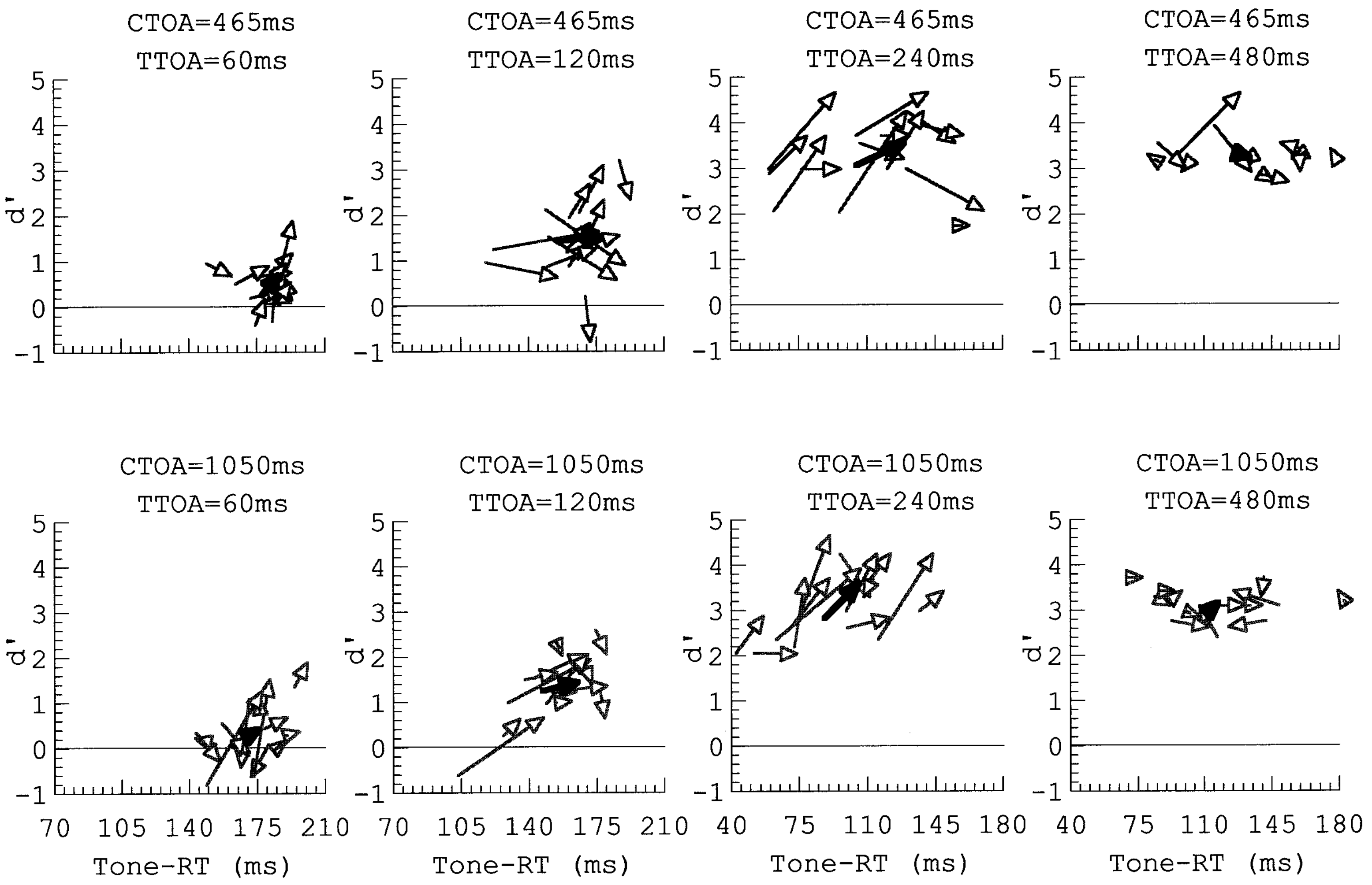
CTOA=465ms
TTOA=60ms
CTOA=465ms
TTOA=120ms
CTOA=465ms
TTOA=240ms
CTOA=465ms
TTOA=480ms
CTOA=1050ms
TTOA=60ms
CTOA=1050ms
TTOA=120ms
CTOA=1050ms
TTOA=240ms
CTOA=1050ms
TTOA=480ms
d'
5
4
3
2
1
0
-1
70 105 140 175 210
40 75 110 145 180
Tone-RT (ms)

Figure 12.

As Figure 12 clearly shows, most of the arrows point up and to the right. This is a remarkable finding because it stands in stark contrast to what Cheal and Chastain (1998), Handy et al. (1999), Klein and Dick (2002), and others have observed: namely that IOR reduces accuracy. Recall, however, that because these studies used a post-target mask (or, stimuli were presented in rapid succession so that stimulus *n*+1 may mask stimulus *n*; Klein & Dick, 2002) information would have been extracted while target information decayed. In the current experiment, the target was not masked and sensitivity was measured while information was accumulating. Thus, the effect of IOR on d' in the current experiment does not support the inhibited attention and the disconnection theories of the IOR effect. The increased sensitivity on cued trials is consistent with the inhibited response and the criterion-shift proposals of the IOR effect.

Criterion (c)

That responding was more conservative at the cued location than it was at the uncued location does not support an explanation of the IOR effect solely in term of inhibited attention. This finding is consistent with the inhibited response, disconnection, and the criterion-shift accounts. While responding to uncued targets was quite liberal with the short TTOAs, responding to cued targets was conservative. At the longer TTOAs, the effect of cueing on the criterion was eliminated. However, with long TTOAs, sensitivity is at a maximum. Thus, responding to cued targets is conservative when there is limited information available concerning the target's relevant feature (i.e., black versus black and white checkerboard).

Anticipations

Perhaps the only fly in the ointment for the criterion-shift and the inhibited response proposals is that anticipations were not significantly affected by IOR. If the criterion was higher for cued targets, then it should have reduced the number of anticipations. However, there are two reasons for sweeping this finding under the rug, at least temporarily. First, there is the chance of committing a type II error when disconfirming a theory by accepting the null hypothesis. IOR may affect anticipations, but the effect is too small to observe with a small sample. Second, in the present experiment, the temporal onset of the target was variable (i.e., there were two CTOAs). This may have discouraged a high level of response preparation before the tone (e.g., Miller, 1998) and therefore reduced the chances of observing an effect of IOR on anticipatory responding. Whatever the reason, the absent effect of IOR on anticipations is a little unsettling but not a serious blow to any account of IOR.

Summary

That sensitivity (d') was higher for cued than for uncued targets supports the criterion-shift and the inhibited response theories and is not consistent with the inhibited attention and the disconnection theories of the IOR effect. That the criterion (c) was higher for cued targets provided further support for the inhibited response and the criterion-shift theories. However, before accepting this conclusion, it is necessary to ascertain the generality of these findings. Accuracy can be measured in a variety of tasks, including a choice-RT task. This is the type of task used by Cheal et al. (1998), and many others (see Table 1), who have observed performance detriments when identifying targets at the cued location. Thus, it is important to determine whether the evidence supports an interpretation of the IOR effect in terms of a criterion-shift in this kind of task using the SAT methodology. Moreover, the go/no-go task in Experiment 1 setup a bias for responding: go targets were more frequent than no-go targets. Although there may be a high bias for responding in a choice-RT task (in that a response is needed on every trial), it is free from bias (Green & Swets, 1966) in that neither response alternative is is in a highly prepared state. Thus, a choice-RT task may provide a stringent test of the criterion-shift and inhibited response theories.

Experiment 2

Goals

The present experiment had two goals. The first goal was to extend the findings in Experiment 1 from a go/no-go task to a choice-RT task. Determining whether IOR improves accuracy in a choice-RT task is important because those who have found evidence of reduced accuracy on cued trials compared to uncued trials have generally used choice-RT tasks (see Table 3; but see Handy et al., 1999, who found that d' was lower on cued trials than on uncued trials in a go/no-go task). As was pointed out earlier, those studies that have found lower accuracy on cued trials have also used a post-target mask (Cheal & Chastain, 1999), or have used brief target displays (Klein & Dick, 2002; Lupiàñez et al., 1997), making the interpretation of the reduced accuracy on cued trials ambiguous because one cannot rule out the possibility that the reduced accuracy is the result of greater information decay on cued trials. In the current study, the SAT methodology, rather than a post-target mask, will be used to assess accuracy to cued and uncued targets.

The four theories of IOR make the same predictions in this experiment as they did in the previous experiment, so I will not reiterate them here. However, it is worth mentioning that some of the measures are defined differently in choice-RT than in go/no-go tasks. In the current choice-RT task, a "hit" is now defined as *any* response made within the response window. A hit reflects the ability to execute a response within the response window. It is not factored into the measurement of accuracy. "Accuracy" is the percentage of responses that were executed with the proper key within the response window.

The four theories of the IOR effect predict different patterns of results depending on whether IOR slows tone-RTs. Had IOR not affected tone-RTs it may haved posed a problem for the inhibited response and criterion-shift theories because the absence of an IOR effect on tone-RTs may be taken to mean that the IOR mechanism was in effect but was not observed or that IOR was never generated in the first place. Fortunately, IOR slowed tone-RTs in Experiment 1 and so it was highly likely that IOR was generated. To be sure that the cue generates IOR in Experiment 2, I will include two blocks of trials with the usual "fast and accurate" instructions and without SAT methodology. These blocks will be completed before and after the SAT task. The purpose of these supplementary blocks is to provide converging evidence that the cues in the SAT task also generate IOR without the SAT methodology.

The second, and perhaps peripheral, goal of this experiment is to determine how IOR affects processing along the pathway originating from the location of the target and that terminates at the response (cf., Ivanoff, Klein, & Lupiáñez, 2002). By introducing a choice-RT task, there is an additional factor (i.e., the Simon effect; see Lu & Proctor, 1995, for a review) that can be explored. It is necessary to introduce it here to appreciate the advantages of including this factor.

Simon effect

As in Experiment 1, a non-spatial feature of the target is used to select the correct response. Unlike Experiment 1, in the current choice-RT task, one target signals that a left response should be made and the other target signals that a right response should be made. In this context, there is ample evidence that the spatial location of the target influences the speed and accuracy of responding (see Lu & Proctor, 1995, for a review). To be specific, responses are faster and more accurate when the location of the target spatially corresponds with the location of the response (e.g., a left response made to a left target or a right response made to a right target) than when they do not correspond (e.g., a right response made to a left target or a left response made to a right target). Note, however, that the location of the target is completely irrelevant: there is no correlation between the location of the target and the correct response. This performance advantage for spatially corresponding responses is referred to as the *Simon effect*, named after it discoverer (Simon & Rudell, 1967; see Simon, 1990, for a review of his early work).

Although a complete discussion of the Simon effect is beyond the scope of the current work, there is some common ground among the different theories concerning the underlying mechanisms responsible for the performance advantage for corresponding trials. Generally, it is thought that the Simon effect occurs at a late, response processing stage. Moreover, the location of the target - inadvertently and pseudo-automatically (Ivanoff, 2003; Valle-Inclán & Redondo, 1998) - activates its spatially corresponding response thereby facilitating corresponding responses and/or inhibiting non-corresponding responses. Thus, there are two component processes operating in a Simon task (DeJong, Liang, & Lauber, 1994). The first is *relevant* and is related to the instructions provided to the participant (i.e., respond to the "+" with the right hand and to the "X" with the left hand). The second, *irrelevant* component process occurs earlier than the relevant process and is related to the prepotent tendency to make a corresponding response (i.e., any left target activates the left response and any right target activates the right response). Hence, it is common in the Simon effect literature to speak of two routes to the response: a non-spatial task-relevant route and a spatial task-irrelevant route.

How does IOR alter the Simon effect? A previous analysis of the Simon and IOR effects revealed an interaction between these factors (Ivanoff et al., 2002). Specifically, the Simon effect was about twice as large for cued than for uncued targets. Likewise, the IOR effect was larger on noncorresponding trials than on corresponding trials. Ivanoff et al. were left with a series of explanations for this interaction, including the possibility that IOR delays the activation somewhere along the task-irrelevant route (so long as one also presupposes there is a criterion-shift component to the IOR effect), increases the magnitude of the activation along the task-irrelevant route, or delays the suppression of the activation along the irrelevant route. In the present experiment, there is the potential to discern how IOR affects the irrelevant route.

In a recent SAT exploration of the Simon effect (Ivanoff & Klein, in preparation) a declining influence of the irrelevant route on the percentage of correct responses was observed as TTOA increases. Moreover, at a short TTOA (120ms), responding was almost entirely controlled by the location of the target. This finding suggests that there is a strong tendency to respond towards the location of the target (Simon & Rudell, 1967) shortly after the onset of the target but that this tendency fades with accumulating evidence concerning the relevant target feature.

Signal detection theory and choice-RT

The analysis of the proportion of correct responses provides a direct measure of accuracy. Choice-RT tasks, with symmetric S-R probabilities (i.e., each stimulus and response pair is equally likely to be presented) are generally considered to be free from bias (Green & Swets, 1966), thus there is no need to calculate the criterion[5]. While it is not essential to translate percent correct into the d' metric, doing so allows for a direct comparison between experiments. However, d' and percent correct are redundant. Rather than analyze two measures that are redundant, I will use d' to assess sensitivity to the two features of the target. First, d' will be calculated according to whether responding is in accord with the task-*relevant* instructions. In this analysis, the correspondence between the target's location and the location of the response is not considered, only the ability to identify the relevant feature of the target and select the appropriate response. Second, d' will be calculated according to whether responding was sensitive *to* the *irrelevant* location feature of the target. In this

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[5] Criterion (c) values can be calculated, but they are not meaningful measures in the context of the goals of this experiment because they reflect biases toward a particular response (i.e., right) over the other response (i.e., left). There is no reason to expect that IOR would bias responding in this way, so criterion values will not be considered. However, response frequency (correct + incorrect responses / total number of trials) may be taken as an analogue of c.

analysis, the task instructions are inconsequential. Rather, the purpose of this analysis is to ascertain how IOR affects the tendency to respond to the location of the target. These measures ought to reveal the effect of IOR on the relevant (non-spatial) and irrelevant (spatial) routes to the response.

On their own, the four theories of the IOR effect do not make any specific predictions regarding how IOR might affect the location information when this is not relevant to the task. Nevertheless, because IOR has ubiquitous effects when the task is localization, the predictions listed in Table 2 ought to hold for the sensitivity towards the irrelevant location code of the target.

Methods

Participants, apparatus, and procedure

Thirteen people participated in the experiment for pay ($6/hr) or for course credit. The methodology of this experiment was the same as that of Experiment 1 with the following exceptions. The experiment was conducted on a 630 MAC and participants were seated approximately 57cm from the computer monitor.

The trial sequence is depicted in Figure 13. Every trial began with a blank 450ms inter-trial interval (not shown in Figure 13). Following this, three horizontally aligned squares were presented with the fixation point in the middle square. Each side of the square was 1.3° (visual angle). The fixation point was a hollow circle, 0.9° in diameter and 0.2° thick. This fixation display remained on throughout the trial but was removed during the blank inter-trial interval. After the onset of the fixation display, the cue appeared in the left or right square for 90ms. The cue

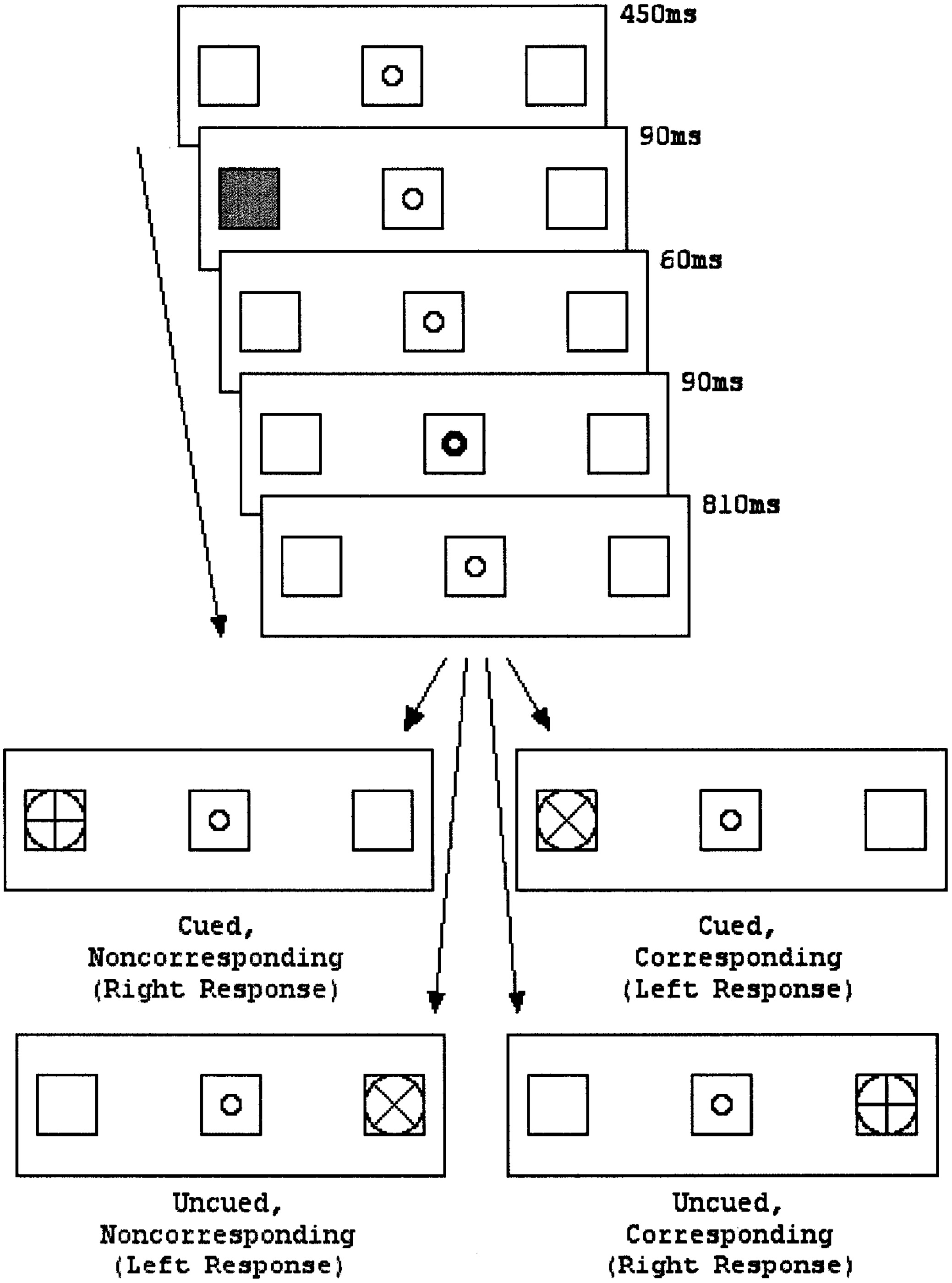

Figure 13. The procedure of Experiment 2. See text for further details.

was a gray square, the same size as the existing square placeholder. After the cue was removed, the fixation point and the three squares were presented alone for 60ms. The central fixation point enlarged (to 1.1° in diameter and 0.6° thick) for 90ms. The fixation point and square placeholders were then presented alone for 810ms. Finally, the target appeared in the left or right square. As always, the cue's location did not predict the target's location (i.e., the cue and targets were shown at the same location only 50% of the time). The target was a "+" or an "X" with a circle surrounding it. The + symbol was 1.3° wide and 1.3° tall. The X was the same size as the +, but rotated 45°. The + and X targets were presented with equal frequency. As shown in Figure 13, there were four types of trials, each equiprobable.

The SAT methodology was similar to that used in Experiment 1, with the following differences. One of four TTOAs (120ms, 240ms, 360ms, and 480ms) was presented in separate blocks. The order of TTOAs was in ascending or descending order, roughly counterbalanced between subjects. I replaced the 60ms TTOA from Experiment 1 with a 360ms TTOA because responding within 270ms of the target's onset (i.e., with a the 60ms TTOA and a 210ms response window) was very difficult in this task. After the tone, there was the 210ms response window in which participants were instructed to make the appropriate response. Participants were instructed to make a key-press with the index finger of the left hand on the "x" key whenever the x was presented and a key-press with the right index finger on the "." key whenever the + was presented. As before, the cueing condition referred to whether the cue and target appeared in the same location (cued targets) or in different locations (uncued targets). Correspondence referred to whether the location of the target and the response were spatially *corresponding* (e.g., a + on the right or a x on the left) or *noncorresponding* (i.e., a + on the left or a x on the right). Feedback was provided, as in Experiment 1. No feedback was given with respect to whether the correct key was pressed.

There were six blocks of trials, taking nearly two hours to complete. The blocks were completed in two 1-hour sessions. The first and last blocks were comprised of 40 trials for which participants were instructed to respond quickly and accurately. The response signal was not presented, and so this was not an SAT task. The purpose of these blocks was to assess performance before and after the SAT task. The middle blocks were the SAT blocks. Each SAT block had 400 trials comprised of 100 cued and 100 uncued trials for corresponding and noncorresponding targets.

Results

First and last blocks

RTs less than 200ms and greater than 1000ms were excluded from further analyses. The mean RTs and percentage of incorrect key-presses are presented in Figure 14. The mean RTs were entered into a 2 (session: first and last) x 2 (cueing: cued and uncued) x 2 (correspondence: corresponding and noncorresponding) ANOVA. All main effects were significant: order [$F(1,12)=30.56$, $p<0.0005$], cueing [$F(1,12)=25.27$, $p<0.0005$], and correspondence [$F(1,12)=16.04$, $p<0.005$]. Responses were 113ms faster after the SAT task than they were before the SAT task. There was also a 34ms Simon effect overall. The order x cueing interaction was significant [$F(1,12)=4.93$, $p<0.05$], indicating that the IOR effect (uncued RT - cued RT) was larger before the SAT (M=-49ms) than it was after the SAT (M=-25ms). The interaction between cueing and correspondence was non-significant [$F(1,12)=3.59$, $p=0.083$], but a one-tailed t-test indicated that the Simon effect was was 19ms larger for cued targets than for uncued targets [$t(12)=1.89$, $p<0.05$].

The same analysis performed on RTs was performed on errors. There was a main effect of session [$F(1,12)=16.21$, $p<0.005$], indicating that there were 5% more errors after the SAT task (last session) than there were before the SAT task (first session). There was also a significant effect of correspondence [$F(1,12)=15.15$, $p<0.005$]: there were fewer errors for corresponding trials (M=3.56%) than there were for noncorresponding trials (M=8.75%). The cueing effect was non-significant [$F(1,12)=0.61$, $p=0.45$], although there were slightly more errors for cued targets (M=6.54%) than there were for uncued targets (M=5.77%).

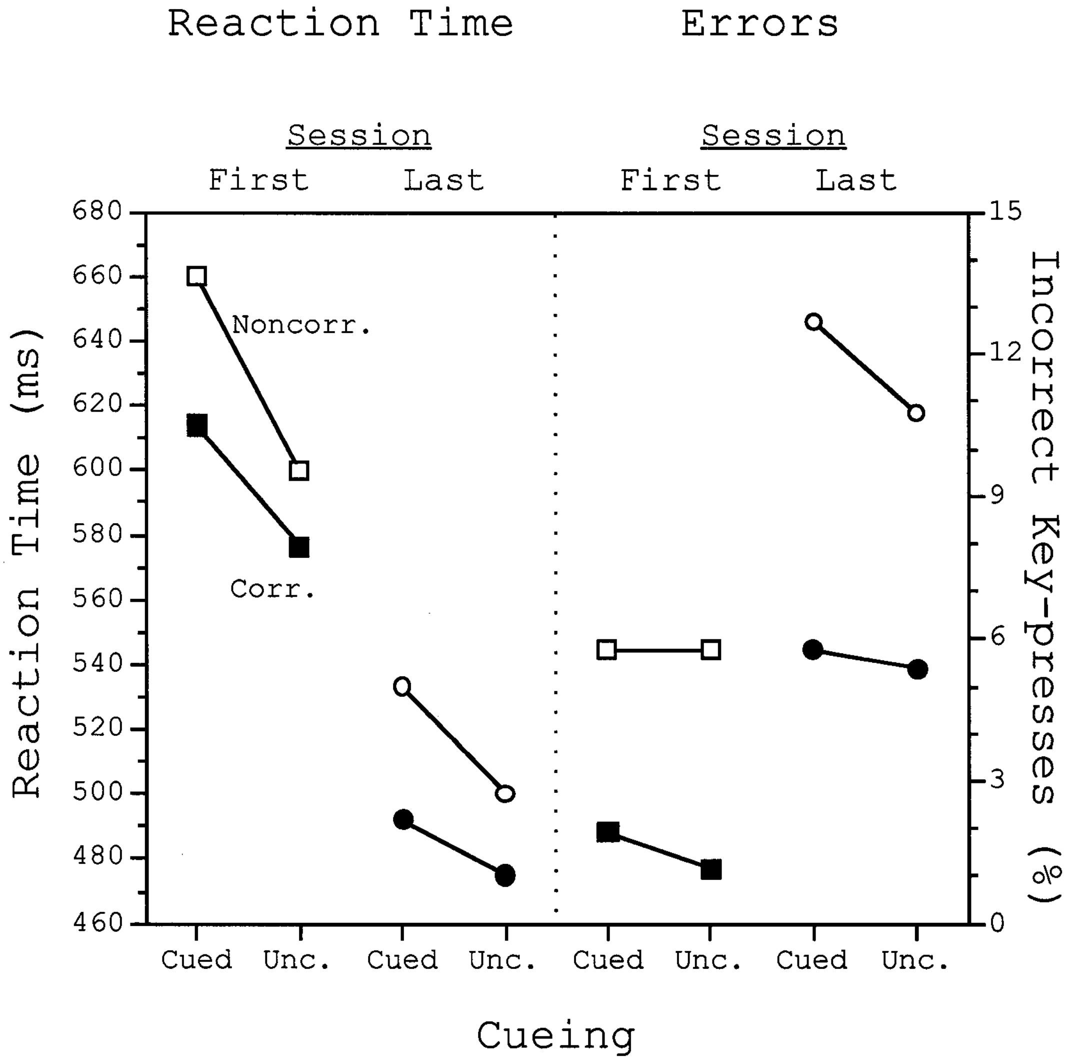

Figure 14. *Mean reaction times (in ms) and incorrect key-presses (%) for the first and last block as a function of cueing and correspondence in Experiment 2. Unc = Uncued.*

Speed-accuracy tradeoff task

The following factors were analyzed using a repeated measures ANOVA for all of the measures except for d': TTOA (120ms, 240ms, 360ms, and 480ms), cueing (cued and uncued), and correspondence (corresponding and noncorresponding). The d' measures were analyzed using a repeated measures ANOVA with TTOA and cueing as factors.

Tone reaction time

The tone-RTs are presented in Figure 15. All three main effects were significant: TTOA [$F(3,36)=14.00$, $p<0.0001$], cueing [$F(1,12)=18.94$, $p<0.001$], and correspondence [$F(1,12)=17.48$, $p<.005$]. The interaction between correspondence and TTOA was also significant [$F(3,36)=11.32$, $p<0.0001$] indicating that the difference between corresponding and noncorresponding (M=18ms) was only significant at the 240ms TTOA [$t(12)=5.06$, $p<0.0005$]. The interaction between TTOA and cueing [$F(3,36)=6.22$, $p<0.005$] was also significant, indicating that tone-RTs to targets at the cued location were significantly slower than RTs to uncued targets at the 120ms TTOA [uncued tone-RT - cued tone-RT = -8ms; $t(12)=-3.81$, $p<0.005$] and at the 240ms TTOA [uncued tone-RT - cued tone-RT= -14ms; $t(12)=-3.81$, $p<0.005$]. The IOR effect was non-significant at the other TTOAs. Finally, the three-way interaction between TTOA, cueing, and correspondence was significant [$F(3,36)=2.89$, $p<0.05$]. This three-way interaction was analyzed by examining the Simon effect (noncorresponding RT - corresponding RT) at each level of TTOA and cueing because previous work (Ivanoff et al., 2002) has shown that the Simon effect is greater on cued trials than on uncued trials. For targets at the uncued location, the Simon effect was only significant at the 240ms TTOA [M=17ms; $t(12)=4.48$, $p<0.001$]. For targets appearing at the cued location, remarkably there was a significant *reverse* Simon effect (i.e., slower responses to spatially corresponding targets than to noncorresponding targets) at the 120ms TTOA [$M=-11$; $t(12)=2.70$, $p<0.05$] and a normal Simon effect at the 240ms TTOA [$M=19$ms; $t(12)=3.83$, $p<0.005$]. The Simon effect was not significant at the other TTOAs.

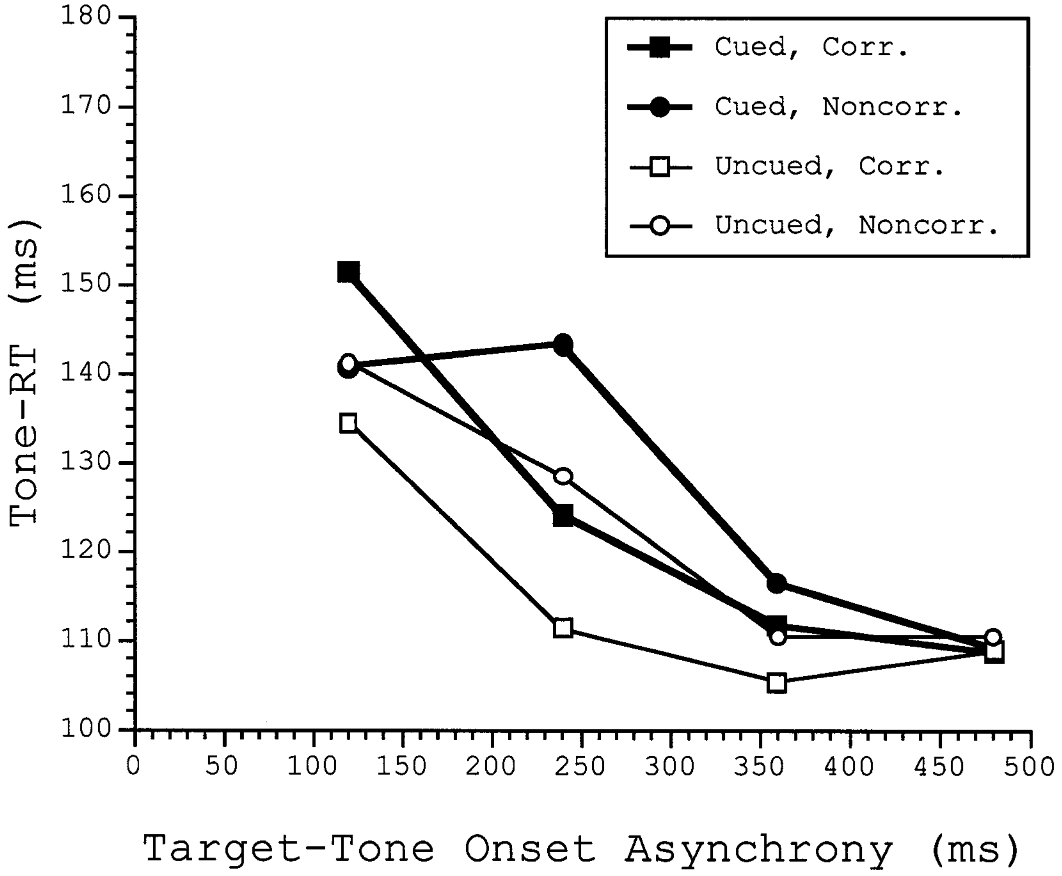

Figure 15. *Tone reaction time (RT; in ms) versus target-tone onset asynchrony as a function of cueing (cued and uncued targets) and correspondence (corresponding and noncorresponding) in Experiment 2. Corr. = corresponding, Noncorr. = Noncorresponding.*

Percent correct

The percentage of correct responses are shown in Figure 16 versus TTOA. The main effects were significant: TTOA [$F(3,36)=180.51$, $p<0.0001$], cueing [$F(1,12)=5.72$, $p<0.05$], and correspondence [$F(1,12)=28.50$, $p<0.0005$]. The following interactions were also significant: TTOA x cueing [$F(3,36)=5.37$, $p<0.005$], TTOA x correspondence [$F(3,36)=7.79$, $p<0.0005$], and cueing x correspondence [$F(1,12)=12.20$, $p<0.005$]. Although the three-way interaction was not significant, there was an *a priori* expectation for the Simon effect to vary as a function of TTOA and correspondence (Ivanoff et al., 2002).

To maximize statistical power, the 120ms and 240ms TTOAs, and the 360ms and 480ms TTOAs, were combined and will be called the "early" and "late" TTOAs, respectively. The error data from early and late TTOAs were entered into separate 2 x 2 ANOVAs with cueing and correspondence as factors. With the late TTOAs, only the main effect of cueing was significant [$F(1,12)=9.34$, $p<0.05$]. There were fewer correct responses for targets at the cued location (M=89.23%) than at the uncued location (M=91.86%). With the early TTOAs, the main effect of correspondence was significant [$F(1,12)=24.22$, $p<0.0005$] as was the interaction between cueing and correspondence [$F(1,12)=9.47$, $p<0.001$]. The Simon effect (noncorresponding percent correct - corresponding percent correct) was larger for targets at the cued location (M=22.05%) than for targets at the uncued location (M=14.91%). Alternatively, for corresponding targets there were 3.71% more correct responses for cued targets than for uncued targets [$t(12)=2.36$, $p<0.05$]. For noncorresponding targets the pattern was reversed: there were 3.43% more correct responses for targets at the uncued location than for targets at the cued location [$t(12)=2.73$, $p<0.05$].

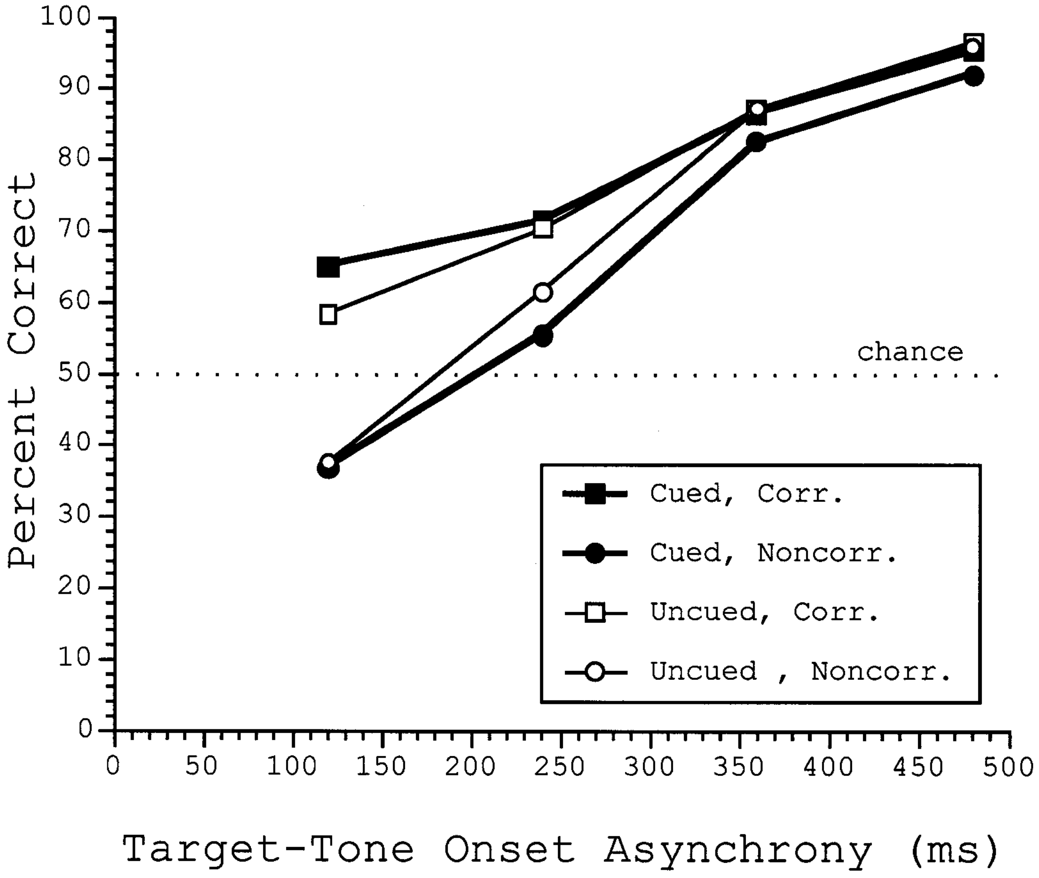

Figure 16. The percentage of correct responses versus target-tone onset asynchrony as a function of cueing (cued and uncued targets) and correspondence (corresponding and noncorresponding) in Experiment 2. 50% is chance performance. Corr. = corresponding, Noncorr. = Noncorresponding.

Anticipations

A correct anticipation is a correct key-press to the target during the TTOA (i.e., before the tone). Incorrect anticipations were infrequent (<2%) and were not considered in the following analysis. The percentage of anticipations are shown in Figure 17 versus TTOA. All of the main effects were significant: TTOA [$F(3,36)=19.48$, $p<0.0001$], cueing [$F(1,12)=8.71$, $p<0.05$], and correspondence [$F(1,12)=12.25$, $p<0.005$]. The TTOA effect was the result of increasing anticipations as TTOA increased (see Figure 17). Furthermore, there were more anticipations for corresponding targets ($M=5.47\%$) than there were for noncorresponding targets ($M=3.99\%$). The main effect of cueing was significantly modified by TTOA [$F(3,36)=5.09$, $p<0.005$]. At the 360ms and the 480ms there were 2.27% [$t(12)=2.39$, $p<0.05$] and 3.00% [$t(12)=3.96$, $p<0.005$] significantly more anticipations for targets at the uncued location than for targets at the cued location, respectively.

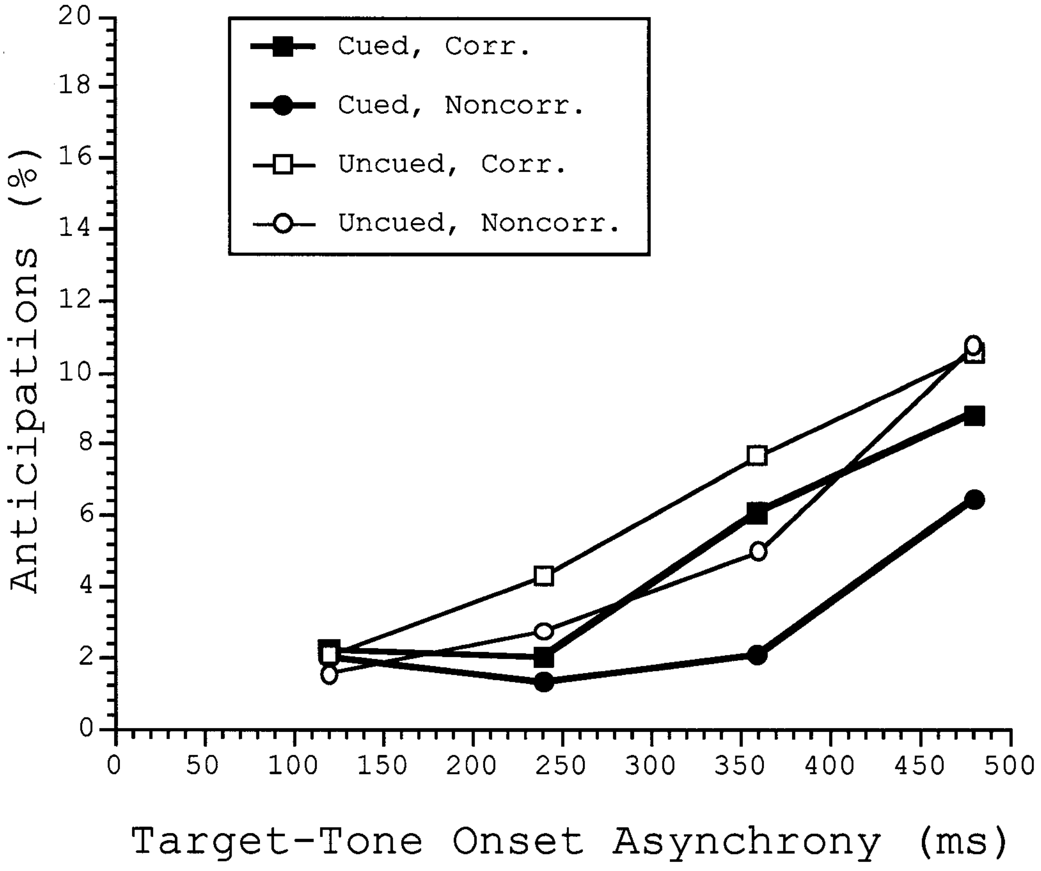

Figure 17. Anticipations (%) versus target-tone onset asynchrony as a function of cueing (cued and uncued targets) and correspondence (corresponding and noncorresponding) in Experiment 2. Corr. = corresponding, Noncorr. = Noncorresponding.

Response Frequency

The response frequency is defined as the percentage of all responses (correct or incorrect) that were made during the response window (i.e., within 210ms of the tone). The response frequency provides an indication of how often participants were able to respond during the response window (irrespective of accuracy). The mean response frequencies are plotted in Figure 18. The main effect of TTOA was significant [$F(3,36)=12.63$, $p<0.0001$] indicating that response frequency increased with TTOA. There was also an interaction between cueing and TTOA [$F(3,36)=6.96$, $p<0.001$]. Only at the 120ms TTOA were there 5.27% significantly [$t(12)=3.53$, $p<0.01$] fewer responses for targets at the cued location than for targets at the uncued location. At the other TTOAs, the cueing effect was non-significant.

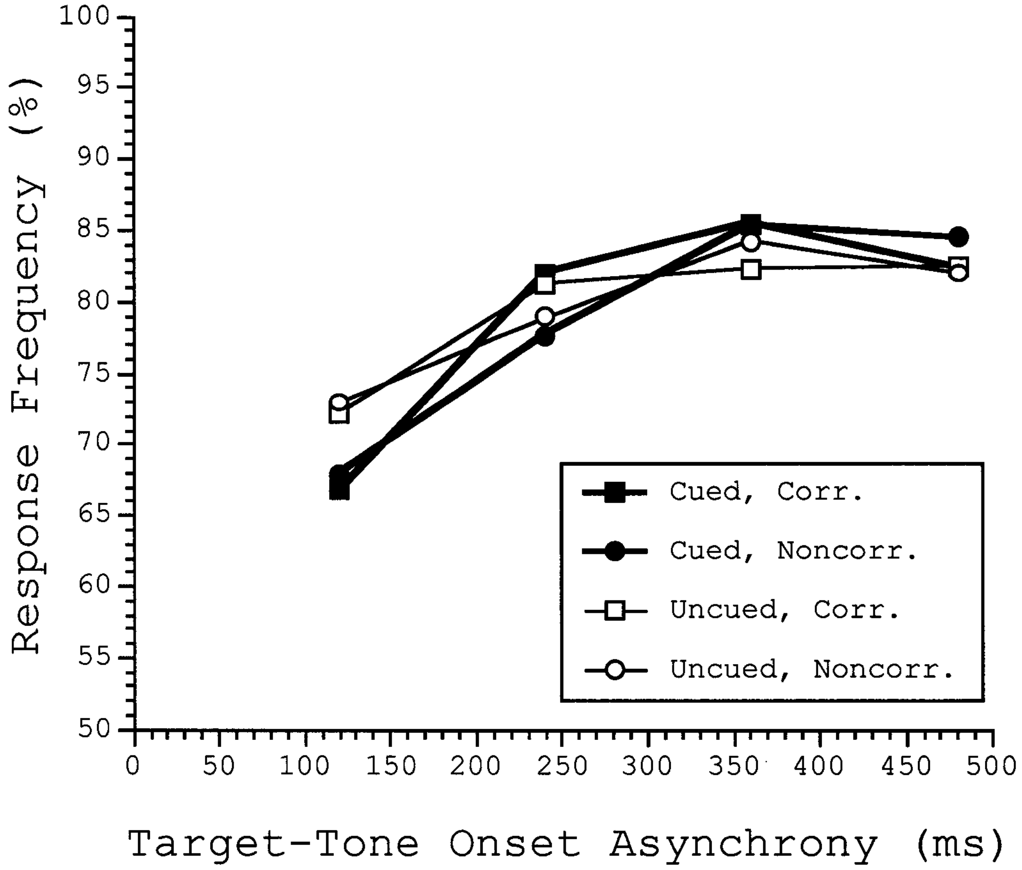

Figure 18. *The response frequency (%) versus target-tone onset asynchrony as a function of cueing (cued and uncued targets) and correspondence (corresponding and noncorresponding) in Experiment 2. Corr. = corresponding, Noncorr. = Noncorresponding.*

Misses

A miss is defined as a response that was not made during the TTOA or 210ms after the TTOA. Misses are plotted versus TTOA in Figure 19. Only the main effects of TTOA [$F(3,36)=22.16$, $p<0.0001$] and cueing [$F(1,12)=16.17$, $p<0.005$] were significant. The percentage of misses decreased as TTOA increased. In addition, targets presented at the cued location (M=15.46%) were missed more often than targets presented at the uncued location (M=12.80%).

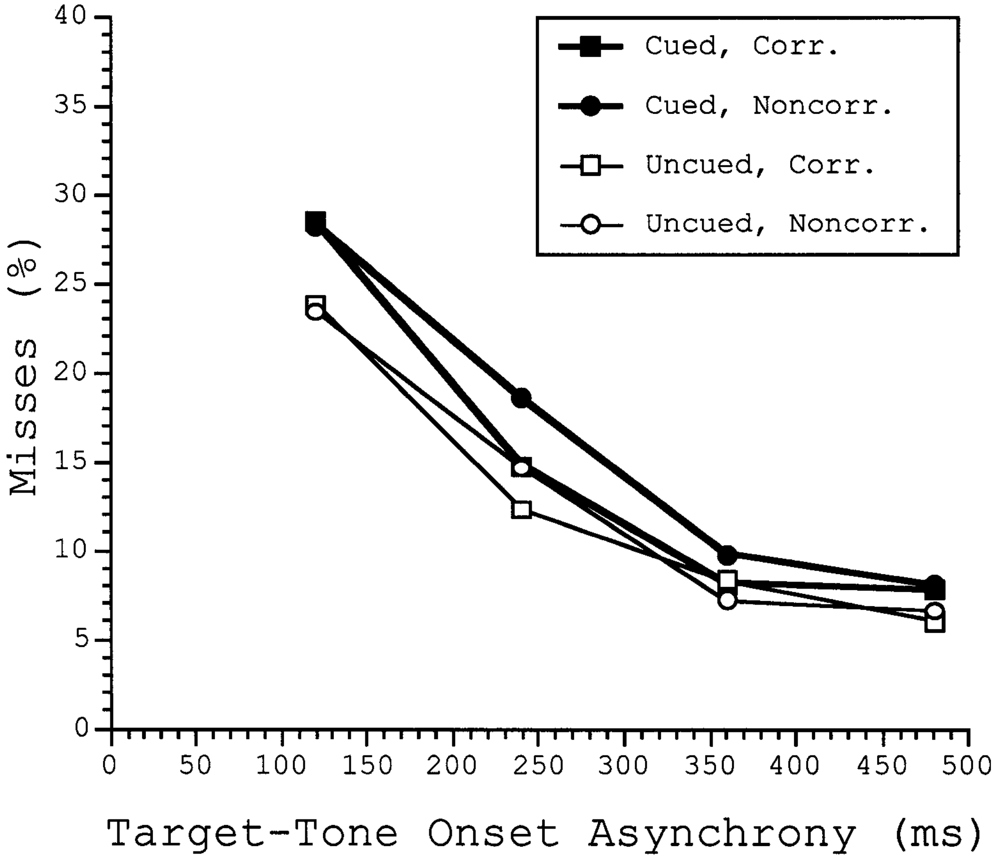

Figure 19. *The percentage of misses versus target-tone onset asynchrony as a function of cueing (cued and uncued targets) and correspondence (corresponding and noncorresponding) in Experiment 2. Corr. = corresponding, Noncorr. = Noncorresponding.*

Sensitivity (d')

Sensitivity was assessed according to responding based on the relevant and irrelevant feature of the target. Sensitivity to the relevant target feature was calculated by arbitrarily assigning right responses to "+" targets as hits and right responses to "X" targets as false alarms. Sensitivity to the irrelevant target was calculated by designating right responses to right targets as hits and right responses to left targets as false alarms[6]. TTOA and cueing were the only factors considered in the analyses. Correspondence was not considered, although it is clearly responsible for the ability to measure sensitivity to the irrelevant (spatial) feature of the target.

Responding based on the task-relevant feature

The mean d' values for responding based on the relevant target feature versus TTOA are shown in Figure 20 as a function of cueing. The mean d' values were entered into a 4 (TTOA) x 2 (cueing) repeated measures ANOVA.

The effects of TTOA [$F(3,36)=162.86$, $p<0.0001$], cueing [$F(1,12)=7.45$, $p<0.05$], and their interaction [$F(1,12)=4.18$, $p<0.05$] were significant. The TTOA effect was due to an increase in d' values as TTOA increases. The interaction between cueing and TTOA was the result of reduced sensitivity on cued trials ($M=3.42$) compared to uncued trials ($M=3.81$) at the 480ms TTOA [$t(12)=3.03$, $p<0.05$]. In addition, there was a marginal [$t(12)=2.08$, $p=0.06$] cueing effect at the 240ms TTOA where d' was 0.16 less on cued trials than on uncued trials. The cueing effects at the other TTOAs were not

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[6] Had the reverse assignments been calculated (e.g., left responses to "X" and left responses to left targets are designated as hits), the same sensitivity scores would have been attained.

significant (*ps*>0.15)[7] .

Responding based on the task-irrelevant feature

The mean d' values for the irrelevant feature are shown in Figure 20 versus TTOA as a function of cueing. The d' values for the irrelevant target dimension were entered into the same analysis performed on the d' values for the relevant feature. The main effect of TTOA [F(3,36)=6.23, p<0.005] and the main effect of cueing [F(1,12)=12.37, p<0.005] were significant, but their interaction was not [F(3,36)<0.2, p>0.9]. d' values decreased with TTOA and they were not significantly different from zero at the 360ms and 480ms TTOAs. In addition, d' values were 0.15 units higher for cued targets than they were for uncued targets.

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[7] If the 120ms TTOA is removed from the ANOVA, and only the remaining three TTOAs (240ms, 360ms, and 480ms) are analysed, the main effect of cueing is significant [F(1,12)=11.52, p<0.01], indicating that sensitivity was lower to cued targets (*M*=2.11) than it was to uncued targets (*M*=2.35). The interaction between cueing and TTOA, however, was not significant [*F*(2,24)=1.58, *p*=0.23].

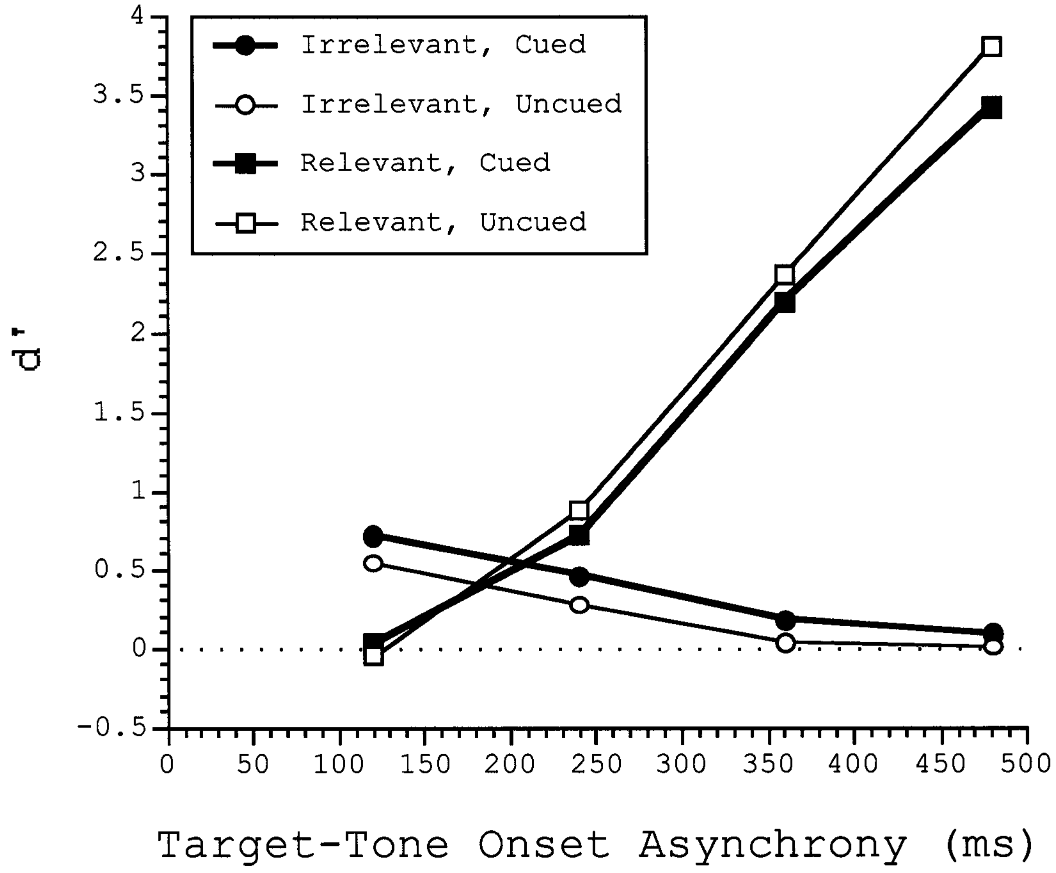

Figure 20. Sensitivity (d') versus target-tone onset asynchrony as a function of cueing (cued and uncued targets) and according to whether sensitivity is based on responding to the task-relevant feature (square symbols) or the spatial, task-irrelevant feature (circle symbols) in Experiment 2.

Discussion

All of the measures were affected by IOR. As in Experiment 1, there were more misses for cued trials than there were for uncued trials. This finding is consistent with all four theories of the IOR effect, and so it is not very informative. However, the proportion of anticipatory responses, the response frequency, and the measures of sensitivity were informative and they will be discussed in turn. That IOR slowed tone-RTs has implications for the interpretation of sensitivity measures (see Table 2).

Anticipations

In Experiment 1, IOR had no effect on the percentage of anticipations. In Experiment 2, it did: there were significantly fewer anticipatory responses for cued targets than for uncued targets. Perhaps the effect appeared in Experiment 2, but not in Experiment 1, because CTOA was fixed in Experiment 2. The implication of this procedure in Experiment 2 (i.e., having a single CTOA) is that it may have encouraged high levels of response preparation by reducing the uncertainty of the target's onset (e.g., Miller, 1998). When the criterion is raised, responses are inhibited, or the S-R link is temporarily disconnected, is it less likely that premature response activation will incidentally trigger an overt response. The importance of finding an effect of IOR on anticipatory responding is that it cannot be readily explained by the inhibited attention account of IOR.

Criterion?

Responses, correct and incorrect, were more frequent for uncued targets than they were for cued targets. That participants were insensitive to the relevant feature of the target, during the time when their responses to cued targets were less frequent than to uncued targets, seems to resemble the effect of IOR on the criterion (c) in Experiment 1. Both c (in a go/no-go task; Experiment 1) and the response frequency (in a choice-RT; Experiment 2) ought to be susceptible to a bias to respond irrespective of the sensitivity to the target. Accordingly, the lowered response frequency on cued trials, compared to uncued trials, is consistent with a bias to respond to targets away from the cue in the absence of sufficient information concerning the target's task-relevant feature. This bias does not seem to be related to spatial responding or else there ought to have been a cueing x correspondence interaction at this early TTOA. If this analysis is correct, this does not support the idea that attention is being inhibited when responding is fast.

Sensitivity (d')

There were three measures of "accuracy" in this experiment that tapped into information extracted from the irrelevant and relevant features of the target. The percentage of correct responses is a direct measure of accuracy, and it was susceptible to both the relevant and irrelevant sources of information. The two sensitivity (d') measures independently tapped into responding that was susceptible to the relevant and irrelevant target features. In many respects, the effects of IOR on percent correct are the same as those on the two d' measures. Therefore, when I discuss the effects of IOR on accuracy I will point out how percent correct and the d' measures were informative.

Before delving into interpretations of the effects of IOR on accuracy, it is important to consider the dynamics of information processing as a function of TTOA. As I outlined in the introduction to Experiment 2, in this choice-RT task there are two potential routes from the stimulus to the response: a task-relevant route that is conditional on the instructions and a task-irrelevant route that presumably arises from a predisposition to respond toward the source of the target. As Figure 20 illustrates, the relevant route has little influence on responding at the short TTOAs, but its influence quickly grows as TTOA increases. On the other hand, the irrelevant route has relatively more influence on responding at the shortest TTOA and its influence gradually declines as TTOA increases. This same pattern is present in Figure 16, but extracting this information is a little more cumbersome. The accumulation of relevant information is reflected in the general increase in percent correct with TTOA. The reduction of irrelevant information with TTOA is related to the decrease in the Simon effect (i.e., percent correct on noncorresponding trials - percent correct on corresponding trials) with increasing TTOA. Generally, what the results suggest is that spatial information, although irrelevant, is predominate at short TTOAs but becomes less influential as information regarding the target's identity (X versus +) accumulated.

Another piece of evidence that must be considered before interpreting the effect of IOR on accuracy is the effect of IOR on tone-RT. Figure 21 is an illustration of the relationship between speed and accuracy for uncued and cued (arrow end) targets. The top row plots tone-RT versus d' for the relevant feature. The bottom row are plots of tone-RT versus d' for the irrelevant feature. Generally, this figure illustrates that IOR *reduced* the sensitivity (d') of responding to the relevant feature of the target and it *enhanced* the sensitivity (d') of responding to the target's irrelevant location. This pattern is clearly illustrated in

Figure 21. (Next page). Summary of the relationship between tone-RT (abscissa) and sensitivity (d'; ordinate) for each target-tone onset asynchrony (TTOA) in Experiment 2. Sensitivity scores (d') for the relevant and irrelevant target feature is along the top and bottom rows of plots, respectively. Each end of the vector is the mean tone-RT and d' values for uncued and cued trials. The vector points toward the values for cued targets. The gray vectors are those belonging to individual participants and the dark black vector is the average.

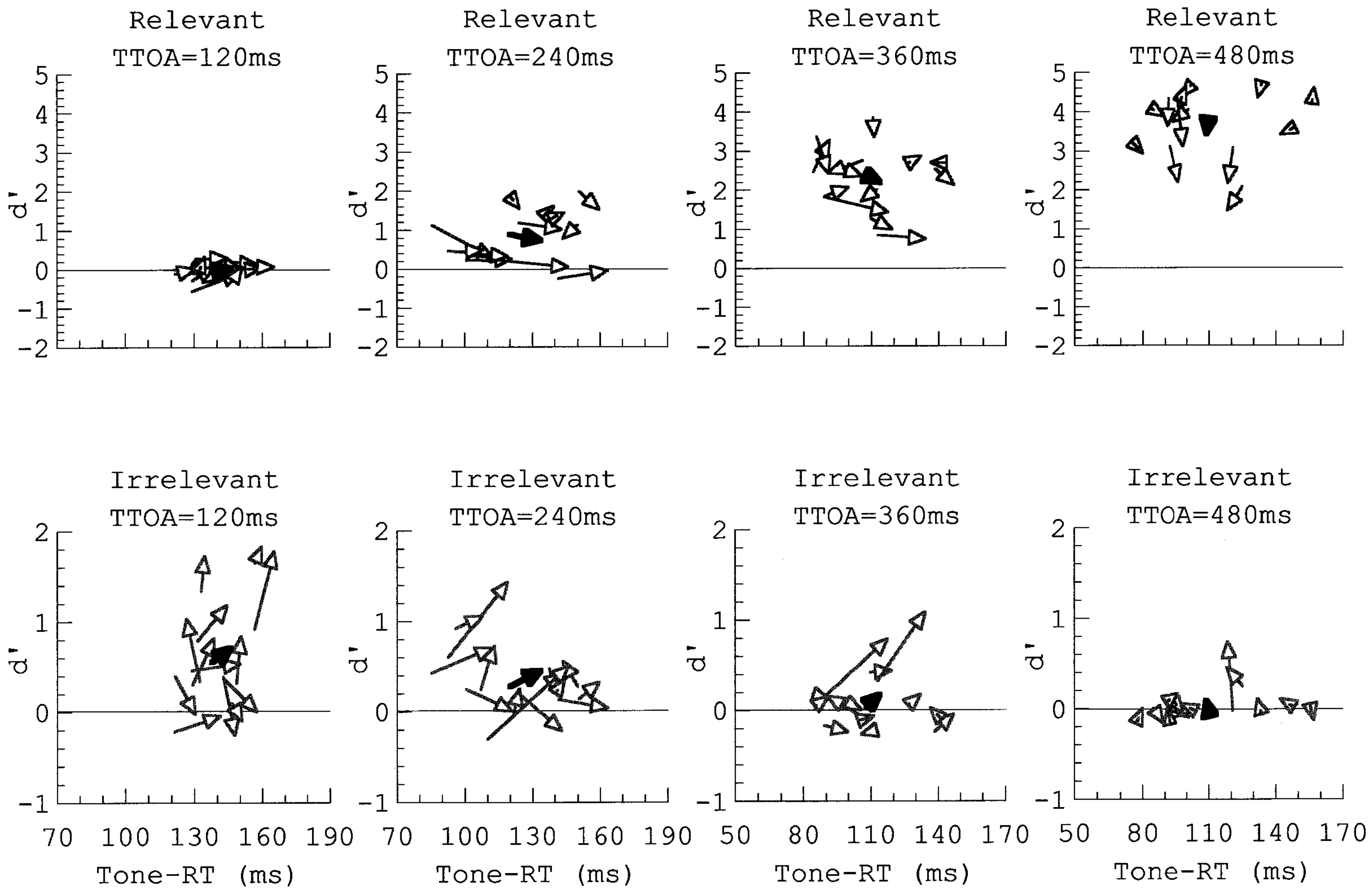
Relevant
TTOA=120ms
Relevant
TTOA=240ms
Relevant
TTOA=360ms
Relevant
TTOA=480ms
d'
5
4
3
2
1
0
-1
-2
Irrelevant
TTOA=120ms
Irrelevant
TTOA=240ms
Irrelevant
TTOA=360ms
Irrelevant
TTOA=480ms
2
1
0
-1
70 100 130 160 190
70 100 130 160 190
50 80 110 140 170
50 80 110 140 170
Tone-RT (ms)

Figure 21.

Figure 20. It was also evident in the analysis of percent correct: IOR had reduced the percentage of correct responses overall for the late TTOAs (360ms and 480ms) and IOR has increased the Simon effect (i.e., the higher accuracy for corresponding trials than for noncorresponding trials) at the earlier TTOAs (120ms and 240ms). This pattern of results poses a conundrum: how is it that IOR increases and decreases sensitivity to different features of the same object?

On the one hand, the apparently contradictory effects of IOR on accuracy may be the result of IOR having at least two effects on information processing. While previous work has argued that IOR acts on attentional and oculomotor processes (e.g., Kingstone & Pratt, 1999; Taylor & Klein, 2000), the results from the current work suggests that IOR operates differently on spatial and non-spatial information. In the introduction, I mentioned that the four theories of the IOR effect are not necessarily mutually exclusive. It is possible that IOR operates differently on different features of the target (e.g., see Tanaka & Shimojo, 1996). Perhaps IOR acts to increase the criterion (or inhibit a response) to respond towards the target's location. Later, as more information accumulates, IOR inhibits a shift of attention to the target's relevant feature (or disconnects the relevant target feature to its appropriate response)[8].

On the other hand, a single account of the IOR effect may be able to account for the opposite effects on sensitivity. This is not to say that one could have predicted that IOR would enhance the sensitivity to

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[8] When the same variable (i.e., cueing) has two opposite effects, there are many interpretations that are plausible. First, there may be one mechanism (IOR) that operates differently on different target features. Second, there may two mechanisms (e.g., IOR and *x*) that operate uniquely and independently on different target features. Lastly, it may be the case that IOR has one effect (e.g., on the target's location feature) and there is a cascade of causal events such that increasing sensitivity to the target's location decreases sensitivity to the non-spatial features of the target.

responding to the target's location and reduce the sensitivity to responding to the target's non-spatial identity according to the current status of the four theories. Rather, a single account of the IOR effect may be able to explain the opposite effects on sensitivity so long as a few additional assumptions are made.

The inhibited attention account

Clearly, the inhibited attention idea can account for the late, detrimental effect of IOR on the sensitivity to the target's relevant feature. How might the inhibited attention theory account for the effect of IOR on the sensitivity to the target's irrelevant (spatial) feature? Previous work suggests that the activation of the irrelevant route is the result of a shift of attention (e.g., see Ivanoff & Peters, 2000, for a full discussion of this proposal). Thus, if the only effect of IOR was to inhibit attention, then the sensitivity to the irrelevant (spatial) target feature ought to be reduced. Given that this was clearly not the case, the inhibited attention theory cannot account for the full range of finding in Experiment 2.

The criterion-shift account

The effect of IOR on the sensitivity to the target's location is consistent with the criterion-shift account, so I will focus on the result that seems to be inconsistent (i.e., the negative effect of IOR on the sensitivity to the target's relevant feature). Perhaps, the reduced sensitivity to the cued target's relevant feature is related to the enhanced sensitivity to the target's relevant feature (see footnote 8). In a Simon task, being particularly sensitive to location will increase accuracy on corresponding trials, but decrease accuracy on noncorresponding trials. Indeed, a post-hoc analysis the percentage of correct responses at the 360ms and 480ms TTOAs combined indicates that the cueing effect (uncued percent correct - cued percent correct) was not significant when the location of the target corresponded with the response location [cueing effect: M=-0.96; $t(12)$=1.13, p>0.25], but there were fewer erroneous responses to uncued targets than to cued targets when the target's location did not correspond with the response's location [cueing effect: M=-4.29%; $t(12)$=2.26, p<0.05]. The problem with this explanation is that one would expect that IOR would improve accuracy on corresponding trials, which it did not. Thus, the results are difficult to reconcile exclusively with a criterion-shift account of the IOR effect.

The inhibited response and S-R disconnection accounts

In the introduction, I had imposed certain processing assumptions onto the inhibited response and disconnection accounts so that I could differentiate between them. Here, I will focus on their common processing assumption: that the activation of the response from a stimulus feature is temporarily interrupted. I will treat the dynamics of information processing as a "free parameter." If the location S-R route is disconnected, without decay, then it would *appear* as though IOR had enhanced the sensitivity to the target's location. It would only appear this way because a delay, without decay, may simply serve to prolong the effect of the target's location on responding. As Ivanoff et al. (2002) pointed out, this cannot be the only effect of IOR on responding as IOR occurs in detection tasks for which spatial target information has virtually no effect (Hommel, 1996; Ivanoff & Klein, 2001; Poffenberger, 1912). Hence, if one assumes that IOR also delays the translation from the relevant feature of the target to the correct response, then we are left with a dilemma. Delaying the stimulus-response translation of both the irrelevant and relevant S-R routes ought to have no net effect on the Simon effect (cf. Ivanoff et al., 2002). Indeed, this account predicts that the Simon and IOR effects ought to be perfectly additive, and clearly they are not. Ivanoff et al. noted that the Simon effect was nearly twice as large for targets at the cued location than for those targets at the uncued location. In Experiment 2 of the present investigation, the Simon effect measured with percent correct was larger for targets at the cued location than it was for uncued targets. Clearly the disconnection and inhibited response accounts cannot explain the opposing effects of IOR on sensitivity.

Summary

The results from Experiment 2 simply cannot be explained exclusively by one of the preexisting theories of the IOR effect. Therefore, IOR seems to have two effects on information accumulation. First, IOR enhances irrelevant spatial target information by increasing the criterion (based on spatial target information) or by inhibiting response preparation (i.e., a spatial response to the target's location). Second, IOR reduces the relevant non-spatial information of the target by disconnecting stimuli from their associated responses or by inhibiting attention.

Perhaps the opposing effects of IOR on sensitivity is due to the nature of the task. When responding is largely controlled by spatial information (120ms TTOA of Experiment 2), or a go/no-go decision is required (Experiment 1), IOR increases the criterion or inhibits responding. Alternatively, if a response must be selected according to the target's non-spatial identity, and there is an alternative response (Experiment 2), then IOR inhibits responding or disconnects stimuli from their associated responses. Before this rendition of the results is accepted, it should be noted that there are more methodological differences between Experiment 1 and Experiment 2 than just the demands of the task. Thus, a further experiment is needed to place the comparison between Experiments 1 and 2 on a common ground.

Experiment 3

While it is tempting to attribute the different patterns of results between Experiment 1 and 2 to the nature of task demands (go/no-go versus choice-RT, respectively), there are obvious visual and temporal methodological differences between these experiments too. The goal of this experiment is to determine whether the different patterns of results in Experiments 1 and 2 were the result of visual and/or temporal methodological differences (e.g., the characteristics of the cue and/or different set of TTOAs) or whether the differences emerged as a result of task demands (go/no-go versus choice-RT). In Experiment 3, the exact same methodology from Experiment 2 will be used except that the target's non-spatial feature ("X" versus "+") was used to signal whether a single response should be withheld (a no-go target: "X") or executed "go" (a go target: "+").

Methods

Participants

Ten students from Dalhousie participated in the study for course credit. None of them had participated in the previous experiments.

Apparatus, stimuli, and procedure

The methods of the current experiment were precisely the same as they were in Experiment 2, but with one important difference. Participants were instructed to respond with the right index finger on the “n” key whenever the "+" target appeared but they were to withhold responding when the "X" target was presented.

Results

First and last blocks

RTs less than 200ms and greater than 750ms were eliminated from the analysis. I lowered the upper response criterion in this experiment to 750ms (from 1000ms in Experiment 2) because responses are generally faster in go/no-go experiments than they are in choice-RT experiments. This criterion eliminated only 5.4% of trials. The mean RTs and false alarm rates are shown in Figure 22. The RTs and false alarms were entered into a 2 (session: first and last) x 2 (cueing: cued and uncued) ANOVA. Only the main effect of session was significant in the analysis of RTs [$F(1,9)=44.41$, $p<0.0001$], indicating that responses were 106ms slower in the first session than they were in the last session. The interaction between session and cueing approached significance, $F(1,9)=4.64$, $p=0.06$. In the first session, responses to cued targets were 23ms slower than responses to uncued targets [$t(9)=2.28$, $p<0.05$]. However, in the second session, responses to cued targets were 3ms faster than responses to uncued targets, but this effect in the last session was not significant. No effects were significant in the analysis of false alarms, but there were 1.5% and 0.5% more false alarms for uncued targets than for cued targets in the first and last session, respectively.

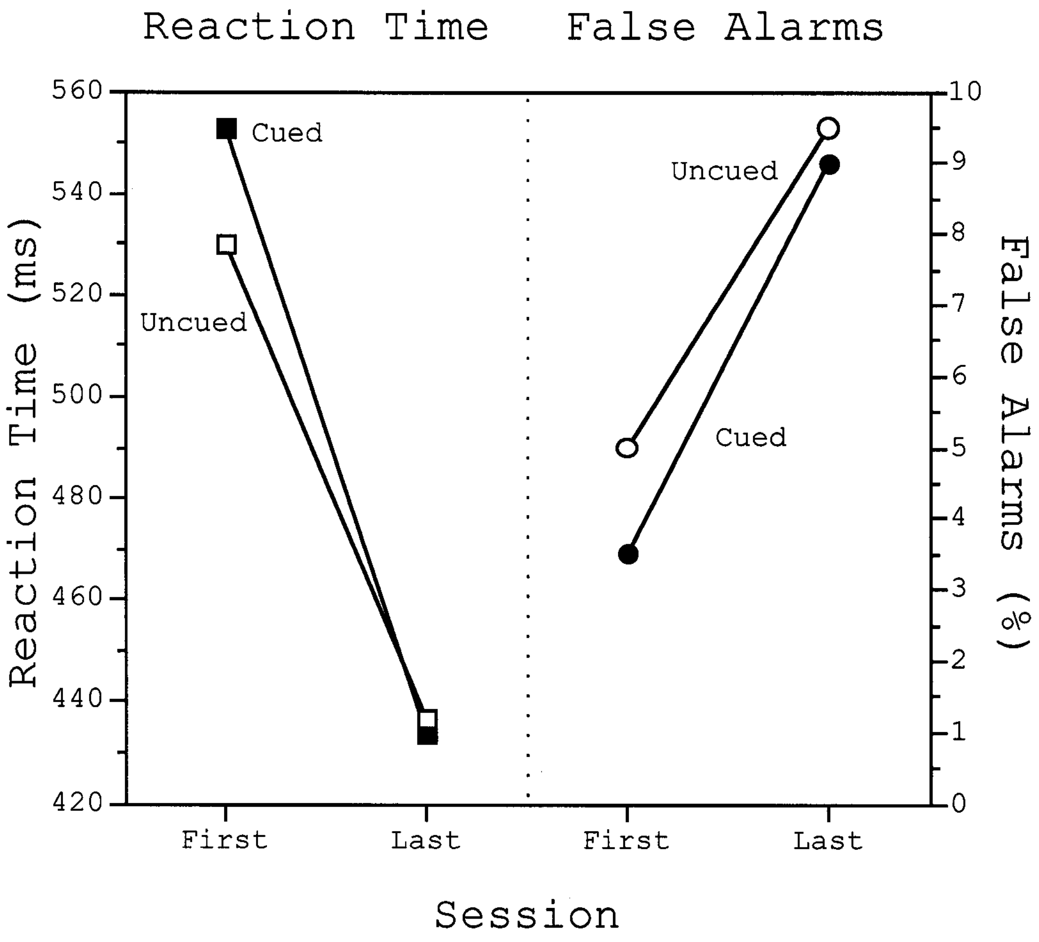

Figure 22. Mean reaction times (ms) and false alarm rates (%) as a function of whether the task was before the SAT session (first) or after the SAT session (last) and cueing in Experiment 3.

Speed-accuracy tradeoff task

Each measure was entered into a 4 (TTOA: 120ms, 240ms, 360ms, and 480ms) x 2 (cueing) repeated measures ANOVA.

Tone response time

The mean tone-RTs versus TTOA as a function of cueing is shown in Figure 23. The main effects of TTOA [$F(3,27)=34.70$, $p<0.0001$] and cueing [$F(1,9)=6.94$, $p<0.05$] were significant. The TTOA main effect indicated that tone-RT decreased from the 120ms TTOA to the 360ms TTOA, with a slight (15ms) upturn from the 360ms to 480ms TTOA. More importantly, there was a small, yet significant, 5ms IOR effect overall.

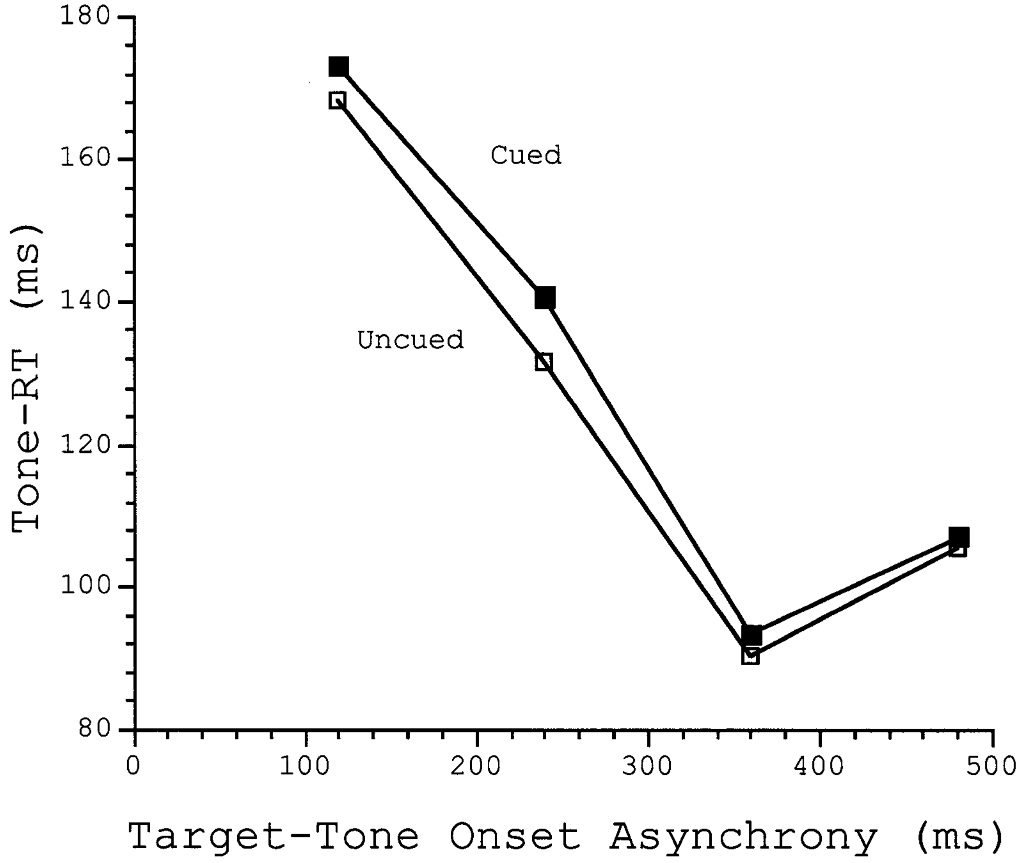

Figure 23. Tone-RT (ms) versus target-tone onset asynchrony as a function of cueing in Experiment 3.

False alarms

The mean false alarm rate versus TTOA, as a function of cueing, is shown in Figure 24. The main effect of TTOA [$F(3,27)=22.31$, $p<0.0001$] and the interaction between TTOA and cueing [$F(3,27)=6.27$, $p<0.005$] were significant. Pairwise comparisons between each level of TTOA indicated that false alarms decreased as TTOA increased and that the only non-significant comparison was between the 120ms and 240ms TTOAs. An examination of the cueing effects at each level of TTOA indicated that there were 6.40% more false alarms to no-go targets at the uncued location than at the cued location for the 120ms TTOA [$t(9)=2.90$, $p<0.05$]. In addition, there were 2.9% more false alarms for no-go targets at the cued location than at the uncued location at the 360ms TTOA [$t(9)=2.80$, $p<0.05$]. The false alarm difference at the other TTOAs were non-significant.

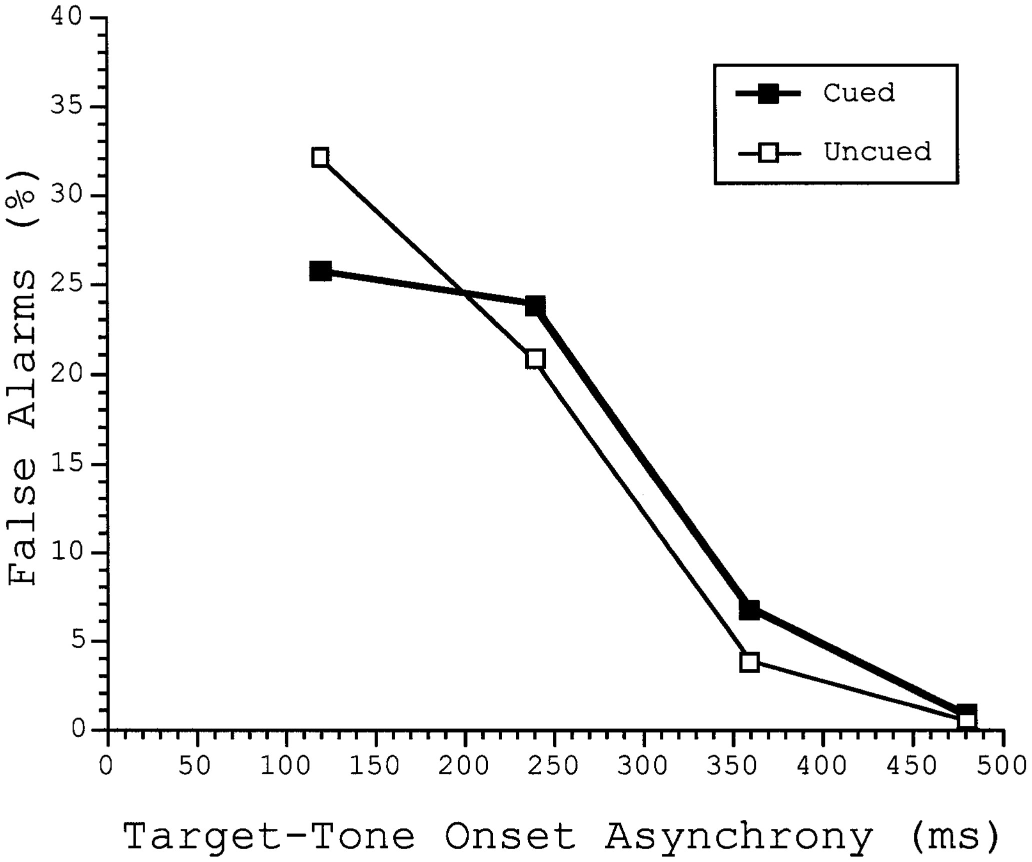

Figure 24. *The percentage of false alarms (i.e., responses to the no-go target within the 210ms response window) versus target-tone onset asynchrony as a function of cueing (cued and uncued) in Experiment 3.*

Anticipations

Figure 25 shows the percentage of anticipations versus TTOA as a function of cueing. The main effects of TTOA [$F(3,27)=29.07$, $p<0.0001$] and cueing [$F(1,9)=6.27$, $p<0.05$] were significant. The percentage of anticipations increased with TTOA. Pairwise comparisons between each level of TTOA indicated that all differences were significant except the difference between the 120ms and 240ms TTOA. There were 2.05% more anticipatory responses on uncued trials than on cued trials (cued targets: $M=6.15\%$).

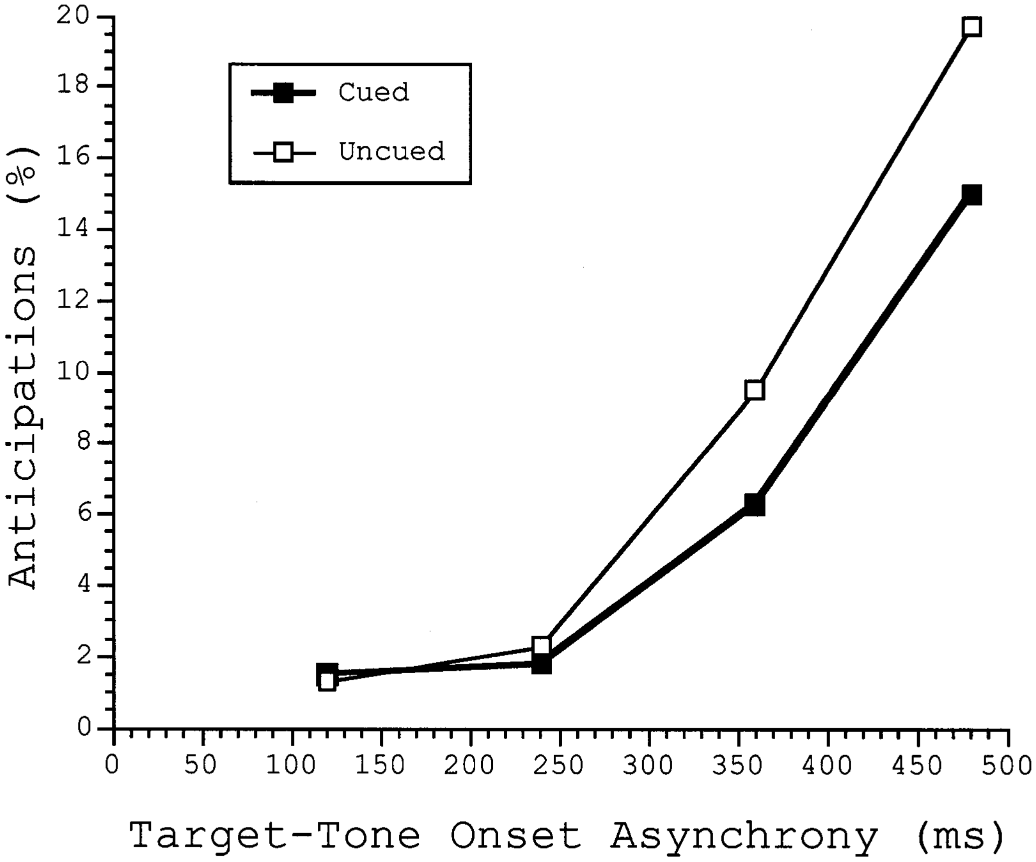

Figure 25. The percentage of anticipatory responses (i.e., responses to the go target before the 210ms response window) versus target-tone onset asynchrony as a function of cueing (cued and uncued) in Experiment 3.

Hits

Figure 26 plots the percentage of hits versus TTOA for cued and uncued targets. The main effect of TTOA was significant, $F(3,27)=49.76$, $p<0.0001$. Generally, the percentage of hits increased as TTOA increased, with the exception that the difference at the 240ms and the 360ms TTOA was non-significant and there was a significant decline in the percentage of hits from the 360ms TTOA to the 480ms TTOA. The interaction between TTOA and cueing was significant, $F(3,27)=8.64$, $p<0.0005$. An analysis of cueing effects at each TTOA showed that there were 9.4% more hits for uncued targets than for cued targets at the 120ms TTOA, $t(9)=4.74$, $p<0.005$. At the 480ms TTOA, however, there were 4.8% more hits at the cued location than at the uncued location, $t(9)=2.43$, $p<0.05$.

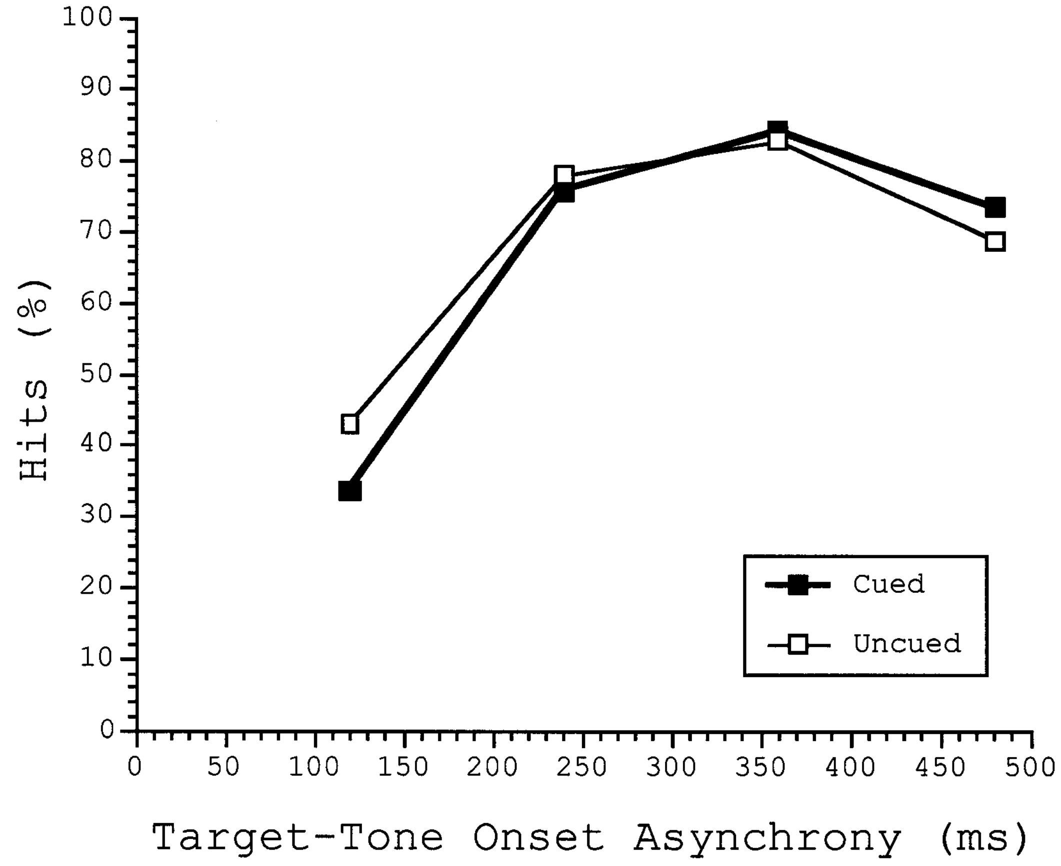

Figure 26. *The percentage of hits (i.e., responses to the go target within the 210ms response window) versus target-tone onset asynchrony as a function of cueing (cued and uncued) in Experiment 3.*

Misses

Figure 27 depicts the percentage of misses versus TTOA. The effects of TTOA [$F(3,27)=75.40$, $p<0.0001$], cueing [$F(1,9)=11.59$, $p<0.01$], and their interaction [$F(3,27)=6.33$, $p<0.005$] were significant. The percentage of misses decreased as TTOA increased, but the difference between the 360ms TTOA and the 480ms TTOA was not significant. The analysis of cueing effects at each TTOA indicated that there were 9.2% more misses for cued targets than uncued targets at the 120ms TTOA [$t(9)=4.53$, $p<0.005$]. The cueing effects were not significant at the other TTOAs.

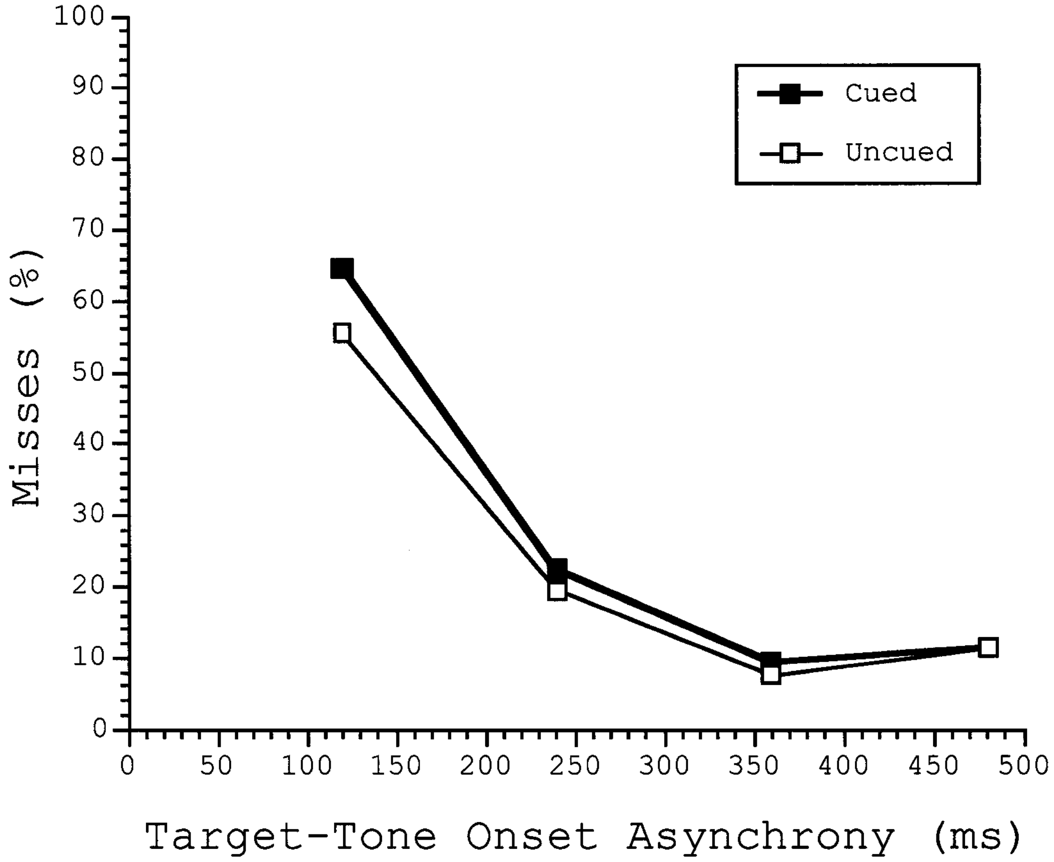

Figure 27. The percentage of misses (i.e., absent responding to the go target within or before the 210ms response window) versus target-tone onset asynchrony as a function of cueing (cued and uncued) in Experiment 3.

Criterion (c)

Figure 28 illustrates the magnitude of c versus TTOA as a function of cueing. The main effect of TTOA [$F(3,27)=22.21$, $p<0.0001$] and the interaction between TTOA and cueing [$F(3,27)=9.34$, $p<0.0005$] were significant. As shown in Figure 30, there is a drop in c from the 120ms TTOA to the 240ms TTOA, but from the 240ms TTOA to the 480ms TTOA, c increased as TTOA increased. To break down the interaction, cueing effects at each TTOA were examined. At the 120ms TTOA c was greater for targets at the cued location ($M=0.59$) than it was for targets at the uncued location ($M=0.34$) [$t(9)=3.32$, $p<0.01$], indicating that responding was indeed more conservative for cued targets than it was for uncued targets. In contrast, at the 360ms and 480ms TTOA, the opposite pattern was observed. Responding to uncued targets was significantly [$t(9)=4.57$, $p<0.005$] more conservative for uncued targets ($M=0.68$) than for cued targets ($M=0.54$). No other cueing differences at the other TTOAs were significant.

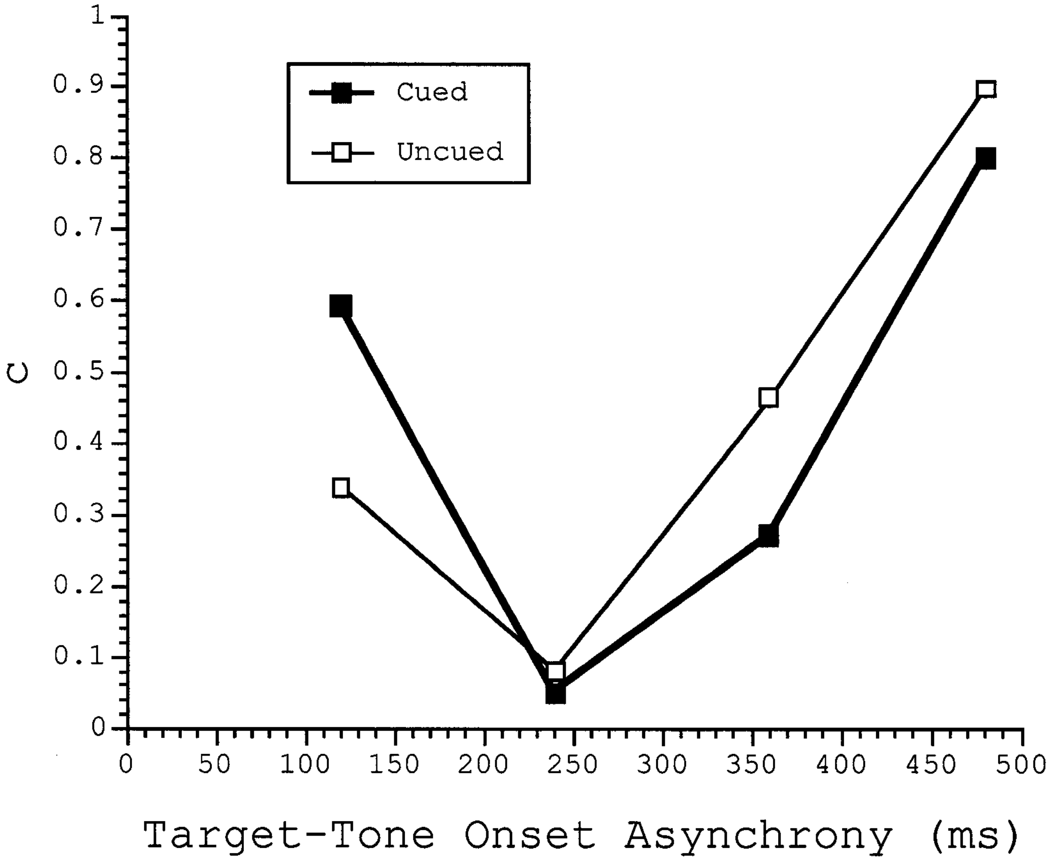

Figure 28. *Criterion (c) versus target-tone onset asynchrony as a function of cueing (cued and uncued) in Experiment 3. Larger criterion values indicate conservative responding while smaller values indicate less conservative responding.*

Sensitivity (d')

Figure 29 shows d' versus TTOA as a function of cueing. Only the main effect of TTOA was significant [$F(3,27)=85.19$, $p<0.0001$] indicating that d' values increased as TTOA increased. Cueing was not significant as a main effect ($p>0.20$) or at any level of TTOA ($ps>0.10$)[9].

---

[9] It appears as though the non-significant cueing effect was the result of one participant. This one participant generally responded 3ms faster to cued targets than to uncued targets. Moreover, this participant had sensitivity scores that were higher for cued trials than for uncued trials (i.e., d' was 0.43 higher for cued targets than for uncued targets). When this one participant was removed from the analysis, d' was significantly reduced on cued trials ($M=1.75$) compared to uncued trials ($M=1.91$) for the remaining nine participants, $F(1,8)=10.80$, $p<0.05$. Moreover, the interaction between TTOA and cueing was significant, $F(1,8)=4.64$, $p<0.05$. The reduction of d' on cued trials was only significant for the 240ms [uncued d' - cued d' = 0.31; $t(8)=2.44$, $p<0.05$] and 360ms [uncued d' - cued d' = 0.34; $t(8)=3.45$, $p<0.01$] TTOAs. Thus, the results seem to suggest that IOR reduced the sensitivity to cued targets.

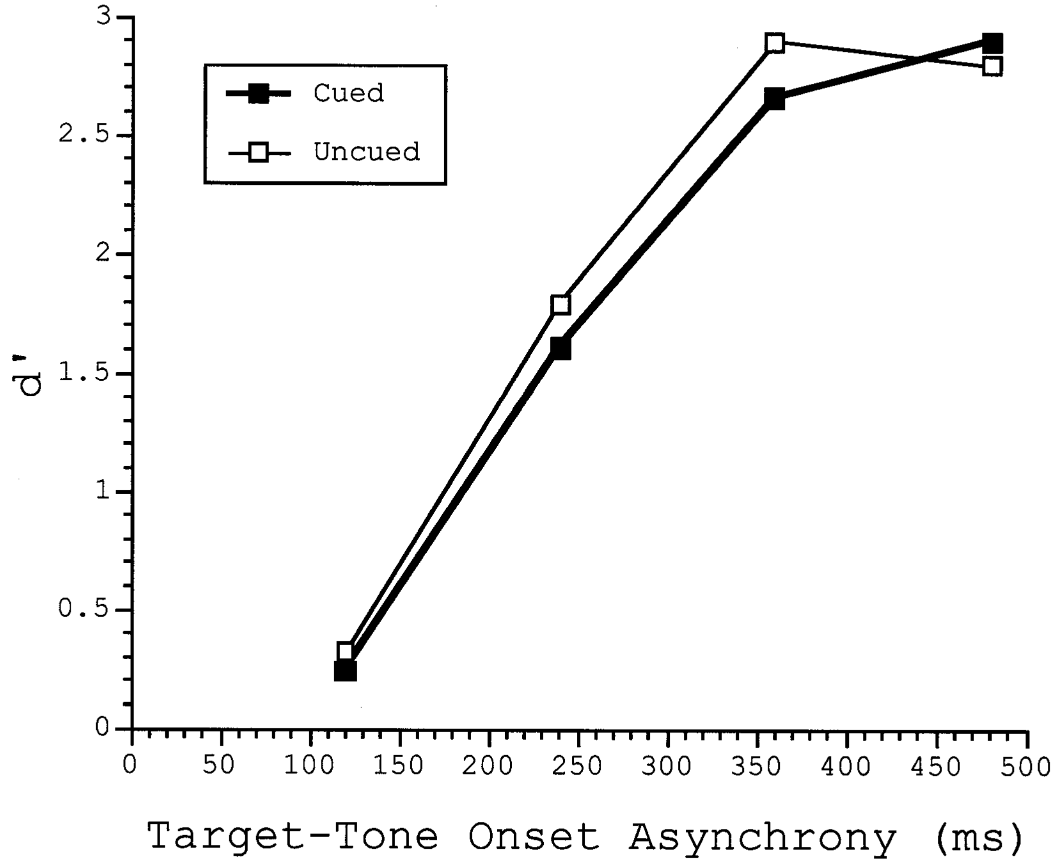

Figure 29. *Sensitivity (d') versus target-tone onset asynchrony as a function of cueing (cued and uncued) in Experiment 3.*

Discussion

Unlike the previous experiments (i.e., Experiments 1 and 2), IOR had very little (-5ms) effect on tone-RTs. The magnitude of the IOR effect measured with the tone-RTs (i.e., uncued tone-RT - cued tone-RT) for the comparable CTOA (1050ms) and TTOAs (120ms, 240ms, and 480ms), in this experiment (M=-5ms) was marginally smaller than in Experiment 1 (M=-12ms; [$t(21)=1.89$, $p=0.07$]). The overall IOR effects in Experiments 2 (*M*=-7) and 3 (*M*=-5ms) were not significantly different at any TTOA (*p*s>0.25).

Figure 30 illustrates the performance vectors (i.e., performance on uncued trials "point" to the performance on cued trials) for each TTOA. These figures illustrate that generally responding was slower, and sensitivity was lower, for cued than for uncued targets. This finding is consistent with the late effects of IOR on the sensitivity to the target's relevant feature observed in Experiment 2, and therefore provides support for the disconnection and inhibited attention hypotheses.

Like Experiment 1, there was an effect of IOR on the criterion at the early TTOA: responding was more conservative for targets at the cued location than for targets at the uncued location. This may have been similarly evident in Experiment 2 as the total proportion of responses within the window were more frequent for uncued trials than for cued trials. The heightened criterion on cued trials does not provide support for the inhibited attention hypothesis.

Remarkably, the effect of IOR on false alarms, and the effect of IOR on the criterion, were "reversed" at the 360ms and 480ms TTOAs. In other words, there were more false alarms for cued targets than for uncued targets and the criterion was more conservative for uncued targets than for

Figure 30. (Next page). Summary of the relationship between tone-RT (abscissa) and sensitivity (d'; ordinate) for each target-tone onset asynchrony (TTOA) in Experiment 3. Each end of the vector is the mean tone-RT and d' values for uncued and cued trials. The vector points toward the values for cued targets. The gray vectors are those belonging to individual participants and the dark black vector is the average.

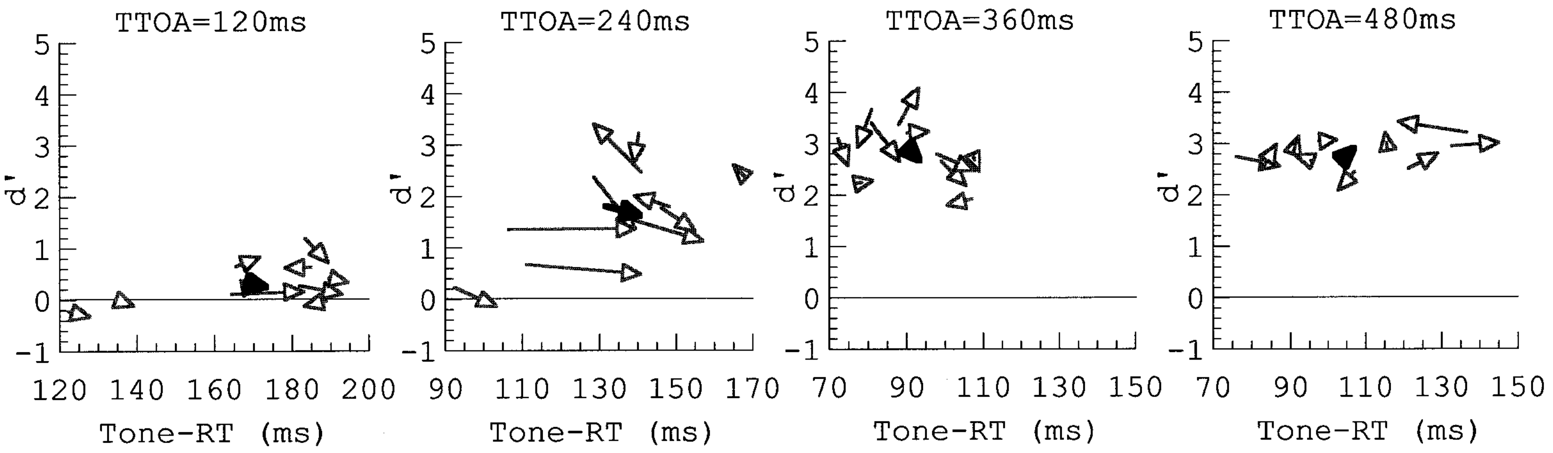
TTOA=120ms
TTOA=240ms
TTOA=360ms
TTOA=480ms
d'
5
4
3
2
1
0
-1
120 140 160 180 200
90 110 130 150 170
70 90 110 130 150
Tone-RT (ms)

Figure 30.

cued targets. These effects cannot be interpreted as reduced perception for cued targets, because there was no evidence that IOR affected sensitivity (nor was there evidence that IOR did not affect sensitivity). It seems that as more information regarding the target's relevant feature accumulates, the criterion reverses such that responding becomes more conservative for targets at the uncued location. Not one of the four theories of IOR would have predicted this unusual finding.

Chapter summary

In three experiments, the effects of IOR on performance was examined using SAT methodology. The goal of this work was to assess IOR's effects on accuracy so as to assess IOR's effect on information processing. In Figure 1, four prominent theories of the IOR effect were depicted. The four theories were split in their predictions concerning the effect of IOR on accuracy. The predictions are listed in Table 2. Importantly, the predictions depended on whether the IOR effect was manifested in tone-RTs. In Experiments 1, 2, and 3, IOR generally slowed tone-RTs and so the predictions listed in the far right column of Table 2 were in effect. Before reviewing the complex pattern of results from the sensitivity measures, I will review the pattern of results concerning the effect of IOR on response bias that was generally consistent across Experiments 1 to 3.

Criterion

In Experiments 1 and 3, there were direct measures of the criterion (c). In Experiment 2, I argued that the response frequency was comparable to the criterion. The criterion (c) is related to the total number of responses that fall within the response window. As more responses - hits and false alarms - fall within the window, the lower c becomes. A high response frequency rate, like a negative value of c, therefore indicates a bias toward responding. To directly compare the response bias across all experiments, I have calculated the frequency of responding within the response window for Experiments 1 and 3. In Experiments 1 and 3, this measure is the total proportion of hits plus false alarms. In Experiment 2, it is response frequency. For the purpose of comparison, I have ignored correspondence in Experiment 2 by collapsing across corresponding and noncorresponding trials. I have also excluded the 465ms CTOA from Experiment 1. The response frequency versus TTOA plots for Experiments 1 to 3 are presented in Figure 31. What should be clear in Figure 31 is that at the early TTOAs, there are generally fewer responses that fell within the response window on cued trials. This finding is consistent with a bias to respond to the uncued location, in the absence of sufficient information concerning the target's relevant identity (Experiment 1: black or checkerboard square; Experiments 2 and 3: X or +). Certainly, this finding is consistent with the theories of the IOR effect except the inhibited attention account.

There was one finding in Experiment 3 that is difficult to reconcile with any of the four theories of the IOR effect. Specifically, the criterion for uncued targets was higher than the criterion for cued targets at the late TTOAs. In Experiment 2, an analysis of the response frequencies for cued and uncued trials at the 360ms and 480ms TTOAs combined indicated that responses were potentially *more* frequent for cued trials than for uncued trials [cued hits - uncued hits = 1.65%; $t(12)=2.09$, two-tailed test, $p=0.058$, one-tailed test,

Figure 31. (Next page). The frequency of responding (Experiments 1 and 3: hits + false alarms; Experiment 2: correct + incorrect responses) in Experiments 1, 2, and 3 versus target-tone onset asynchrony as a function of cueing (cued and uncued targets). The cue-target onset asynchrony (CTOA) in all plots is 1050ms. In Experiment 2, corresponding and noncorresponding trials have been combined. The horizontal dotted line reflects the hypothetical performance of an observer sensitive to the frequency of trials calling for a response.

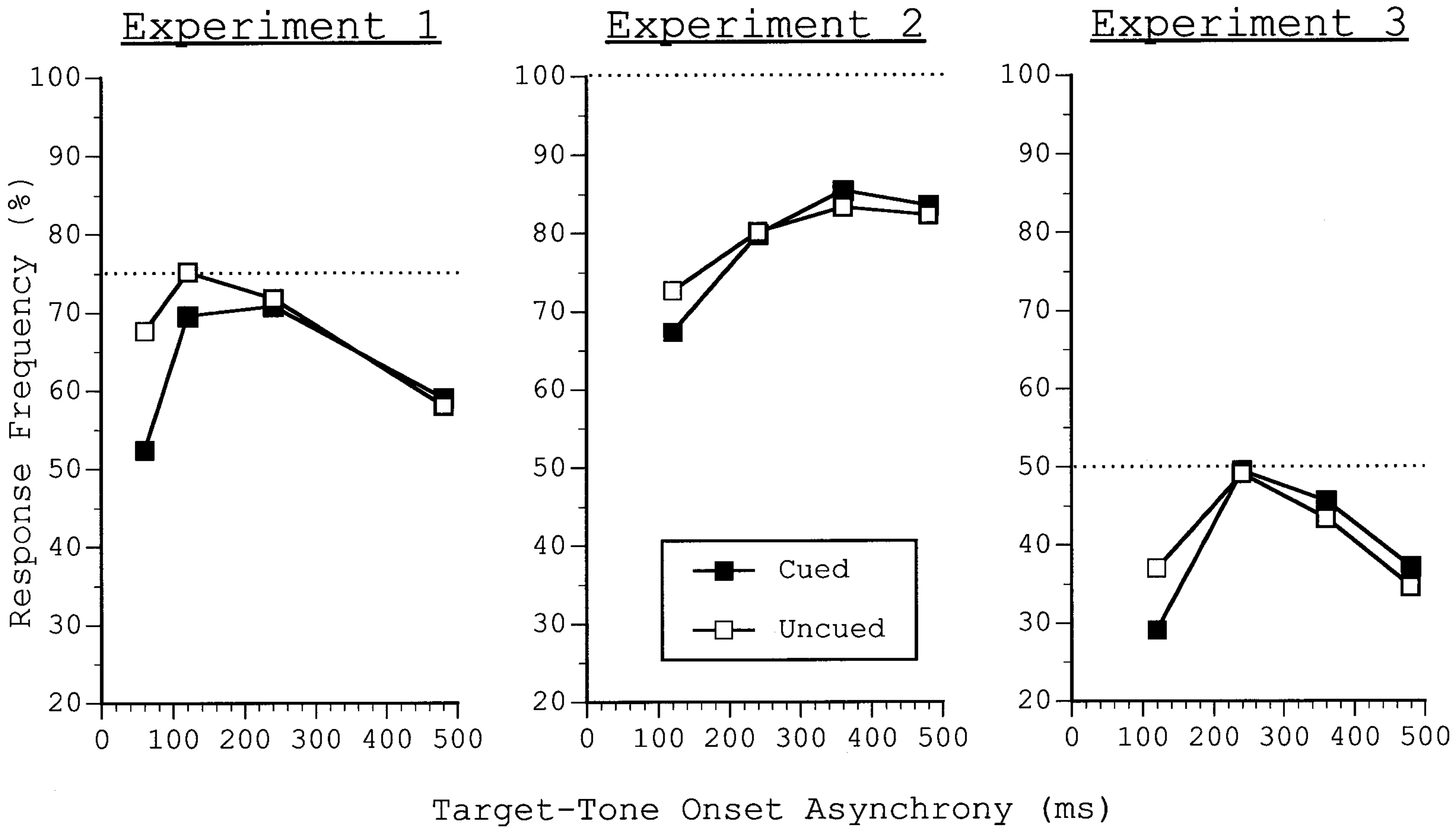
Experiment 1
Experiment 2
Experiment 3
Response Frequency (%)
100
90
80
70
60
50
40
30
20
0
100
200
300
400
500
Cued
Uncued
Target-Tone Onset Asynchrony (ms)

Figure 31.

$p<0.05$]. There was no evidence to support this effect in Experiment 1. Not one of the four theories of the IOR effect would have predicted this finding. Indeed, it is something of a paradox: why would the criterion reverse with long TTOAs? Why would it occur at the time when sensitivity was greater for uncued targets than for cued targets? Why was this effect not observed in Experiment 1? At this time, it is best to cast this finding aside until Chapter 4 (General Discussion). But, this finding does not refute the possibility that IOR creates a reluctance to respond to cued targets during an early component of target processing.

Sensitivity

The results from Experiment 1 demonstrated that IOR improved accuracy while slowing RTs. In Experiment 2, the sensitivity to responding to the target's location, although irrelevant, was higher for cued targets than it was for uncued targets. As Table 2 shows, these findings are consistent with the predictions of the criterion-shift and the inhibited response proposals. It was also shown, however, that IOR reduced the sensitivity to the target's relevant feature in Experiment 2 and IOR tended to reduce accuracy in Experiment 3.

Clearly, there is not one theory of the IOR effect that can account for this entire pattern of results exclusively. Accordingly, the next step is to demarcate the conditions for which IOR is expressed as a criterion-shift or as an inhibited response and those conditions for which IOR is expressed as inhibited attention or a S-R disconnection. There are at least four possible boundaries for which IOR may be manifested differently. These are discussed below.

(1) *Task*

Perhaps it is the nature of the task that influences whether IOR increases or decreases sensitivity. This proposal may be rejected without further discussion because Experiments 1 and 3 were go/no-go tasks and yet they demonstrated different effects of IOR on sensitivity.

(2) *Processing Time*

Perhaps the temporal processing constraints were responsible for the disparate effects of IOR on sensitivity. When responses were made very quickly, IOR improved accuracy. When responses were slow, IOR reduced accuracy. Unfortunately, this proposal does not mesh with the finding that IOR improved sensitivity to the cued target's location at every TTOA in Experiment 2 (i.e., the interaction between TTOA and cueing was non-significant). It also does not mesh with the finding that the largest effect of IOR on sensitivity occurred at intermediate TTOAs. In Experiment 1, the effect of IOR on increasing sensitivity was numerically greatest at the 240ms TTOA. In Experiment 3, when one participant was removed from the analysis (see FN 7), the effect of IOR on reducing sensitivity was greatest at the 240ms and 360ms TTOAs. Thus, it is unlikely that processing time is responsible for influencing the effect of IOR on sensitivity.

(3) *Perceptual Processing Demands*

The purpose of Experiment 3 was to determine whether the different visual displays used in Experiments 1 and 3 were responsible for the different effects of IOR on sensitivity. The pattern of results from Experiments 2 and 3 were similar in that IOR reduced sensitivity to the relevant feature of the target. However, the results from Experiments 2 and 3 were dissimilar from the results from Experiment 1 for which there was evidence demonstrating higher sensitivity to cued targets than to uncued targets. In Experiment 1, the cue was an X and the targets were black and checkerboard squares. In Experiments 2 and 3, the cue was a gray square, and the target was an X or a +. Unfortunately, it is not known whether the differences in the cue or the target were responsible for the difference. However, Pratt, Hillis, and Gold (2001) demonstrated that the IOR effect, measured with detection RTs, is generally unaffected by the type of cue. Thus, if this is true across a wider range of cues, it suggests that the focus may be put on the target differences. To illustrate how sensitivity changed between Experiments, I have plotted sensitivity versus TTOA for uncued trials (i.e., the "baseline" condition) with the 1050ms CTOA in Figure 32. As illustrated in this figure, information accrues earlier in Experiment 1 than it does in Experiments 2 and 3. Unpaired t-tests between d' values for each experiment for the common TTOAs (120ms, 240ms, and 480ms) revealed that all of the differences between experiments were significant. Thus, at the 120ms and 240ms TTOAs, sensitivity was highest for Experiment 1 and lowest for Experiment 2, with Experiment 3 having d' values in the middle. At the 480ms TTOA, however, sensitivity was highest in Experiment 2 and lowest for Experiment 3, with sensitivity values for Experiment 1 in the middle. What is the cause of this sensitivity difference?

In Experiment 1, the discrimination - between a solid black square and a checkerboard square - may be based solely on the presence of a single feature, "white". If there is white in the target, then a response ought to be withheld; no white, then a response ought to be executed. Alternatively, the discrimination may be based on the degree to which there is "black" in the target. If there is a relatively high

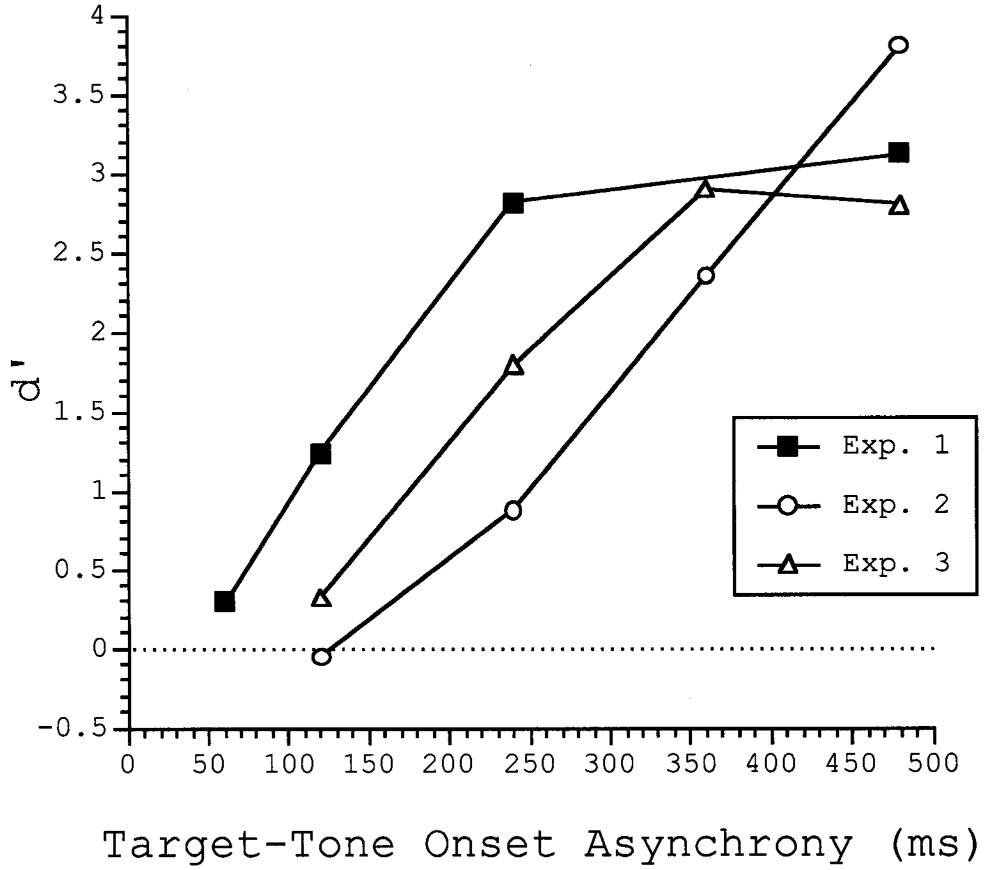

Figure 32. *d' values for the uncued conditions of Experiments (Exp.) 1, 2, and 3. The cue-target onset asynchrony in all of these experiments is 1050ms. In Experiment 2, only sensitivity to the relevant target feature is plotted.*

proportion of black, then the response ought to be executed. If there is relatively less black, then a response ought to be withheld. In Experiments 2 and 3, the discrimination may be little more difficult. The discrimination may be based upon whether there are diagonal or horizontal/vertical lines present or whether there are lines present on a particular portion of the target (e.g., if there is a line on the top part of the target, then it must be a +, if the line is absent, it must be an X). Note that an X/+ discrimination may be an *orientation* discrimination, similar to the *orientation* discrimination tasks used by Cheal et al. (1998) and Handy et al. (1999), two studies in which reduced sensitivity to cued targets was observed. Thus, if there is something inherently more difficult in an X/+ orientation discrimination, it may call upon more attentional resources. If these resources are under the influence of inhibition, then it may be difficult to recruit more attentional resources. A serious difficulty with this account is that sensitivity in Experiments 2 and 3 ought to be virtually identical because the exact same stimuli are used, only the task differs. As shown in Figure 32, the sensitivity to the target's relevant feature at a location unaffected by IOR is different in Experiments 2 and 3. Moreover, there is another (confounding) difference between Experiment 1 and Experiments 2 and 3 other than just the physical characteristics of the targets. The alternative targets were not presented with the same frequency.

(4) *S-R Probability*

The last possible explanation for the disparate effects of IOR on accuracy concerns the relative frequencies of the targets. In Experiment 1, the probability that the go target would be presented on any given trial was .75. In

Experiments 2 and 3, the probability that a particular target (i.e., X or +) would be shown was .50. This is not to say that the *probability of responding* was the critical factor because the probability of responding was highest in Experiment 2 (p=1.0) because a response was always required on every trial. Nonetheless, the probability that a particular stimulus, requiring a particular response, would be presented was .5 in Experiment 2 (and Experiment 3). Thus, Experiments 2 and 3 were alike in that the *S-R probability* was symmetric (.50/.50), but in Experiment 1 the S-R probability was asymmetric (.75/.25). Why would S-R probability matter?

It has been long known that frequent stimuli are responded to faster and more accurately than less frequent stimuli (e.g., Hick, 1952; Hyman, 1953; Laming, 1968). The *S-R probability effect* refers to the performance advantage (i.e., faster and more accurate responding) for responding to stimuli that are likely over stimuli that are less likely. It has been suggested that the S-R probability effect is the result of a lowered criterion toward responding to the likely stimulus (Laming, 1968) and perhaps partially the result of sub-threshold preactivation of the likely response (Miller, 1998).

Regardless of the precise explanation for the S-R Probability effect, a discovery by Klein and Hansen (1990; see also Klein, 1994) is worth mentioning for the purposes of understanding why S-R probability might affect IOR. Klein and Hansen observed that the S-R probability effect interacted with the effect of endogenous attention. Specifically, they observed that the effect of endogenous attention on RTs (i.e., faster responding to cued targets than to uncued targets) was nearly three times as large for a likely target than it was for an unlikely target. In some experiments (Handy, Green, Klein, & Mangun, 2001; Klein, 1994), the effect of endogenous attention for the unlikely target was less than 10ms which is unusually small for an effect of endogenous attention. Quite a different pattern of results emerged from the analysis of errors. There was a modest effect of endogenous attention when the likely stimulus was presented (and the unlikely response was made). Although the effect was small (less than 0.5%), the direction of the effect was consistent with the RT pattern: there were faster responses and fewer errors for likely targets presented at the cued location. However, the effect of endogenous attention *reversed* when the unlikely target was presented (and the likely response was made): there were *more* errors, and slightly faster responding, for cued targets than for uncued targets.

Klein and Hansen's (1990) pattern of results for the unlikely target - faster responding and more errors for the cued targets than for uncued targets - is reminiscent of a criterion-shift. Indeed, Klein and Hansen argued that their findings could not be explained solely in terms of endogenous attention affecting sensitivity to the target. Rather, they argued that the effect of endogenous cueing on the unlikely target was the result of spotlight masking: a late effect of endogenous attention on the response criterion was obscuring the earlier effect of endogenous attention on the sensitivity to the signal. Handy et al. (2001) recorded event-related potentials (ERPs) and provided converging evidence for this proposal.

The reason that Klein and Hansen's results are informative is that, by analogy, they may provide a solution to the problem concerning the boundary conditions for observing enhanced versus reduced sensitivity to cued targets. In Experiment 1, S-R probability was asymmetric in that go targets were more likely than no-go targets. In Experiment 3, S-R probability was symmetric in that go trials occurred with the same frequency as no-go trials. Although the difference was marginally significant, the IOR effect with tone-RTs tended to be larger for a likely go target (Experiment 1: *M*=-12ms) than it was for a less likely go target (Experiment 3: *M*=-5ms). In Experiment 1, with asymmetric S-R probabilities, IOR had a strong effect on false alarms (i.e., there were more likely "go" responses to unlikely "no-go" targets for uncued trials than there were for cued trials) that persisted until the 480ms TTOA. In Experiment 3, with symmetric S-R probabilities, false alarms (equiprobable "go" responses to equiprobable "no-go" targets) were initially higher for uncued targets than for cued targets, but this finding reversed as TTOA increased. Thus, perhaps IOR inhibits attention, or disconnects stimuli from their responses, but this "early" effect of IOR is masked by a criterion-adjustment when target probabilities are asymmetric.

This proposal may account for contrasting results in the preexisting literature. Ivanoff and Klein (2001), using a 2:1 ratio of go to no-go trials, observed increased accuracy (i.e., fewer false alarms) and slower responses for cued targets than for uncued targets. Handy et al. (1999), using a ratio of 1:1, found that responding was slower and sensitivity (d') was reduced for cued targets. Thus, Ivanoff and Klein observed higher false alarms to uncued targets than to cued targets because no-go trials were infrequent.

To assess the idea that responding to likely stimuli may mask the other effects of IOR on information processing, the IOR effect will be directly compared for likely and unlikely targets within the same testing session in Chapter 3. The SAT methodology will not be used in Chapter 3.

Chapter 3: S-R Probability and Inhibition of Return

The purpose of the experiments in this chapter is twofold. First, I will combine the S-R probability and IOR effects orthogonally to discover whether they interact. An interaction would be telling with regard to whether they operate at a common processing stage - adopting the logic of additive factors (Sternberg, 1969, 1998). The S-R probability effect refers to the finding that responding to targets that appear frequently within a series of trials is faster and more accurate than responding to targets that appear less frequently. Essentially, what happens in this kind of task is that there is an *expectancy* for the frequent (or likely) target on any given trial. As I will discuss shortly, generating an expectancy for a likely event may be implemented via a criterion-shift. Thus, if IOR is partially implemented via a criterion-shift, it ought to interact with the S-R probability effect. If IOR *only* operates by inhibiting attention, disconnecting stimuli from their associated responses, or inhibiting responding, all of which are presumed not to directly affect the response preparation stage[1], then we ought to find additivity between the S-R probability and IOR effects.

The second purpose of this chapter, which is related to the first purpose, is to understand why IOR had both increased (Experiment 1) and decreased (Experiment 2 and 3) sensitivity in Chapter 2. Klein and Hansen (1990) proposed that the "attentional" effects of a central, predictive cue may be masked by a "response" effect of these cues on the

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[1] Note that the disconnection and the inhibited response theories do not presuppose that IOR operates *on* the response preparation stage. Rather, these theories contend that IOR delays the onset of the response preparation stage. According to additive factors logic, this would predict addivitity between IOR and the S-R probability effect, given that the S-R probability effect is the result of reducing response preparation by lowering the criterion for likely targets (Laming, 1968).

criterion. If IOR operates in a similar manner to endogenous attention, in that it affects perceptual (by way of inhibited attention) *and* response (criterion-shift) stages of processing, then an interaction between IOR and S-R probability effects ought to resemble the interaction between endogenous attention and S-R probability effect. That is to say, the effect of IOR on RTs ought to be larger for the likely target than it is for the unlikely target. Furthermore, there ought to be *more* errors on uncued than on cued trials when the unlikely target is presented, and this effect may disappear (or reverse) when the likely target is presented.

Expectancies and criterion-shifts

How does an expectancy speed and improve responding to likely stimuli? An expectancy for a particular stimulus may be implemented by altering the criterion (e.g., Broadbent, 1967; Laming, 1968; Morton, 1968; Sperling, 1984). To explain how S-R probability effects arise from criterion-shifts I will borrow Broadbent's (1967, 1987) "test tube" analogy. Consider two test tubes of unequal heights. The shorter tube is associated with the frequent (likely) target and the taller tube is associated with the infrequent (unlikely) target. Water (i.e., evidence) is added to the tubes when a stimulus is presented. A particular response is made when the water overflows in a tube. The response is executed for the first tube that overflows. When water is added to one tube, due to the presentation of a signal, some water will also be added to the other tube (i.e., due to internal noise). The rate at which noisy water accumulates in the incorrect tube is assumed to be random, and although on average there will be less "noise" water than there is "signal" water, there will be some trials for which the noise water exceeds the signal water and therefore an error is made.

Broadbent (1967) argued that the word frequency effect in identification tasks was not due to water being poured faster into "frequent" word tubes, but rather that the frequent word tubes required less water to overflow. The primary reason for this proposal came from an examination of errors. When an error was made on a low frequency word trial it was often a high frequency word. The relatively infrequent errors on high frequency word trials were often other high frequency words (i.e., they were rarely low frequency words). If the water was poured faster when a high frequency word was presented, one would expect that the errors would be equally distributed between low and high frequency words. Thus, by analogy, S-R probability effects may not be due to an increase in the rate of water flow into the tubes (i.e., sensitivity), but rather due to the differing heights of likely and unlikely target tubes (criterion level).

How does this analogy explain S-R probability effects? The critical component of this metaphor is that the likely target tube is shorter than the unlikely target tube, and each tube has the same width. Hence, it will take less water to overflow the likely tube than it takes to overflow the unlikely tube (this corresponds to shorter RTs for likely stimuli). Thus, if water flows into the likely and unlikely tubes at a constant rate, water will overflow in the likely tube earlier than it would in the unlikely tube. Accordingly, RTs to likely targets will be faster than RTs to unlikely targets. How does Broadbent's test tube metaphor explain errors? When the likely stimulus is presented, most of the water will flow into the likely tube (signal), but some water will flow into the unlikely tube (noise). Because the likely tube is shorter than the unlikely tube, the likely tube will overflow quickly. Moreover, it would be rather improbable that the unlikely tube will overflow due to noise because a lot of "noisy" water is needed for the unlikely tube to erroneously overflow (due to increased height of the unlikely stimulus tube). In contrast, presenting the unlikely stimulus will trigger water flowing into the unlikely tube and some (noise) into the likely tube. It will take longer for the water to overflow in the unlikely tube because the initial water level is so low. However, there is a good chance that noisy water will cause the likely tube to overflow (in the presence of the unlikely stimulus), thereby causing an erroneous response, because the likely tube is shorter than the unlikely tube. Thus, the expected pattern is that responses will be faster, and errors less frequent, to likely targets than to unlikely targets.

S-R probability and inhibition of return

Broadbent's (1967) test tube analogy can be used to explain why IOR can slow RTs and enhance sensitivity (as in Experiment 1). According to a criterion-shift explanation, the cued tube is taller than the uncued tube. Hence, responding will be slower to cued targets than to uncued targets. Erroneous responding (e.g., false alarms; Ivanoff & Klein, 2001; Experiment 1 of Chapter 2) will occur more frequently for the shorter tube (i.e., uncued target).

If we introduce asymmetric target frequencies (i.e., to generate a S-R probability effect) into an IOR paradigm, how should the two effects combine? First, if IOR is a kind of criterion-shift it must interact with the S-R probability effect. This prediction is rooted within additive factors logic (Sternberg, 1969). Second, previous work (e.g., Klein, 1994; Klein & Hansen, 1990) has shown that the S-R probability effect interacts with the effects of endogenous attention. Recall that a shift of endogenous attention is elicited when a central cue predicts the location of the target. Sperling (1984) has argued that the effects of endogenous cues may be explained by adjustments in the criterion. Posner (1980) argued that endogenous attention serves to increase the rate of gain of information. Klein and Hansen (1990) essentially argued that both suggestions may be correct when alternative targets are presented with an asymmetric frequency, but only a sensitivity change (Posner, 1980) can explain the effect of endogenous attention on responding when targets are presented with a symmetric frequency. If endogenous attention were partially due to a criterion-shift, then one would expect that endogenous attention and S-R probability effects would interact on the basis of additive factors logic. Indeed, that is what Klein and Hansen discovered.

Recall that Klein and Hansen discovered that the effect of endogenous attention on RTs was larger when the target was likely than when it was unlikely. Moreover, the reverse pattern was observed on errors: specifically there were more errors to cued targets than to uncued targets when the target was unlikely (i.e., and the response was likely). Why was this specific interactive pattern obtained? Klein and Hansen suggested that the interaction was due to a combined expectancy for likely targets to appear at the cued (attended) location. The other way to put this, again in terms of Broadbent's (1967) test-tube analogy, is that the spatial and non-spatial expectancies combine such that the height of the likely-cued tube is particularly low. Hence, the location and S-R expectancies interact such that there is an expectancy for the likely target (S-R expectancy) to appear at the likely (cued) location. The implication of this interaction is that responses will be fastest for the likely-cued combination. Moreover, when an unlikely target appears at the cued (attended) location, there will be many errors (i.e., likely responses).

In the ensuing experiments, the conditions that give rise to S-R probability and IOR effects will be combined in an orthogonal manner to assess whether, and more importantly how, they interact. If IOR does indeed raise the criterion to respond towards cued targets, then the IOR effect measured with RTs ought to be greater for likely targets than for unlikely targets. Likewise, there ought to be more errors to uncued targets than to cued targets and this difference ought to be larger for unlikely targets (where a likely response is made) than it is for the likely target (where an unlikely response is made). This interaction is anticipated because likely targets are "expected" to appear at the uncued locations. At the cued location, the raised criterion ought to allow more information to accrue and therefore mediate any potential target misclassifications. Thus, if IOR and S-R probability effects interact, this supports an interpretation of the higher sensitivity to cued targets in Experiment 1 in terms of a criterion-shift (rather than inhibited responding). However, if S-R probability and IOR are perfectly additive, this would support an interpretation of the sensitivity enhancement to the cued target as resulting from inhibited responding.

Experiment 4

In this experiment, a go/no-go task will be used to assess whether the IOR and S-R probability effects interact. Specifically, the methodology will closely resemble that of Experiment 1 without the response signal and the ensuing feedback. In one block of trials, a go target (black square) occurred more frequently (75% of the time) than the no-go target (checkerboard square: 25%). In the other block, the probabilities were reversed (i.e., 75% no-go targets, 25% go targets). Errors are responses to the no-go targets (i.e., false alarms). If the IOR effect is partly the result of a criterion-shift, then it ought to be larger in the block of trials with a 75% go targets than in the block of trials with 25% go targets. Moreover, the increase in false alarms for uncued trials compared to cued trials ought to be greater when no-go targets are unlikely (i.e., the 75% go target block) than when they are likely (i.e., the 25% go target block).

Methods

Participants

Nine undergraduate students from Dalhousie University participated in this experiment for course credit or for pay ($6/hr).

Apparatus, stimuli, and procedure

The same apparatus and stimuli used in Experiment 1 were used in this experiment. The procedure was the same as in Experiment 1 except for the following (see Figure 3). First, there was no response signal (i.e., the tone to signal a response) and no feedback. The participants were asked to respond as quickly as possible when the go target (the black filled square) appeared and not to respond when the checkerboard target appeared. Second, the no-go target was presented for a maximum of 1050ms or until an erroneous response (i.e., a false alarm) was made. Go targets were presented for 750ms. Previous work has shown that this is ample time for responding in a go/no-go task with similar stimuli (Ivanoff & Klein, 2001, 2003). As is indicated in the results section, this time limit was not a severe constraint on responding. Third, there were two blocks of trials with 320 trials each. In one block, the go target appeared 75% of the time (and the no-go appeared 25% of the time). In the other block, the go target appeared only 25% of the time (and the no-go target appeared on the remaining 75% of the trials). Block order (75% versus 25% go targets) was approximately counterbalanced between participants (i.e., 5 participants received the 75% go target block first).

Results

Reaction time

RTs less than 150 and more than 750ms were excluded from further analysis. This criterion eliminated less than 1% of trials. Figure 33 shows the mean RTs and mean false alarm rates for each condition. A repeated measures ANOVA was performed on the RTs with go probability (75% and 25%), cueing (cued and uncued), and CTOA (465ms and 1050ms) as factors. There were three significant main effects: CTOA [$F(1,8)=17.03$, $p<0.005$], go probability [$F(1,8)=10.70$, $p<0.05$], and cueing [$F(1,8)=53.43$, $p<0.0001$]. The interaction between CTOA and cueing was marginally significant [$F(1,8)=5.06$, $p=0.055$]. IOR was smaller at the 1050ms CTOA (uncued RT -cued RT; $M=-24$ms) than it was at the 465ms CTOA ($M=-33$ms). The interaction between go probability and cueing was significant [$F(1,8)=19.49$, $p<0.005$]. The IOR effects when the go probability was 75% [$M=-38$m; $t(8)=7.71$, $p<0.0001$] and 25% [$M=-20$ms; $t(8)=5.12$, $p<0.001$] were both significant. The IOR effect, however, was larger when the go target was likely than when it was unlikely.

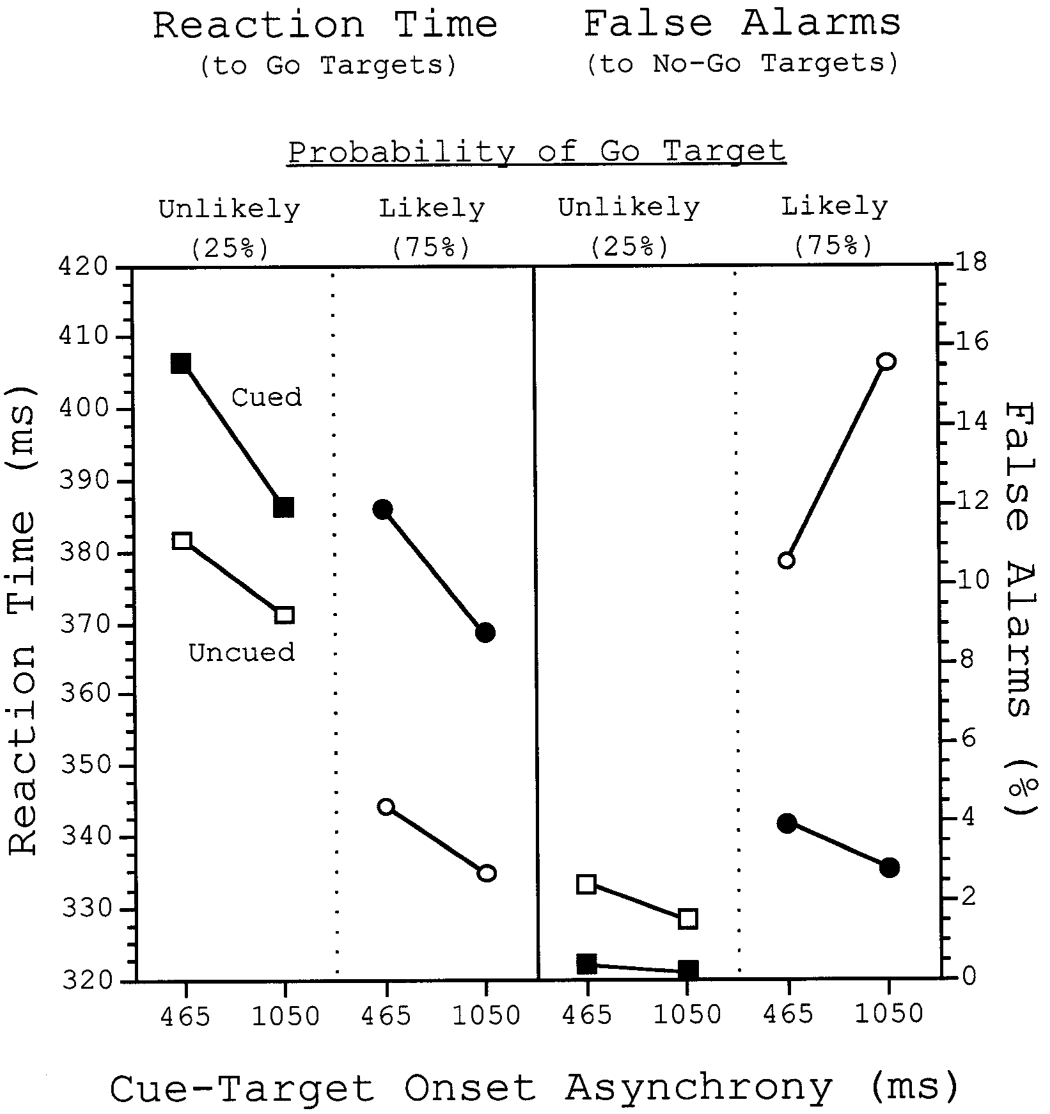

Figure 33. Mean reaction time (RT; ms) and the mean percentage of false alarms in Experiment 4. Symbols with black fill are cued targets and those without fill are uncued trials.

False alarms

The same analysis performed on RTs was performed on false alarms. The main effects of go probability [$F(1,8)=9.81$, $p<0.01$] and cueing [$F(1,8)=9.35$, $p<0.05$] were significant. In addition, the interaction between go probability and cueing [$F(1,8)=8.27$, $p<0.05$] was significant. There were more false alarms to no-go targets when they appeared at the uncued location than when they appeared at the cued location. The effect of cueing on false alarm rate was larger when the probability of the go target was high [uncued false alarm rate - cued false alarm rate; M=9.72%; $t(8)=3.03$, $p<0.05$] than when the probability of the go target was low [M=1.67%; $t(8)=2.27$, $p=0.053$; one-tailed t-test: $p<0.05$]. To put this another way, the effect of cueing on the false alarm rate was larger when the probability of a *no-go* target was low (i.e., 75% go targets) than when the probability of the *no-go* target was high (25% go targets).

Discussion

The results of this experiment agree with the predictions of the criterion-shift account. The IOR effect - measured with RTs and false alarms - nearly doubled when the probability of a go target was 75% than when it was 25%. This finding is reminiscent of Klein and Hansen's (1990) finding that endogenous attention and S-R probability effects combine in an interactive fashion. However, there is one very important difference between the methodology of the current experiment and the methodology used by Klein and Hansen. Namely, they used a choice-RT task and the current experiment used a go/no-go task. In Klein and Hansen's choice-RT task, different responses were made to likely and unlikely stimuli within the same block. In the present experiment, the probability of a signal was manipulated in different blocks of trials. The goal of Experiment 5 is to seek a replication of this interaction using a choice-RT task. Failure to obtain the interaction suggests that the interaction may have been an incidental feature of the go/no-go task. However, a replication will demonstrate that the interaction obtained in Experiment 4 between S-R probability and IOR is robust and akin to the interaction reported by Klein (Klein & Hansen, 1990; Klein, 1994) using endogenous orienting.

Experiment 5

In the present experiment, a choice-RT task was used with a noncompatible (i.e., orthogonal) S-R mapping. Ivanoff et al. (2002; see also Experiment 2 in the present study) observed that the IOR effect is larger when the spatial relationship between the target and response is noncorresponding than when it is corresponding. To avoid any interaction between correspondence and S-R probability effects, the arrangement of the responses will be up-down and the stimulus display will be left-right. This orthogonal arrangement will preclude any Simon effects (Eskes, MacIssac, Ivanoff, & Klein, 2003) because there is no dimensional overlap (Kornblum, Hasbrouq, and Osman, 1990) between the response and stimulus elements.

In the current experiment, the likely target will require one response and the alternative unlikely target will require a separate response. Thus, likely and unlikely targets are presented within the same block of trials and not between blocks (as in Experiment 4). The predictions are the same as before. The IOR effect for RTs ought to be larger for the likely target than for the unlikely target. In addition, the IOR effect for incorrect key-presses ought to be greater for the unlikely target (where a likely response is made) than for the likely target.

Methods

Participants

Nineteen participants from Dalhousie University participated in the experiment as part of a third-year course.

Apparatus, stimuli, and procedure

Unless otherwise noted, the methodology was the same as that in Experiment 4. Participants were tested simultaneously in a psychology lab on separate IMAC computers. The keyboards were placed so that the number pad was aligned with the centre of the monitor. Unlike previous experiments, there was no attempt to control for the distance between the participant's head and the computer monitor, although the participants were instructed to seat themselves approximately 60cm away from the monitor.

The peripheral cue (i.e., the "+" with a circle around it) was presented for 60ms and, 15ms following the removal of the cue, the central fixation point increased (i.e., it became thicker and larger) for 60ms. The target was then presented 15ms, 315ms, or 900ms later for CTOAs of 150ms, 465ms, and 1050ms. The temporal changes to the trial events were altered to incorporate the short (150ms) CTOA. The additional CTOA (150ms) was added in an attempt to measure early facilitation. As will be shown, there was no early attentional facilitation present at the 150ms CTOA, likely due to the removal of attention upon presentation of the second cue at fixation (Posner & Cohen, 1984; McPherson, Klein, & Moore, 2002; Pratt & Fischer, 2002). The likely target was a black filled square and the unlikely target was a checkerboard stimulus. The likelihood of the black square target was 75% and the likelihood of the checkerboard target was 25%. Responses were made with the right and left index fingers, on the "8" and "2" keys of the IMAC's number pad, to the black square and checkerboard targets, respectively. Participants were instructed to respond quickly and accurately to the target. In total, there were 384 trials.

Results

Reaction time

RTs less than 200ms and those greater than 1000ms were removed from the analysis. The RT criteria were raised in this experiment to accommodate slower responding associated with a choice-RT task. This criterion excluded less than 1% of all trials (similar to the number of excluded trials in Experiment 4). The mean RTs and the percentage of incorrect key-presses are shown in Figure 34. The mean RTs were entered into a 3 (CTOA: 150ms, 465ms, and 1050ms) x 2 (target probability: likely and unlikely) x 2 (cueing: cued and uncued). There were main effects of target probability [$F(1,18)=96.29$, $p<0.0001$], CTOA [$F(2,36)=97.21$, $p<0.0001$], and cueing [$F(1,18)=31.19$, $p<0.0001$]. Target probability interacted with CTOA [$F(2,36)=6.10$, $p<0.01$]. Although RTs to the likely target were generally faster than RTs to the unlikely target, the difference was smaller at the 150ms CTOA (unlikely - likely: M=57ms) than it was at the 465ms [unlikely - likely: M=78ms; $t(18)=3.65$, $p<0.005$] and 1050ms CTOA [unlikely - likely: M=74ms; $t(18)=2.66$, $p<0.05$]. More importantly for the purposes of this experiment, target probability interacted with cueing [$F(1,18)=8.83$, $p<0.01$].

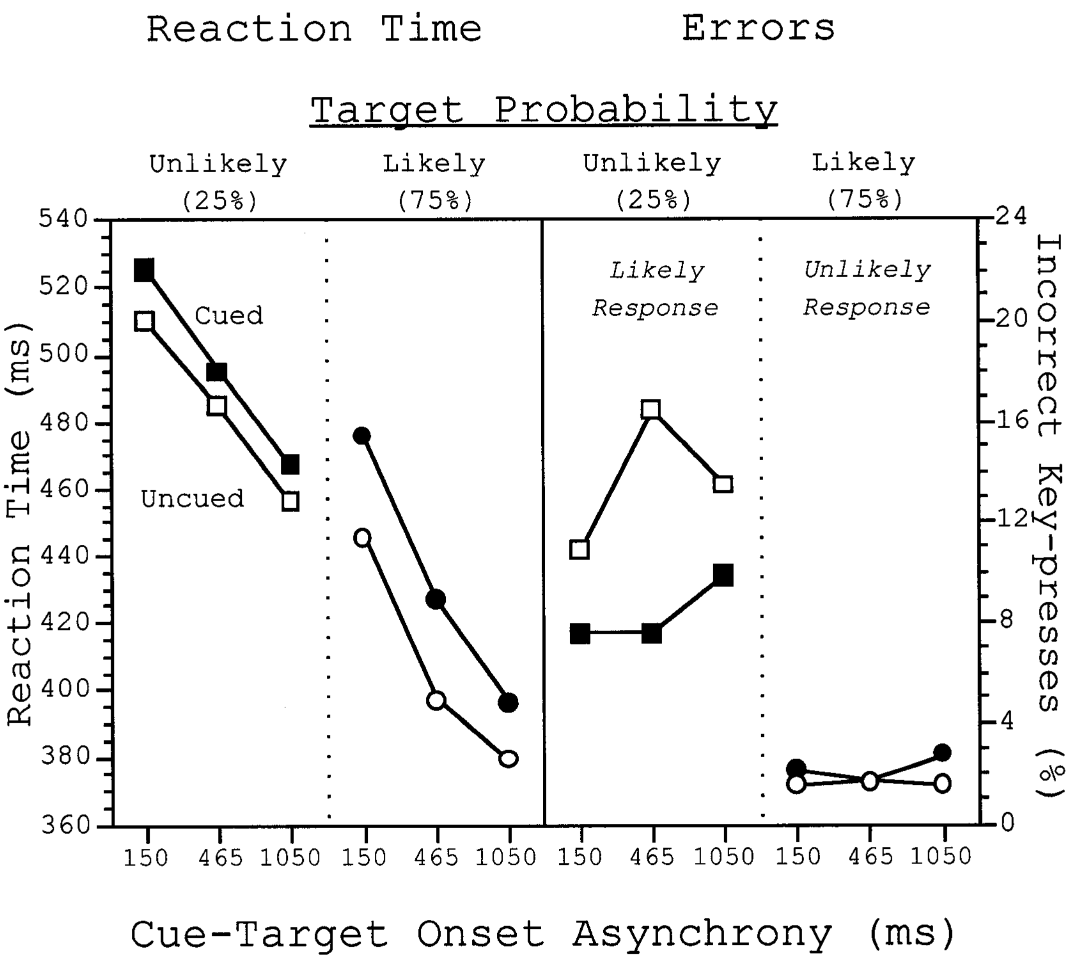

Figure 34. Mean reaction time (RT; ms) and the mean percentage of incorrect key-presses in Experiment 5. Symbols with black fill are cued targets and those without fill are uncued trials. Note that an erroneous response to the likely target is the unlikely response and that an erroneous response to the unlikely target is the likely response.

The IOR effect (uncued RT - cued RT) was significantly larger for the likely target (*M*=-26ms) than it was for the unlikely target (*M*=-12ms).

Incorrect key-presses

The percentage of incorrect key-presses were entered into the same analysis performed on the RTs. The main effect of target probability was significant [$F(1,18)=31.94$, $p<0.0001$]. Target probability interacted significantly with cueing [$F(1,18)=6.50$, $p<0.05$]. When the unlikely target was presented, there were significantly [$t(18)=2.31$, $p<0.05$] more errors for targets at the uncued location (*M*=13.60%) than for targets at the cued location (*M*=8.33%). However, when the likely target was presented, there were relatively few errors altogether (*M*=1.86%) and the difference between errors for targets at the cued and uncued locations was not significant. A dedicated analysis of the cueing effects (uncued - cued), for the *likely* target (to which an *unlikely* response was erroneously made) for each CTOA a showed that there were marginally more errors for cued targets than for uncued targets at the 1050ms CTOA [$t(18)=1.87$; one-tailed t-test: $p<0.05$; two-tailed t-test: $p=0.07$].

Discussion

The results from the RT analysis were remarkably similar to those of Experiment 4. In the current experiment, the IOR effect measured with RTs was nearly twice as large for the likely target (uncued RT - cued RT: *M*=-26ms) than it was for the unlikely target (*M*=-12m). When the unlikely target was presented, there were many more errors to uncued targets than to cued targets. On the other hand, when the likely target was presented, there was no significant effect of cueing on the error rate, although there was a slight tendency for there to be more errors to cued targets than to uncued targets. Thus, the interaction between the IOR and the S-R probability effect does not seem to depend on the use of a go/no-go task or the use of a blocked manipulation of target probability (or their combination).

Another finding worth mentioning is the small effect of IOR on the accuracy of responding to the likely target. Errors were, on average, generally low. More importantly, there was a trend for there to be *more* errors to cued targets than to uncued targets. Clearly this finding does not support the idea that IOR is a tradeoff between speed and accuracy when likely targets are presented. It is consistent with the literature in demonstrating a modest effect of IOR on accuracy in choice-RT tasks (e.g., see Table 1). In the summary section of Chapter 2, the possibility was raised that perhaps IOR is a criterion-shift when the task is to discriminate black squares from checkerboard squares. The trend towards more errors for cued than uncued targets in this experiment using the square/checkerboard discrimination is inconsistent with this idea.

Chapter summary

The goal of Chapter 3 was to assess whether IOR and S-R probability effects interact. There were two reasons for determining whether these effects interact. First, interpreting an interaction with respect to additive factors logic would provide a direct test the criterion-shift account of IOR. An interaction between the IOR effect and the S-R probability effect would suggest that they share a common processing stage. Provided that a criterion-shift interpretation of the S-R probability effect is valid

(Laming, 1968), an interaction between IOR and the S-R probability effects would support the idea that part of the IOR effect is implemented via a criterion-shift. This would cast doubt on an inhibited response interpretation of the enhanced sensitivity to cued targets in Experiment 1. However, the interaction between S-R probability and IOR effect does not necessarily disconfirm the inhibited attention or disconnection theories of the IOR effect.

The second reason that an interaction between S-R probability and IOR may be informative is that it may provide a solution to the problem regarding the effect of IOR on sensitivity. In Experiment 1 IOR increased sensitivity to the target's relevant feature and in Experiments 2 and 3 it decreased it. If the interaction between S-R probability and IOR was analogous to Klein and Hansen's interaction, which it was, then it is plausible that the effect of IOR on increasing the sensitivity to the target in Experiment 1 was the result of a criterion-shift. This criterion-shift effect may have masked the effect of IOR on inhibiting attention (or disconnecting stimulus and response stages).

An additive factors interpretation

In Experiments 4 and 5, the IOR effect measured with RTs was bigger whenever the likely response was made. Furthermore, the IOR effect measured with errors (false alarms or incorrect key-presses) was greater for the unlikely target than it was for the likely target. An additive factors interpretation suggests that IOR and the S-R probability effect share a common stage. According to the interpretation of the S-R probability effect operating on the response criterion (e.g., Laming, 1968), the common stage on which IOR and S-R probability effects operate is the response preparation stage. Thus, the interaction is completely consistent with the criterion-shift account of the IOR effect. This is not to say that the IOR effect is not also implemented by other mechanisms (inhibited attention, S-R disconnection, or inhibited responding), but only that one of the effects of IOR on information processing happens to be on the response criterion.

A further appraisal

The specific form of the interaction between IOR and S-R probability effect suggests that whenever a target appears away from the cue, there is an expectancy for it to be the likely target. When the target appears at the cued location, the raised criterion allows more information to accrue. Consequently the propensity to make the likely response to the unlikely target is attenuated. In reference to Broadbent's (1967) "test tube" metaphor, it is as though the test tube height for the likely/uncued event is lower than that of the other possible events. What makes the interaction between the S-R probability and IOR effects astounding is that cued targets are just as frequent as uncued targets. In an experiment with endogenous cues, cued targets are more frequent than uncued targets. Thus, a location expectancy engendered from an endogenous cue is rational. When a central cue predicts the location of the forthcoming target 80% of the time, and when the likely target is presented 75% of the time, the probability that the likely target will be at the cued location is 0.60. This is clearly higher than the probability of an unlikely target at the cued location (0.2), likely target at the uncued location (0.15) and an unlikely target at the uncued location (0.05). However, a location expectancy engendered from a non-predictive peripheral cue is irrational because the cue does not predict the location of the target. Thus, that the

IOR and S-R probability effects interact is actually quite surprising.

Perhaps what makes the interaction between the IOR and S-R probability effects even more intriguing is that while endogenous attention interacts with S-R probability, the effect of exogenous attention is additive with the S-R probability effect (Kingstone & Egly, in review; Klein, 1994; but see Milàn & Tornay, 2001). Note also that the same conditions that typically attract exogenous attention with short CTOAs also engender the IOR effect with longer CTOAs (but see Gibson & Amelio, 2000, for an exception to this idea). However, IOR, like endogenous orienting, normally requires long CTOAs for it to be observed. The timecourse similarities between the IOR effects and endogenous orienting may be just a coincidence, as there is a possibility that IOR exerts its effect even during early CTOAs but is "masked" by exogenous attention (Danziger & Kingstone, 1999; Klein, Munoz, Dorris, & Taylor, 2001; Samuel & Weiner, 2001). Nonetheless, the interaction between the S-R probability and IOR effects suggest that IOR shares more processing features with endogenous than exogenous orienting.

If IOR and endogenous attention operate similarly by affecting the criterion (i.e., IOR raises, and endogenous orienting lowers, the criterion), then one might expect that IOR and endogenous attention ought to interact. Berger and Henik (1999) found a smaller IOR effect at an expected location than at an unexpected location. Endogenous cueing was elicited by a central informative cue. However, Berlucchi, Chelazzi, and Tassinari (2000) demonstrated near perfect additivity between endogenous attention and IOR. In Berlucchi et al.'s experiments, endogenous attention was brought to a location via a predictive peripheral cue. Thus, there appears to be discrepancy in that IOR has been shown to interact *and* add with endogenous attention. Perhaps the discrepancy owes to a subtle difference between "pushing" endogenous attention with a central predictive cue versus "pulling" endogenous (and exogenous?) attention to a peripheral predictive cue. This is an issue that remains open for further research.

An experiment by Chasteen and Pratt (1999) seems to provide results that conflict with the results in Experiments 4 and 5. They examined IOR and word frequency effects in a lexical decision task. In their experiments, a low- or high-frequency word could appear at a cued or an uncued location. The task was to make a decision concerning whether the target was a word or a nonword (Experiment 1) or whether the word described a person or a thing (Experiment 2). Low and high frequency words were equiprobable in their experiments. They observed larger IOR effects (measured with RTs) for the low frequency words than for the high frequency words. In Experiments 4 and 5 of the current investigation, the IOR effect was larger for the likely (high frequency) than for the unlikely (low frequency) events. However, it is possible that the the word frequency effect in a lexical decision task does not operate via the same mechanisms that are presumed to operate when the task is to identify the target word (e.g., Broadbent, 1967; Morton, 1968).

A recent experiment by Taylor (2003) demonstrated that the IOR effect (measured with RTs) was greater with an unlikely target than with a likely target. In Taylor's experiment, as in Experiment 5 in the current investigation, the location of the stimuli (cues and targets) were orthogonal with the location of the responses, thereby excluding S-R compatibility issues. In her experiment, the location (up versus down) of a peripheral cue signaled which of two colour targets, each associated with a unique response, was likely to be presented.

The similarity between Chasteen and Pratt's (1999) and Taylor's (2003) interactive patterns may be superficial and the mechanisms responsible for the interactions may be very different. However, there is a close similarity between Taylor's (2003) non-spatial expectancy and the non-spatial expectancy generated in Experiment 5 and so this warrants further discussion. Rather than list all of the methodological differences between Taylor's experiment and Experiment 5, I will focus on one in particular that is highly suspect.

Before I consider a key methodological difference between the methodology of Experiment 5 and Taylor's (2003) methodology, a brief segue to a recent dissertation (Fenske, 2001) is needed. Fenske demonstrated a *smaller* effect of endogenous attention (on RTs) for a likely target than for an unlikely target. Note that this interaction is opposite to that observed by Klein and Hansen (1990). A critical difference between Fenske's and Klein and Hansen's methodology is that Klein and Hansen's participants knew what target to expect *before* the location information was provided. Fenske's participants were given target expectancy information at the cued location. Given that location information can be extracted before non-spatial information (Hillyard & Münte, 1984), then it seems that Fenske's participants may have expected locations before they expected targets.

In Experiments 4 and 5 of the current investigation, participants knew what to expect before IOR was generated. This is analogous to the order of expectancies in Klein and Hansen's (1990) tasks. However, in Taylor's (2003) experiment, IOR was generated (via the onset of the cue) before the non-spatial expectancy was generated. This is akin to Fenske's (2001) methodology. Thus, whether the effect of cueing (i.e., IOR or endogenous attention) is larger for the unlikely target than for the likely target (Fenske, 2001; Taylor, 2003) or vice versa (Klein & Hansen, 1990; Experiments 4 and 5) may depend on which expectancy is generated first.

Why might the order for expecting "where" (cueing) and "what" (target) matter for the interaction? First, consider the situation where the location expectancy is generated ahead of the target expectancy (cf. Fenske, 2001; Taylor, 2003). That the effects of IOR and endogenous attention are larger for the unlikely target in Fenske's and Taylor's experiments may not be the result of *two* mechanisms operating on the response criterion. If one mechanism operates on the criterion, and the other affects the rate of gain of information, then the process associated with the faster accrual of information will be *less* susceptible to a criterion adjustment than a process with a lower rate. In other words, borrowing Broadbent's (1967) metaphor, when water flows into a tube quickly, it will take less time for it to overflow in an augmented tube than it would have had the water been flowing at a slower rate. Thus, this idea predicts that an overadditive interaction of the type that Fenske and Taylor observed between the cueing effect (endogenous attention or IOR) and S-R probability. Unfortunately, while this interpretation provides a *qualitative* fit to the interactive pattern demonstrated by Taylor and Fenske, it does not indicate which process (endogenous attention/IOR or target probability) is acting on the criterion and which is acting on the accrual of information. However, if it is presumed that endogenous attention and IOR are implemented via a sensitivity change *and* a criterion-shift, but S-R probability is *only* due to a criterion-shift, then it is reasonable to suspect that the interaction is due to IOR slowing, and endogenous attention accelerating, the accrual of information. Clearly, the idea that IOR slows the accrual of evidence supports the inhibited attention view of IOR.

Quite a different situation arises when there is underadditivity between IOR, or endogenous attention, and a non-spatial expectancy. In this case, the criteria for the likely and the unlikely tubes are adjusted before the location information is provided. Once the location information is provided, the location expectancy combines with the target expectancy in the way described earlier - producing an underadditive interaction between IOR or endogenous attention and S-R probability (Experiments 4 and 5; Klein & Hansen, 1990).

How does this theory account for the additivity between exogenous and S-R probability (Fenske, 2001; Kingstone & Egly, 2001; Klein, 1994)? Suppose that there are two test tubes for the likely, and two for the unlikely, target. For both targets, the tubes are aligned in sequence and they are nonleaky. The heights of the first tubes, for the likely and unlikely targets, are exactly the same. However, the height of the second tube is taller for the unlikely target than it is for the likely target (i.e., the criterion-shift). Further suppose that the second tube does not begin to accumulate water until its paired predecessor overflows (i.e., the flow of water is nonleaky between the tubes) and that the rate of water flow is equal in the second tubes, irrespective of the rate of water flowing into the first tube. A change in the rate at which water flows into the first tube, which corresponds to a sensitivity change associated with exogenous orienting and is presumed to have no effect on the rate of flow into the second tube, will be perfectly additive with a criterion adjustment in the second tube.

The explanation for the disparate results between Fenske (2001) and Klein and Hansen (1990) and between the results of Experiments 4 and 5 in the present chapter and Taylor (2003) is descriptive not causal. Although the simple model can account for the overadditive (Fenske, 2001; Taylor, 2003) and underadditive (Experiment 5; Klein & Hansen) interactions, it fails in that it does not explain *why* these different interactive patterns materialize. Why would IOR and endogenous attention operate on the criterion when the target is expected in advance of the cue (Experiments 4 and 5; Klein & Hansen, 1990) and on the rate of information accumulation when the cue affords the non-spatial information (Fenske, 2001; Taylor, 2003)? This remains an important issue for further research, but it should not detract from the important contribution from Experiments 4 and 5. IOR is implemented, at least in part, by a criterion-shift. This criterion-shift may mask the other effects of IOR (inhibited attention or S-R disconnection) that are responsible for reducing sensitivity.

Chapter 4: General Discussion

The goal of the current investigation was to provide further insight into the effects of IOR on information processing. Four theories of the IOR effect were considered: the inhibited attention theory, the S-R disconnection theory, the inhibited responding theory, and the criterion-shift theory. The purpose of the five experiments in the present thesis was to assess the plausibility of these proposals. Experiments 1 to 3 examined SATs to measure the effects of IOR on sensitivity. These experiments were groundbreaking in that previous investigations of the IOR effect had only looked at one point along the SAT function for cued and uncued targets. The SAT studies provided a much more detailed picture of the effect of IOR on the dynamics of information processing. The purpose of Experiments 4 and 5 was to assess the criterion-shift proposal using additive factors logic and to further understand a seemingly contradictory finding between Experiments 1, 2, and 3 (i.e., that IOR can both increase and decrease sensitivity).

A summary of the findings is listed in Table 3. In the ensuing discussion, I will use the reference codes (R1, S1, S2, etc.) to refer to those findings listed in Table 3. These findings will be discussed with specific reference to the four theories of the IOR effect.

Four theories of the IOR effect

Criterion-shift account of the IOR effect

The criterion-shift account presumes that RTs are slowed to cued targets because of a raised response criterion. This amounts to being conservative, or cautious, when responding to cued targets. The strongest preexisting evidence that

TABLE 4. A summary of the key findings from Experiments 1 to 5 pertaining to the inhibition of return effect.

Ref	Exp(s)	Finding
R1	1-5	Responses (tone-RTs and RTs) to cued targets were generally slower than responses to uncued targets
S1	1	Sensitivity to the target's relevant feature was higher for cued targets than it was for uncued targets
S2	2	Sensitivity to the target's irrelevant feature was higher for cued targets than it was for uncued targets
S3	2,3†	Sensitivity to the target's relevant feature was lower for cued targets than it was for uncued targets
S4	5	For the likely target, there was potentially more errors for cued targets than for uncued targets
C1	1,2‡,3	Responding was more conservative for cued targets than it was for uncued targets (for 60ms and 120ms TTOAs)
C2	3	Responding was less conservative for cued targets than it was for uncued targets (long TTOAs)
A1	2,3	Anticipatory responding was less frequent for cued targets than it was for uncued targets (long TTOAs)
M1	1,2,3	Misses were more frequent for cued targets than they were for uncued targets (short TTOAs)
I1	4,5	RTs: IOR effect was greater for likely targets than it was for unlikely targets
I2	4,5	Errors: IOR effect* was greater for unlikely targets than it was for likely targets

Notes:
Ref = Reference for text. Exp(s) = Experiment(s).
† This was true so long as the one participant who demonstrated generally faster responding to cued targets than to uncued targets was removed from the analysis.
‡ So long as one accepts the proposition that response frequency is analogous to c.
* An error in Experiment 4 was a false alarm and in Experiment 5 it was an incorrect key-press. The "IOR effect" refers to errors occurring more frequently for uncued, than cued, targets.

supports this proposal has come from the analysis of false alarms in go/no-go tasks (Ivanoff & Klein, 2001, 2003; Taylor & Ivanoff, in press). False alarms are generally more frequent, and responses are faster, for uncued targets than for cued targets.

Support for the criterion-shift hypothesis was evident from diverse sources in the current investigation. First, while the sensitivity to the target's relevant feature was relatively poor, the criterion (c) was higher for cued targets than it was for uncued targets (C1). In Experiment 2, c was not measured but response frequency was taken as an analogue. The effect of IOR on the criterion is consistent with the idea that the IOR mechanism is like an expectancy. While awaiting the target, it is as though a passive expectancy is generated (Kahneman & Tversky, 1982; Sommers, Leuthold, & Matt, 1998) for the target to appear at uncued locations. It is doubtful that this expectancy is intentional given that the IOR effect occurs in the absence of awareness of the cue (Ivanoff & Klein, 2003). In an ERP study of the IOR effect, McDonald et al. (1999) discovered that IOR increased the P300 potential[11]. As they noted, the P300 is often larger for infrequent or unexpected stimuli (e.g., see Sommer et al., 1998, for a discussion). The implication of a larger P300 effect on cued trials than on uncued trials is that it supports the contention that IOR generates a nonconscious expectancy for targets to appear at uncued locations.

Why was the effect of IOR on the criterion (C1) limited to the early (120ms and 60ms) TTOAs? Perhaps the effect of IOR on the criterion at the early TTOAs owes to the existence

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[11] The P300 was significantly larger for the cued than for uncued targets in McDonald et al.'s (1999) Experiment 1. It failed to reach significance in their second experiment, but the direction of the effect (i.e., larger P300 for cued trials) was consistent with their finding in Experiment 1.

of "fast guess" responses (cf. Yellott, 1971). Fast guesses are responses that are uninfluenced by target information. Sacrificing accuracy for speed may be partially accomplished by predicting the target's identity and location. It may be actualized by planning to respond to onsets at a particular location. If the criterion-shift component to the IOR effect is the result of a passive expectancy for targets to appear at an uncued location, then this expectancy ought to sway fast guesses away from the cued location. That the effect of IOR on raising the criterion is absent at the late TTOAs is no surprise given that fast guesses ought to be very rare when there is ample time to process the target.

The effects of IOR on anticipatory responding (A1) and on the rate of misses (M1) also provided support for the criterion-shift account. A raised criterion will make responding within the deadline difficult and so misses will be frequent with cued targets. However, there is a benefit to raising the criterion in that it reduces responding before the tone by providing less opportunity for activation to "slip" over the threshold.

An interpretation of the effect of IOR on accuracy in an SAT task must take into consideration any effect of IOR on tone-RTs. In Experiments 1-3, IOR significantly slowed tone-RTs. Hence, the criterion-shift account predicted that IOR ought to increase sensitivity. In Experiment 1, it did. However, in Experiments 2 and 3, the evidence showed that IOR reduced sensitivity. A possible solution to this paradox came from an analysis of the IOR effect for likely and unlikely targets (Experiments 4 and 5). Here, the results suggest that IOR may be implemented via a criterion-shift when the frequencies of targets are asymmetric (i.e., asymmetric S-R probabilities; I1 and I2). When target frequency is symmetric, as it was in Experiments 2 and 3, IOR does not seem to have an effect on the criterion. Thus, there must be an alternative effect of IOR on information processing. This proposal is analogous to Klein and Hansen's (1990) suggestion that the effects of endogenous attention may be solely explained by adjustments to the response criterion when S-R probabilities are asymmetric, but that adjustments to the response criterion cannot account for the effects of endogenous orienting when S-R probabilities are symmetric. That IOR must have a detrimental effect on sensitivity to the non-spatial features of the target opens the door for the possibility that the IOR effect may be partially due to inhibited attention or a S-R disconnection.

Inhibited attention account of the IOR effect

The inhibited attention account suggests that IOR slows attention from returning to a recently visited location. Some have even suggested that the IOR effect is better tuned to discern where attention *has been* than the early facilitative effect of a peripheral cue which is thought to gauge where attention *is* at the time the target is presented (Pratt, Hillis, & Gold, 2001; Pratt & Fischer, 2002).

The literature has provided mixed support for the inhibited attention view. While there have been some reports showing that IOR reduces accuracy (Cheal et al., 1998; Handy et al., 1999; Klein & Dick, 2002), putatively due to a negative effect of IOR on perception (Handy et al., 1999), there are other reports demonstrating that IOR has no effect on perception. For instance, Schmidt (1996) failed to find evidence of an effect of IOR on a perceptual illusion (i.e., illusory line motion). Likewise, in a reanalysis of Gibson and Egeth's (1994) work, Klein, Schmidt, and Müller (1998) also failed to find any evidence of an effect of IOR on a another perceptual effect (temporal-order judgments; see also

Posner et al., 1985). That both illusory line motion and temporal-order judgments are sensitive to attention (Schmidt, 2000; Shore, Spence, & Klein, 2001; Sternberg & Knoll, 1973), but not IOR, suggests that IOR is not due to inhibited attention.

The inhibited attention proposal received some support in the present experiments. First, and foremost, was the finding that errors were more frequent for cued trials than for uncued trials (S3). Although this decrement in accuracy for responding to cued targets occurred in SAT go/no-go and SAT choice-RT tasks, with equal target probabilities, it also may have occurred in the choice-RT task with an equal emphasis placed on response speed and accuracy with the likely target (Experiment 5; S4).

How can the inhibited attention theory account for reduced accuracy to identify cued targets (S3, S4) and the absence of an effect of IOR on temporal-order judgments and illusory line motion? In the current work, accuracy was reflected by the ability to discern the object (S3: X or +; S4: black square versus checkerboard square). The object's location is irrelevant. In a temporal-order judgment task, and in an illusory line motion task, location is the feature that is being assessed. The results from Experiment 2 point to IOR actually *increasing* the sensitivity to the target's location (S2). This is not to say that speeded localization responses will not demonstrate slowed RTs to cued targets (e.g., Tanaka & Shimojo, 1996; Taylor & Klein, 2000). Rather, if the absent effect of IOR on temporal-order judgments and illusory line motion is due to spatial processing of the target in these tasks, then IOR ought not to have a negative influence on the *accuracy* of localizing an object in space. Moreover, IOR may have no effect on the accuracy of localizing an object if sufficient time passes (as with long TTOAs in SAT tasks). Thus, while the inhibited attention hypothesis is successful in accounting for reduced identification accuracy for cued targets (S3), it is difficult to understand why it would not also reduce localization accuracy.

Inhibited response account of the IOR effect

The inhibited response account (Tassinari et al., 1987) attests that the IOR effect is due to the suppression of a prepotent response (oculomotor or otherwise) to the cue. Prior research that has found evidence for IOR in tasks where responses are made to the cue and target (e.g., Maylor, 1985; Rafal et al., 1989; Taylor & Donnelly, 2002; Taylor & Klein, 2000) does not provide much support for this idea. Moreover, there is evidence for IOR when the cue is placed at fixation (Ivanoff & Klein, 2001; Maylor & Hockey, 1985; Possamaï, 1986). When the cue is presented at fixation, responses are slower to targets that are also presented at fixation compared to targets that are presented in the periphery. If this "central IOR effect" is no different from IOR that results from peripheral stimulation[12], then it argues against the idea that IOR is the result of an inhibited saccade to the cue.

Despite the preexisting evidence against the inhibited response account of IOR, it was nonetheless given full credibility in the context of a cue-target paradigm. The inhibited response proposal was able to account for the effects of IOR on sensitivity (S1 and perhaps S2), it could readily explain the effects of IOR on anticipations (A1) and miss rates (M1), and it could handle the early effects of IOR

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[12] Ivanoff and Klein (2001) noted that the peripheral and central IOR effects were similarly characterized by slower RTs, and fewer false alarms, to cued targets than to uncued targets. That there was a slight RT timecourse difference (measured with two CTOAs) between peripheral and central IOR effects hints that perhaps they are different in kind.

on the criterion (C1). However, these findings were also consistent with the criterion-shift proposal and may be accounted for by either mechanism. The results from Experiments 4 and 5 (I1 and I2) were consistent with the criterion-shift account, and while they do not necessarily rule out the inhibited response account of the IOR effect, they certainly do not support it.

S-R disconnection account of the IOR effect

The disconnection hypothesis is a relatively new theory, having only been introduced to the field in 1999 by Fuentes and his colleagues to explain a pattern of interactions between the IOR effect and the semantic priming and flanker effects (Fuentes et al., 1999). Unfortunately, there has been little development of the theory and consequently I had to make some assumptions concerning the presumed underlying dynamics of information processing. Had these assumptions not been made, the processing dynamics of the disconnection theory would have been indistinguishable from those of the inhibited response theory. In particular, I presumed that during the "disconnection" between perceptual and response stages there is a passive decay of perceptual information. By the time that perceptual and response stages are "reconnected," the quality of the information passed along to the response stage will be worse had there not been a disconnection (i.e., as with uncued targets).

Those experiments that support the disconnection hypothesis (Fuentes et al., 1999; Vivas & Fuentes, 2001) have generally used irrelevant stimuli at the cued or uncued location and relevant targets appear elsewhere (e.g., at centre). Vivas and Fuentes have recently argued that there are two, late effects of peripheral cues. First, there is an orienting delay (i.e., inhibited attention). Second, there is a disconnection between stimuli from their responses. Hence, according to Vivas and Fuentes (2001), the disconnection and inhibited attention processes are not mutually exclusive processes and they seemingly operate differently under different conditions.

The difficulty in assessing the disconnection hypothesis, assuming that there is perceptual decay during the disconnection, is that the predictions are the same as those of the inhibited attention hypothesis. However, there are at least three possible ways that that these ideas may be dissociated. First, the disconnection hypothesis can explain the effects on the criterion (C1). According to the disconnection proposal, the effect of IOR on the criterion (C1) is due to an inability to respond while the disconnection is in effect[13]. The inhibited attention hypothesis can not account for the effect of IOR on the criterion. Second, the disconnection hypothesis can explain the effect of IOR on anticipations (A1). The S-R disconnection helps to reduce anticipations by delaying the onset of response preparation. If the onset of response preparation is delayed, then it is less likely that the response preparation will end prematurely (i.e., before the response signal). The inhibited attention theory cannot readily explain the effect of IOR on anticipations. Third, the disconnection theory can explain the effect of IOR on enhancing the sensitivity to the target's location (S2). As outlined by Ivanoff et al. (2002) a delay in the activation of the response, from the irrelevant location of the target, will increase the Simon effect. If there is some measure (e.g., lateralized readiness potentials; DeJong et al., 1994), or some technique (e.g., SATs), that can tap into the

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[13] It can not explain, however, why there would be an effect of IOR on reducing false alarms when there are no constraints on responding (Experiment 4; Ivanoff & Klein, 2001).

activation of the response from the irrelevant location of the target, then it may be possible to have an unambiguous measure of the delay[14]. Unfortunately, in Experiment 2, the sensitivity to the irrelevant location feature of the target only decreased with TTOA. Thus, the range of TTOAs that were used (120ms - 480ms) did not seem to tap into the activation portion of the function (assuming that it can be measured). While the increased sensitivity to the target's location (S2) does not unambiguously support the disconnection hypothesis, it certainly does not readily support any other theory of the IOR effect. That the disconnection theory can account for so many results suggests that it may not be necessary to consider alternative explanations of the IOR effect. However, there are some effects that the disconnection theory cannot explain.

The interaction between the IOR and S-R probability effects poses a serious problem for the disconnection theory. Simply put, if IOR was only the result of delayed response preparation then there ought to have been additivity between the IOR and S-R probability effects. This is the same prediction made by the inhibited response account. Given that the interaction is best explained by a criterion-shift account of the IOR effect, and the criterion-shift account

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[14] The effect of IOR on increasing the sensitivity to the target's location (S2) may be interpreted in three different ways (see Ivanoff et al., 2002, for full details). IOR may increase sensitivity to the target's location by augmenting, delaying, or slowing the decay of the activation/decay function of the target's spatial code. Unfortunately, none of these ideas can be rejected on the basis of the evidence from Experiment 2 because the range of TTOAs only captured the decay function of the spatial code (i.e., there was only evidence of the sensitivity to the target's location dropping, not accumulating). Had earlier TTOAs been used, it may have been possible to tap into the activation functions of the target's spatial code. Thus, if IOR augments the spatial code, then IOR would *increase* sensitivity to the target's location during the activation and decay of the target's spatial code. If there is a delay, then IOR ought to *decrease* the sensitivity to the target's location. Lastly, if IOR has no effect on the activation function, then this would have been evidence in favour of IOR slowing the decay of the target's spatial response code.

can readily explain all of the effects that the disconnection hypothesis can explain (except for S2 and S3), it seems that an exclusive account of the IOR effect in terms of an S-R disconnection is questionable.

If the disconnection theory is limited to its effects on irrelevant, but potentially conflicting, features of a stimulus (e.g., location in a Simon task, flankers in the Eriksen-flanker task, colour-words in the Stroop task, etc.), then there may be some support for the theory (see footnote 14). Note that this possibility also saves the inhibited response theory if it is assumed that the "response" that is inhibited is sub-threshold activation resulting from an irrelevant stimulus feature.

An integrative account of the IOR effect

Each theory was able to account for some of the results, and not one theory was able to account for all of the results. Generally, the results were consistent with the view that IOR has many effects on information processing, and how IOR is expressed depends on the context of the task.

Under conditions that do not encourage pigeonholing mechanisms, such as choice-RT tasks with symmetric S-R probabilities, IOR seems to be expressed as inhibited attention (or, quite possibly, a S-R disconnection with passive decay of perceptual information during the disconnection). Under conditions that promote fast responding by requiring less evidence (e.g., asymmetric S-R probabilities and short response deadlines), IOR is expressed as a reluctance to respond to cued targets. Clearly, IOR must raise the criterion and impair perception (*directly* or *indirectly* by inhibiting attention or disconnecting stimuli from their associated responses) or else there is no way to account for the full range of results. In other words, IOR affects early and late stages of information processing and unless there is a suitable measure of accuracy, it is extremely difficult to tell which form of IOR is expressed or predominant. Figure 35 is an illustration, adapted from Klein (1994), that summarizes the effects of endogenous attention, exogenous attention, and IOR on information processing. The thin lines extending from IOR to feature extraction reflects the possibility that IOR has a direct effect on perception. The thin lines that extend from IOR to endogenous and exogenous attention reflect the possibility that IOR affects perception indirectly by inhibiting attention. Whether IOR affects feature integration, a process that is performed by exogenous attention (Briand & Klein, 1987), is a question worthy of future research.

There were two effects in the present experiment that cannot be accounted for solely in terms of a criterion-shift and inhibited attention. First, one of the unusual results from the present investigation was the effect of IOR on the sensitivity to the target's location (S2). I suggested that this effect supports a disconnection or inhibited response theory. However, given that this effect seems so out of place, it may be wrong to attribute this finding to IOR. Perhaps it is due to some residual processing of the cue. Dorris et al. (2002) noted that the activity of neurons in the superior colliculus were still at an inflated level after the cue was removed. When a current was applied to a network of neurons in the superior colliculus, in the absence of a target, the elicited saccades were often faster towards cued targets than they were for uncued targets. On the surface, this finding is not unlike S2. This effect of increasing the sensitivity to the target may reflect a new mechanism that coexists with IOR. Given the peculiarity of this effect, it

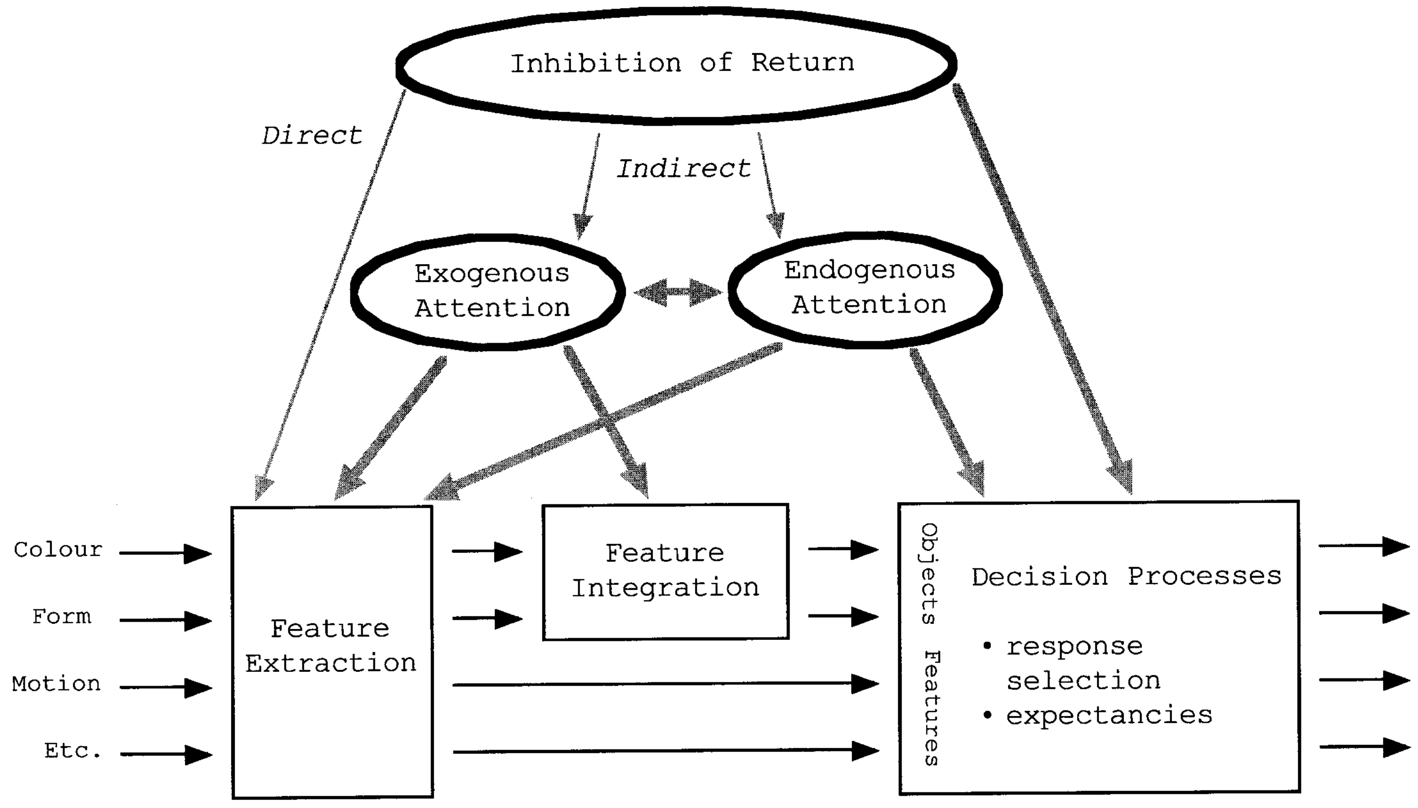

Figure 35. *An illustration of the stages alleged to be affected by endogenous attention, exogenous attention, and inhibition of return. The thin lines reflect possible routes (direct or indirect) whereby inhibition of return affects the perceptual processing (i.e., feature extraction) of the target. This illustration was adapted from Klein (1994). See text for more details.*

certainly warrants further research.

The second finding that did not seem to mesh with any existing theory of the IOR effect appeared in the late TTOAs in Experiment 3. Here IOR caused a significant decrease in the criterion (C2). In other words, as the TTOA increased, and sensitivity to the target's identity increased, responding to uncued targets became more conservative than responding to cued targets. Consistent with this finding, in Experiment 2 response frequency was marginally higher for cued targets than for uncued targets when the 360ms and 480ms TTOAs were combined. In Experiment 1, there was no evidence for this effect at all. This is a peculiar finding considering it occurred while sensitivity was generally reduced at the cued location (S3), and while there was ample target evidence. One possibility is that it functions to counteract the bias (C1) that is present with the short TTOAs. Alternatively, this finding may be a new phenomenon unrelated to IOR. Whatever the cause of this reversal, it is certainly an interesting discovery also worthy of further research.

Limitations of the present work

In any piece of empirical work, there will be methodological limitations that may prevent generalization of the conclusions. The current investigation is no exception. Perhaps the most obvious limitation is that eye position was not monitored. According to some, this may seem to be a critical oversight as prior work has shown that IOR slows eye movement latencies (Abrams & Dobkin, 1994; Taylor & Klein, 2000). Despite this objection, Kingstone and Pratt (1999) observed similar IOR effects (in key-press RTs) irrespective of whether the eyes shifted to the target. Indeed, they actually noted that RTs were generally *slower* when the eyes moved to the target (irrespective of the cue's location). In a SAT task, this would create a problem for responding within the response window. More importantly, however, is that eye movements to the target would not have disproportionately affected key-press responses to cued and uncued targets.

Another important limitation to the previous work is that there were only two possible cue and target locations. This is a common technique in the field, and is not necessary a serious problem. There is evidence of IOR in more complex displays (Klein & MacInnes, 1999; Samuel & Weiner, 2001). An important goal for future work is to discern whether IOR in complex displays reflects the same mechanisms (i.e., inhibited attention and criterion-shifts) that are observed in simpler displays.

My use of the SAT methodology differed from the "ideal" use (Wickelgren, 1977). Quite often the SAT function is used to estimate the intercept, the slope and the asymptote of the SAT function. However, a problem with estimating these parameters (apart from deciding how to plot SAT function; Luce, 1986) is that many TTOAs are needed to provide a reasonable fit to the function. However, there is a cost to this kind of analysis in that there are many (i.e., tens of thousands) trials needed (due to the need for many TTOAs) per participant for a respectable estimation. Given that so many trials are needed, it is common to find SAT experiments with a small (e.g., n<5) sample size. Certainly, this is a suitable design after the SAT space (i.e., time region where accuracy is at chance and asymptotic level) has been plotted for a particular task. Because the use of the SAT methodology in IOR tasks is groundbreaking, this is not a challenge for the present results. However it is an attainable goal for future research.

The utility of IOR

Posner and Cohen (1984) were the first to propose that IOR serves to facilitate search to new locations. If one were on the lookout for prey or predators, for example, there would need to be a mechanism that would allow attention to disengage from one location and prevent it from returning to the same location later on. In their words,

> "We believe that the inhibition effect evolved to maximize sampling of the visual environment. Once the eyes move away from the target location, events that occur at that environmental location are inhibited with respect to other positions. This would reduce the effectiveness of a previously active area of space in summoning attention and serve as a basis for favoring fresh areas at which no previous targets had been presented. The long-lasting nature of inhibition (1.5 sec or more) seems to be about the right length to ensure that the next movement or two will have a reduced probability of returning to the former target position." (p. 550).

The proposal that IOR is more than inhibited attention does not challenge this function. Rather, it argues that visual search may be affected by many different mechanisms, and one of them is bias. Not only does IOR help search by inhibiting attention, but it also helps by biasing the system to nonconsciously expect to respond to new objects at new locations. Further insight into the IOR mechanism may be gained from understanding its relation to expectancies in complex search scenes.

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