Examining Task Difficulty and the Time Course of Inhibition of Return: Detecting Perceptually Degraded Targets

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Abstract The ability to efficiently direct visual attention to salient features in the environment is a critical function of the visual system. The finding that people are slower to detect a target that appears at a previously cued location is thought to reflect a mechanism known as inhibition of return (IOR). Past research has shown that difficult target discriminations result in a greater amount of time needed to inhibit previously attended locations (i.e., a delayed onset of inhibition), suggesting that task difficulty plays a critical role in the allocation of attention. In this study, IOR was measured at a wide range of SOAs while participants detected either a perceptually degraded target or a standard, high luminance target. When responses were made to a perceptually degraded target, the time course of IOR was delayed by approximately 250 ms (relative to the control group), suggesting that the difficulty in detecting targets also influences the allocation of attention. The results are consistent with the notion that IOR is not simply a reflexive subcortical mechanism but rather involves top-down attentional control settings.

The ability to efficiently direct visual attention to salient features in the visual field is important because every day we generate thousands of actions based on countless objects in our environment. A good example of this efficiency is that targets at previously sampled locations are responded to more slowly than are targets at locations that have not been sampled. This is thought to be due to a mechanism termed inhibition of return (IOR), a label that captures the notion that the mechanism inhibits attention from returning to previously searched locations (e.g., Posner, Rafal, Choate, & Vaughan, 1985). Although the attentional explanation for the inhibitory effect has received considerable support over time (e.g., Berlucchi, Chelazzi, & Tassinari, 2000; Tipper, Weaver, Jerreat, & Burak, 1994), motor-based explanations (e.g., Rafal, Brennan, Calebesi, & Sciolto, 1989; Taylor & Klein, 1998), and combinations of motor and attentional explanations (e.g., Kingstone & Pratt, 1999; Taylor & Klein, 2000) have also been proposed. In addition, there is evidence that IOR also involves spatial indices (e.g., Wright & Richard, 1998, 2000) and spatial working memory (e.g., Castel, Pratt, & Craik, 2003). To separate the mechanism from the effect, we will use the term inhibition for the finding of slower reaction times (RTs) at cued locations and IOR as the mechanism that underlies this effect. The focus of the present paper is to provide more information regarding how the inhibition that first appears following a peripheral cue is influenced by the perceptual demands of the task and to integrate these temporal effects into theories of visual attention.

In general, a brief, uninformative cue in the periphery produces a particular time course of effects. For a short time after the onset of the cue, targets that subsequently appear at the cued location are responded to faster than targets at an uncued location. Relatively quickly, however, this pattern of responses reverses and for a longer period of time targets at the cued location are responded to more slowly than targets at an uncued location. To understand this time course of events, an experimental design that includes many different delay periods between the onset of the cue and the onset of the target (i.e., stimulus onset asynchrony or SOA) is required, with a key feature being the time of the first appearance of inhibition (slower responses at cued locations). Cheal and Chastain (2002) examined how SOA range and target discrimination difficulty influenced the onset time of inhibition. In general, inhibition was found earlier when fewer placeholders were presented on the screen and when the range of SOAs within a block of trials was longer. Other studies have been conducted and have shown that factors such as the duration of the peripheral cue (Collie, Maruff, Yucel, Danckert, & Currie, 2000) and brightness and spatial position of the cue (Pratt, Hillis, & Gold, 2001) affect the point in time that inhibition first appears.

Another factor that affects the onset of inhibition is task difficulty. Lupiáñez, Milán, Tornay, Madrid, and Tiudela (1997) showed that inhibition occurs in choice colour discrimination tasks (when one needs to respond based on the colour of the target), but begins at a later SOA and ends at an earlier SOA than does inhibition for simple detection tasks. Thus, the temporal range of inhibition depends on the task and range of SOAs used (see Lupiáñez & Milliken, 1999). Additional experiments by Lupiáñez and colleagues (e.g., Lupiáñez & Milliken, 1999; Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001; Lupiáñez et al., 1997) found that the onset of IOR was related to the complexity of the task. For example, Lupiáñez et al., 1997, found that inhibition in a detection task was found at the 400-ms SOA, but that inhibition for a more difficult colour discrimination task was not found until the 700-ms SOA. Similarly, Lupiáñez et al. (2001) found inhibition for an "X" versus "O" discrimination task at a 700-ms SOA, but inhibition emerged at a 1,000-ms SOA for the more difficult "M" versus "N" discrimination task. Cheal and Chastain (2002) also examined task difficulty and found that the onset of inhibition occurred earlier for detection tasks than for identification tasks, although it was shown that there was no difference in the onsets of inhibition between easy and hard identification tasks.

From findings like these, Klein (2000) suggested that people adopt attentional control settings suitable for the task and that this results in the delayed onset of inhibition for more difficult tasks. For example, consider an easy detection task, where relatively little attention has to be elicited to a peripheral location to make the correct response. In this case, the attentional control setting is set to a low level and therefore the cue will be weakly attended. This results in the quick disengagement of attention from the cued location, and therefore inhibition occurs early in time. In contrast, consider the case when the target involves a difficult discrimination. In this case, the attentional control setting is set to a high level and now the cue will be strongly attended. This results in a slow disengagement of attention from the cued location, and therefore inhibition occurs later in time. In other words, according to Klein, the more difficult the task, the longer it will take for inhibition to appear. While task complexity appears to have a major impact on the onset of inhibition, it does not have a similarly robust effect on its offset (Lupiáñez et al., 2001).

The studies done by Lupiáñez and colleagues suggest that tasks that involve a greater degree of "discrimination difficulty" (i.e., "M" vs. "N" discrimination task or a colour discrimination task) result in a delayed onset of inhibition relative to simple detection tasks. However, given the observations by Klein (2000), it would also stand to reason that if the task difficulty is manipulated by simply making the target harder to perceive (as opposed to making the target harder to discriminate from other potential targets), one would expect a delay in the onset of inhibition. In other words, the complexity effect should not be limited to discrimination tasks but should also occur in detection tasks that vary in difficulty.

To determine if task difficulty exerts a general effect on the onset time of inhibition, the present study employed a paradigm in which two levels of "detection difficulty" were manipulated between subjects. To this end, participants completed one of two conditions, one of which involved a relatively easy target detection task and the other involved a more difficult target detection task. The easy task used a "standard target" that consisted of a large, bright white target presented on a black background. Such a target is typical of many IOR studies (e.g., Dodd, Castel, & Pratt, 2003; Klein & Taylor, 2000; Wright & Richard, 2000). The difficult task used a perceptually degraded target that consisted of a small, dark blue target presented on a black background. Pilot work showed that the RTs in the perceptually degraded target task should be about 100 ms longer than in the standard task.

If our proposal is correct, then it should be the case that participants who had to detect the perceptually degraded targets would show a delay in the onset of inhibition relative to a control group who responded to standard targets. Based on the work of Lupiáñez and colleagues, we also expected the magnitude of inhibition between the two conditions would be similar around the 1,000 ms SOA and that the offset of inhibition would be somewhat similar for both groups at the very longest SOAs. For a thorough examination of the time course, the present experiment used 11 SOAs between the ranges of 50 ms and 3,000 ms. This allowed for a precise examination of when inhibition occurs in each condition.

Method

Participants

In total, 40 undergraduate students at the University of Toronto (nine men) participated in the study, and 20 (five men) of these participants were randomly assigned to the perceptually degraded target condition. The mean age was 21.1 years (*SD* = 1.1), and the mean number of years of education was 16.2 years (*SD* = 1.1). All of the participants had normal or corrected-to-normal vision, and were paid CDN$10 for their participation in the experiment. The data from the participants in the standard target condition (i.e., the control condition) in the present study also served as a control con-

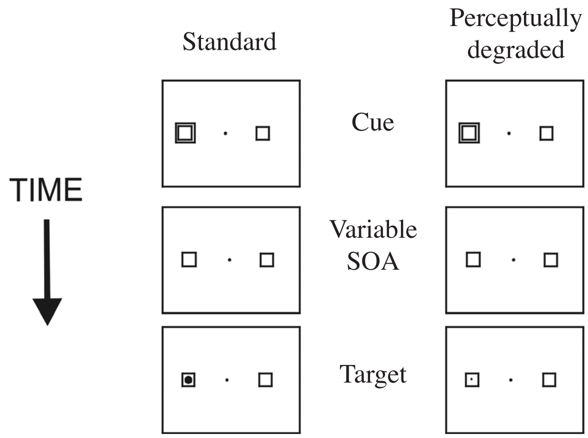

Figure 1. The sequences of events for a given noncatch trial in both the standard target and the perceptually degraded target condition in the present experiment.

TABLE 1
Mean Percentage of Total Errors (Anticipations, Misses, Detection) for Cued and Uncued Locations for the Standard Target Group and the Perceptually Degraded Target Group

	Standard group		Perceptually degraded target group	
SOA (ms)	Cued	Uncued	Cued	Uncued
50	0.1 (0.49)	0.4 (0.29)	0.8 (0.49)	0.4 (0.34)
100	1.3 (0.76)	0.8 (0.51)	0.4 (0.34)	0.8 (0.51)
250	0.8 (0.49)	1.7 (0.93)	1.7 (0.88)	1.7 (0.56)
500	0.8 (0.38)	1.3 (0.76)	1.3 (0.53)	0.4 (0.46)
750	0 (0.00)	0.4 (0.29)	0.8 (0.46)	0.8 (0.51)
1,000	0.4 (0.34)	0.4 (0.29)	0.4 (0.38)	0.8 (0.42)
1,250	0 (0.00)	0 (0.00)	0.8 (0.57)	1.3 (0.87)
1,500	0 (0.00)	0.8 (0.42)	0.8 (0.49)	0.8 (0.41)
2,000	0.4 (0.21)	0.1 (0.38)	0.8 (0.38)	0.8 (0.49)
2,500	0.8 (0.49)	0 (0.00)	0.8 (0.51)	1.3 (0.87)
3,000	0.0 (0.00)	0.8 (0.67)	0.8 (0.65)	0.8 (0.51)

Note. Standard errors of the mean are shown in brackets.

dition for another related study, which was conducted during the same experimental sessions (Castel, Chasteen, Scialfa, & Pratt, 2003).

Apparatus and Procedure

The experiment took place in a dimly illuminated and sound-attenuated room. Participants were seated 44 cm in front of a computer monitor. The viewing distance was held constant with the use of an adjustable head/chin rest. The computer keyboard was directly in front of the participant and was used as the response device. Participants were asked to fixate on a central fixation cross (0.1° by 0.1°) and not to make any eye movements during each experimental trial (see the Design section for more details regarding eye movement monitoring). The sequence of events is shown in Figure 1, although in reality all of the stimuli (with the exception of the target in the perceptually degraded target condition) were presented in white (77.0 cd/m^2) on a black background (0 cd/m^2). The initial display was presented for 1,000 ms, and consisted of two placeholder boxes located on the horizontal meridian to the left and right of the fixation point. The boxes were centred 5° from the fixation point and were 1° square. One of the boxes was then cued by outlining the perimeter of the box for 100 ms. This was done by presenting a new box (white, 77.0 cd/m^2, 1.15° square) around one of the original boxes. These stimuli have previously been shown by Pratt et al. (2001) as being especially useful for detecting early facilitatory and later inhibitory effects. One of 11 randomly assigned SOAs then followed the onset of the cue (50, 100, 250, 500, 750, 1,000, 1,250, 1,500, 2,000, 2,500, or 3,000 ms). In the standard condition, after the variable SOA, a white (77.0 cd/m^2) target circle (0.7° in diameter) appeared in one of the two boxes (on 80% of the trials, while the remaining 20% served as catch trials in which no target was presented). In the perceptually degraded target condition, the target was a small, blue circle (0.2°) that had a much lower luminance (3.5 cd/m^2). This perceptually degraded target was chosen on the basis of pretesting that revealed that the pilot participants' RTs to this target were slower than that of the standard target condition, suggesting that it was more difficult to detect than the standard white target. In both conditions, participants were asked to respond to the target as quickly and as accurately as possible by pressing the space bar (regardless of the location of the target), and to remain fixated throughout each trial. The next trial began 500 ms later.

Design

The entire session consisted of 660 trials (528 experimental trials and 132 catch trials), with cues and targets being equally likely to occur at the left and right locations. Thus, there were 60 trials at each SOA. The participants were given short breaks between blocks of 110 trials, and the experiment took less than 90 min to complete. The perceptually degraded target and standard target condition were blocked, and participants were randomly assigned to one of the two conditions.

In order to ensure that eye movements were not made during the trials, a closed-circuit TV system (similar to the design employed by McCrae & Abrams, 2001) was used to observe and monitor participants' eyes for half of the participants in each group (n = 10). It is

TABLE 2
Mean RTs for the Standard and Perceptually Degraded Target Conditions for the Eye-Monitored (Eye) and Noneye-Monitored (No-Eye) Groups for Both Standard and Perceptually Degraded Target Conditions

			SOA (ms)										
Target	Monitoring	Trial	50	100	250	500	750	1,000	1,500	2,000	2,500	3,000	3,500
Standard	Eye	Cued	420	417	412	433	438	416	420	409	420	420	426
		Uncued	442	417	402	405	410	389	387	386	394	395	416
	No-eye	Cued	433	419	427	462	457	440	434	421	432	428	433
		Uncued	451	428	415	428	418	407	396	397	408	408	422
Perceptually Degraded	Eye	Cued	482	465	471	485	469	484	474	480	469	468	485
		Uncued	506	486	482	498	464	469	454	457	460	473	473
	No-eye	Cued	529	493	475	508	517	502	481	496	486	483	504
		Uncued	533	511	488	495	485	476	460	468	478	485	491

Note. The pooled standard errors for each condition are as follows: standard eye (15.2 ms), standard no-eye (12.2), perceptually degraded eye (18.5), and perceptually degraded, no-eye (20.2).

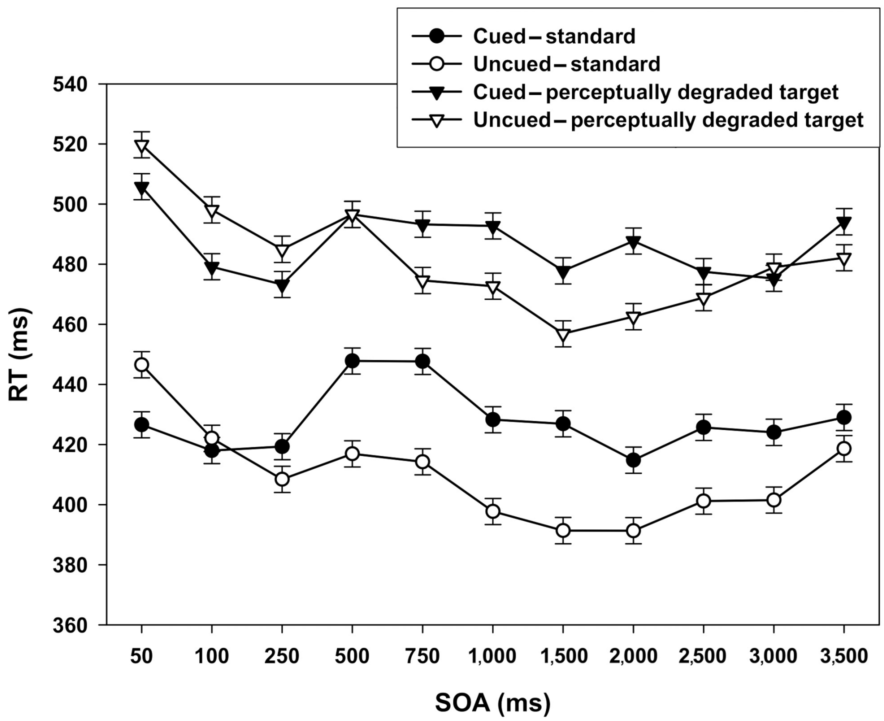

Figure 2. The mean cued and uncued RTs (ms) at each SOA for the standard target condition and the perceptually degraded target condition (error bars reflect standard errors and are calculated from Loftus & Masson, 1994).

possible to detect eye movements as small as 1 degree with this system. For these participants, in addition to the warning that all participants received about staying fixated, they were informed that their gaze would be monitored by a closed-circuit TV system with a camera mounted below the computer screen. During the experimental session, the experimenter visually monitored the eye movements for these participants in order to ensure that the participants remained fixated during each trial. The experimenter provided verbal feedback if it appeared that the participant was having difficulty maintaining fixation. This occurred rarely and early in

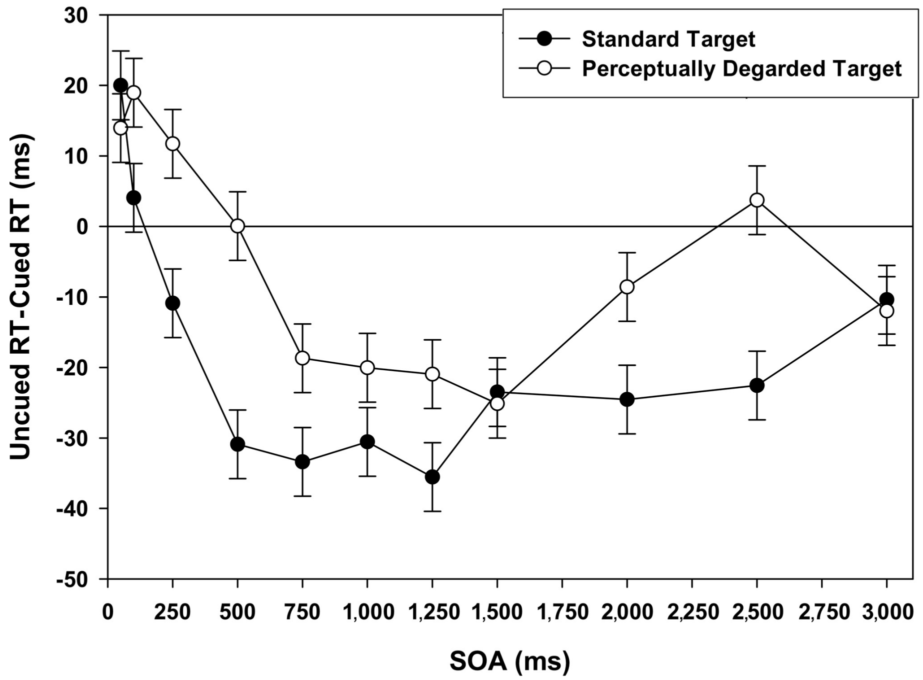

Figure 3. The mean facilitatory and inhibitory effects (uncued RTs-cued RTs) for each condition (error bars reflect standard errors and are calculated from Loftus & Masson, 1994).

the first block of trials, if at all. The majority of the participants had very little difficulty maintaining fixation during the trials, as is typically found in such simple cue-target detection tasks (e.g., Kosnik, Kline, Fikre, & Sekuler, 1987; Pratt & Abrams, 1995).

Results

The error rates are shown in Table 1, and trials in which the RTs were less than 100 ms or greater than 1000 ms were eliminated from the analysis (this occurred on less than 1% of the trials). The detection errors (i.e., errors on catch trials) were analyzed with a 2 (Condition) x 11 (SOA) x 2 (Trial Type) x 2 (Eye Monitoring) repeated-measure analysis of variance (ANOVA), with condition (trial type) as an independent variable factor, and SOA, trial type, and eye monitoring as repeated measures. There was a trend for more errors in the perceptually degraded target condition (1.1%), $F(1,18) = 3.0$, $p > .09$, than the standard condition (0.53%), but no other main effects (ps > .16) nor interaction effects (Fs < 1) were found.

The mean RTs (as shown in Table 2) were analyzed with a 2 (Condition: standard or perceptually degraded target) x 11 (SOA: 50, 100, 250, 500, 750, 1,000, 1,240, 1,500, 2,000, 2,500, or 5,000 ms) x 2 (Trial Type: cued or uncued) x 2 (Eye Monitoring: present or absent) repeated-measure ANOVA, with condition (trial type) as an independent variable factor, and SOA, trial type, and eye monitoring as repeated measures (see Figures 2 and 3). There was no main effect of eye monitoring, $F(1,36) < 1.1$, $p > .30$, nor did it interact with any factor (ps > .17). Main effects were found for condition, $F(1,36) = 18.6$, $p < .001$, standard target = 418 ms, perceptually degraded target = 481 ms, trial type, $F(1,36) = 39.0$, $p < .001$, cued = 457 ms, uncued = 445 ms, and SOA, $F(10, 360) = 13.2$, $p < .001$, RTs longest at the shortest SOAs. Two two-way interactions were found. One was SOA x Trial Type, $F(10,360) = 10.1$, $p < .001$, with cued trials producing faster responses than uncued trials at the shortest SOAs and slower responses across the later SOAs. This can be seen in Figure 2. The other was Condition x Trial Type, $F(1,36) = 11.9$, $p < .001$, with more overall inhibition in the standard task (18 ms) than in the perceptually degraded target task (6 ms). This interaction suggests that differences in the magnitude of inhibition and temporal dynamics of visual attention are present as a result of responding to a perceptually degraded target relative to the control condition. None of the other two-way interactions (Fs < 1), three-way interactions (Fs < 1.5, ps > .142), nor the four-way interaction ($F < 1$), reached significance. Although not detected in the statistical analysis, there was a slightly larger cueing effect at the 50-ms SOA, and less IOR at 500 and 750 ms SOA, for the eye condition in the perceptually degraded target group. It may be that in the eye-monitoring condition, which involves only the covert orienting of attention, disengagement from a peripheral target is more difficult and leads to a slightly increased onset time for IOR.

General Discussion

The present study examined how perceptual properties of the target influence the temporal properties of IOR. The presence of a significant two-way interaction between trial type and condition (and the lack of a significant three-way interaction between SOA, trial type, and condition) suggests two possible explanations for the findings in the present study. One possibility is that responding to the perceptually degraded targets leads to a delay in the onset of inhibition as a result of participants' attention dwelling at the cued location for a longer period of time, leading to a cueing function that is shifted to the right relative to the control condition (as seen in Figure 3). A second possibility is that responding to the degraded targets caused participants to engage a process that is unrelated to how long attention dwells at the cued location, resulting in greater positive cueing effects across all SOAs and a general upward shift in the cueing function shown in Figure 3, relative to the control condition. This would also lead to the observation of a delayed onset of inhibition, but not simply as a result of longer attentional dwelling at cued location. Given that these two explanations would predict a delayed onset in inhibition with degraded targets, both of these explanations suit the data quite well and will be discussed in the context of current theories of visual attention, IOR, and factors related to task difficulty and attentional set.

The finding that the perceptually degraded target group displayed a general shift in the time course of IOR indicates that the effect of task difficulty in a cueing experiment is not limited to discrimination difficulty but also includes detection difficulty. This finding supports and extends Klein's (2000) notion that people can adopt "attentional control settings" suitable for the task at hand, and this results in the delayed onset of inhibition in tasks that require greater focal attention. In the present case, it appears that the perceptually degraded target group adopted a control setting that was appropriate for detecting a less salient target by allocating more attention to the locations of abrupt onsets in the visual field. Thus, the cue may have elicited more attention in the perceptually degraded target group compared with the standard target group, who would have used a control setting appropriate for easier target detection. The extra attention to the cue in the perceptually degraded target group delayed the onset of inhibition.

Previous research by Lupiáñez and colleagues (e.g., Lupiáñez & Milliken, 1999; Lupiáñez et al., 1997, 2001) has shown that the onset of inhibition was related to the complexity of the task. The present findings are in line with this observation, in the sense that it is likely that participants had more difficulty detecting the perceptually degraded target, and this resulted not only in slower overall reaction times, but in a delayed onset of inhibition. Thus, consistent with Lupiáñez et al.'s conclusions, increasing the difficulty of target discrimination (or simply detection in the present study) increases the SOA at which inhibition appears. In a similar vein, Cheal and Chastain (2002) examined how SOA range and target discrimination difficulty influenced the time course of IOR. In general, inhibition was found earlier when fewer placeholders were presented on the screen, and when the range of SOAs was longer. However, they found no difference in inhibition onsets between easy and hard identification tasks, and concluded that difficulty between tasks, but not within tasks, affects the time course of IOR. The results from the present study indicate that a more comprehensive conclusion is that between-task (detection vs. identification) and within-task difficulty for detection tasks affects the time course of IOR, whereas within-task difficulty for identification tasks does not affect the time course.

Also related to the present study is an examination of age-related differences in the time course of IOR. Recent work (Castel et al., 2003) has shown that relative to younger participants, older adults display both a larger facilitation effect at early SOAs and a delayed onset of inhibition in a time course analysis that was very similar to that used in the present study. This observation of a later onset of inhibition in older adults is strikingly similar to that found for the perceptually degraded target group in the present experiment, suggesting that target perception and task difficulty may play an important role in the observation of age-related differences in IOR, and that perhaps deficits in perceptual processing in old age may partially mediate the delayed onset of inhibition. Furthermore, consistent with Klein's (2000) notions regarding the onset of inhibition, it may be that older adults (much like the perceptually degraded target group in the present study) find target detection tasks more difficult than younger adults, and this results in a shift in attentional control settings and a later onset of inhibition.

There is another possible explanation for the present findings, and this notion is based on the observation that the cueing function displayed in Figure 3 is shifted up (rather than simply to the right) for the perceptually degraded target group relative to the standard target group. This suggests that the observation of a delayed onset of inhibition is attributable to a more positive cueing effect at all SOAs for the perceptually degraded target group relative to the control group. In this situation, it may be that responding to the perceptually degraded targets causes participants to simply show a greater degree of facilitation at all SOAs, possibly due to an attentional set that is adopted under these sorts of situations. In other words, a delayed onset of inhibition is observed because more attention is allocated to the cue, influencing the magnitude of facilitation at each SOA. However, it is important to note that both groups showed a similar amount of facilitation at the earliest SOAs, suggesting that responding to perceptually degraded targets does not simply increase the amount of facilitation at all SOAs. A failure to find a significant three-way interaction between SOA, trial type, and task indicates that it may very well be the case that responding to perceptually degraded targets leads to greater facilitation effects, and this in turn contributes to the delayed onset of inhibition. Although it is difficult to determine which of these two explanations best fits the data, it is conceivable that both factors contribute to the observation of an alteration in the magnitude of inhibition and temporal dynamics of visual attention.

It should be noted that a previous study examined the effect of target modality and target intensity on IOR and found an inverse relationship between target intensity and magnitude of IOR (Reuter-Lorenz, Jha, & Rosenquist, 1996). In one of the experiments in this study, they used two different luminance levels for the target, and found that the magnitude of inhibition was greater for dim targets relative to bright targets. Although this finding stands in contrast to the present study, which found more inhibition at three SOAs for the higher intensity target, several variables likely explain the discrepancy. Since Reuter-Lorenz et al. (1996) had different theoretical motivations than the present study, they used only two relatively long SOAs (1,000 and 1,300 ms), they employed a cue-back-to-fixation design, and they carried out the study using LED displays. These variables do not allow for an examination of the time course of IOR, and the LED displays likely are not comparable to the degradation of perceptual intensity that can be achieved using computer screens. Cheal and Chastain (2002) discuss other properties and parameters that likely affect the time course of IOR, and it is clear that more research is needed to fully determine how various perceptual properties influence target detection and inhibitory mechanisms.

The findings from the present study can be incorporated into recent findings regarding the role of spatial working memory and IOR (e.g., Castel et al., 2003; Dodd, Castel, & Pratt, 2003; Klein, 2000). Specifically, it may be that spatial working memory processes govern IOR, and that task difficulty interacts with these processes, resulting in slower RTs, greater cueing effects at all SOAs, as well as a later onset of inhibition. Converging evidence for this notion comes from recent research that has shown that if participants must hold verbal information in memory prior to the cue and subsequent target, the onset of inhibition is delayed, much like the present study (Klein, Castel, & Pratt, 2004). It may well be that the attentional control setting adopted by participants in the perceptually degraded target condition is necessary to allow for sufficient memory processing, which eventually leads to the inhibition of previously attended locations in a difficult detection task. Thus, IOR may critically depend on the output of a memory system that tags previously sampled locations in order to inhibit perceptual, attentional, and motor processes directed to such locations.

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Sommaire

La capacité de diriger de manière efficace l'attention visuelle vers les traits saillants qui sont présents dans le milieu environnant est une fonction essentielle du système visuel. La conclusion selon laquelle la détection d'une cible est plus lente lorsque celle-ci est d'abord présentée dans un emplacement marqué par un indice s'expliquerait par la présence d'un mécanisme appelé inhibition du retour (IOR). Des recherches précédentes ont montré que la discrimination de cibles difficiles à détecter faisait augmenter le temps nécessaire à l'inhibition d'emplacements observés précédemment (c.-à-d., l'apparition tardive de l'inhibition), ce qui laisse croire que la difficulté de la tâche joue un rôle primordial dans l'attribution de l'attention. Dans la présente étude, l'IOR a été mesurée à divers SOA lorsque les participants détectaient soit une cible dégradée sur le plan perceptuel, soit une cible standard à luminance élevée. Lorsque les participants réagissaient à la cible dégradée sur le plan perceptuel, le décours temporel de l'IOR était

retardé d'environ 250 ms (par rapport au groupe témoin), suggérant ainsi que la difficulté à détecter les cibles influence aussi l'attribution de l'attention. Ces résultats sont cohérents avec la notion selon laquelle l'IOR ne serait pas simplement un mécanisme sous-cortical réflexif mais qu'il ferait plutôt appel à des paramètres descendants de contrôle de l'attention.